B-618

The Corporation of the
City of Burlington

EVALUATION OF HALTON REGION LANDFILL TECHNICAL STUDIES
Site D - Milton

HYDROGEOLOGIC REPORT

- Part A - Definition of Hydrogeologic Suitability for Landfilling
- Part B - Critique of Trow Technical Studies
- Part C - Interpretation of Site D Hydrogeology and Suitability for Landfilling

February 1988
Ref. No. 1354-10

CONESTOGA-ROVERS & ASSOCIATES

CRA
Consulting Engineers

CONESTOGA-ROVERS & ASSOCIATES LIMITED
651 Colby Drive,
Waterloo, Ontario, Canada N2V 1C2
(519) 884-0510

February 8, 1988 Reference No. 1354-10

Mr. Mike McQuaid
Weir & Foulds
Barristers & Solicitors
2 First Canadian Place
P.O. Box 480
Toronto, Ontario
M5X 1J5

Dear Mike:

Re: Site D - Hydrogeologic Report
Halton Environmental Assessment

Please find enclosed our report entitled "Evaluation of Halton Region Landfill Technical Studies, Site D Milton, Hydrogeological Report".

This report has been prepared on behalf of the City of Burlington as part of the ongoing Environmental Assessment for the new Halton Region landfill.

Should you have any questions, please do not hesitate to contact us.

Yours truly,

CONESTOGA-ROVERS & ASSOCIATES

Anthony J. Crutcher, P. Eng.

AJC/js
Encl.

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INTRODUCTION

As part of the ongoing Environmental Assessment (EA) process to secure a new landfill site for the Regional Municipality of Halton (RMH), the City of Burlington (City) directed Conestoga-Rovers and Associates (CRA) to review the hydrogeologic studies prepared by Trow Hydrology Consultants (Trow) on behalf of RMH, and to provide additional data interpretation as required.

The report presented herein was written to document the above work undertaken by CRA for Site D. The report is structured as follows:

PART A - Definition of Hydrogeologic Suitability for Landfilling

PART B - Critique of Trow Technical Studies

PART C - Interpretation of Site D Hydrogeology and Suitability for Landfilling

Part A, "Definition of Hydrogeologic Suitability for Landfilling", provides CRA's criteria to determine the hydrogeologic suitability of a site for landfilling.

Part B, "Critique of Trow Technical Studies", reviews the technical studies prepared by Trow Hydrology

Consultants Limited (Trow) for RMH . These studies consist of Volume 1 - Hydrogeologic Report (Exhibit H-39) and Volume 2 - Appendices (Exhibit H-39A) of a three-volume report entitled "Halton Region Landfill Technical Report - Site D Burlington".

Part C, "Interpretation of Site D Hydrogeology and Suitability for Landfilling", contains CRA's interpretation of the hydrogeologic suitability of Site D as developed from examination of the available data.

CRA concludes that the hydrogeology of the Site as interpreted by Trow meets the hydrogeologic suitability criteria as defined in Part A.

PART A: DEFINITION OF HYDROGEOLOGIC SUITABILITY FOR LANDFILLING

A.1.0 INTRODUCTION

In order to conduct an assessment of the hydrogeologic suitability of a site for landfilling the following items must be addressed:

1) The hydrogeologic setting.

2) The level of engineering necessary to provide effective primary protection.

3) The boundary impacts for landfill design option considered.

4) A monitoring program to monitor both the natural hydrogeologic setting as well as the engineering landfill system.

5) A contingency plan in the event that the system, natural or engineered, does not perform as expected.

The hydrogeologic setting is defined initially as this provides the basis upon which to develop the required engineering design. The final three of the above points are addressed following the definition of the hydrogeologic system and the conceptual engineering design.

From this assessment a hydrogeologically acceptable landfill site must meet the following minimum criteria:

1) Migration of contaminants from the landfill must be predictable and the impact from this migration must be determined to be acceptable.

2) The site must be able to be adequately monitored in order to verify the predictions on the behavior of the contaminant migration.

3) Feasible contingency plans must be developed such that if unacceptable contaminant migration results, as determined from the monitoring, this migration can be mitigated.

The following sections provide a discussion of these items.

A.2.0 HYDROGEOLOGIC SETTING

It is accepted practice to site landfills in a hydrogeologic setting which minimizes the risk to public health and safety. Such sites are typically characterized by low permeable materials with a significant capacity to attenuate migrating leachate. Emphasis is placed on a high degree of protection provided by the natural environment because of concerns regarding the reliability and long term performance of an engineered landfill system. The engineered component is generally designed to enhance the natural environment most typically by the collection and removal of leachate in order to reduce the volume of leachate that may potentially migrate from the site.

Acceptable sites are generally characterized by clayey or low permeable strata in which the rate of groundwater movement is measured in centimeters per year. In addition, the capacity of clays to attenuate contaminated groundwater enhances their suitability as landfill sites. Thick clay strata are therefore considered to comprise the most favourable hydrogeologic setting for a landfill.

Commonly however, in most hydrogeologic settings the low permeable strata are interbedded with sandy or more permeable strata in which the rate of groundwater flow is measured in the order of meters or even tens of meters per year. Such strata are conduits for horizontal movement of groundwater and may comprise an exploitable groundwater resource.

It is therefore the basis of any hydrogeologic investigation aimed at assessing the suitability for landfilling to establish the geologic sequence of the site in order to define those strata which provide for the attenuation and limited migration of contaminants, and those which provide for off-site lateral migration. Such investigations require drilling to identify the geologic strata present, the installation of observation wells, and the conducting of various hydrogeologic tests, in both the field and laboratory, to quantify those hydrogeologic parameters that govern the rate and direction of groundwater flow in each of the geologic strata identified. The measurement of water levels, grain size analyses, single well response tests and pumping tests comprise the more common hydrogeological tests undertaken in such investigations.

Groundwater quality is normally established prior to landfilling. Samples are collected from observation wells which have previously been developed to ensure that the samples are representative of the groundwater. A number of these observation wells are typically included in a monitoring program. In addition to analyzing for background water quality, laboratory tests may be completed to assess the attenuation properties of the geologic strata.

The data generated are presented in plan view and cross-section in a manner which represents the groundwater flow system at the site. From an understanding of the flow system it is then possible to define the pathways along which leachate generated at the site may potentially migrate off site. Having defined the contaminant pathways, the travel time taken for contaminants to migrate in the groundwater environment to a discharge point or to the site boundary is undertaken. This assessment may involve a few simple calculations or the application of sophisticated computer models incorporating groundwater flow and contaminant transport.

A.3.0 CONCEPTUAL ENGINEERING DESIGN

The design of a engineered landfill site is controlled by the hydrogeologic conditions encountered as well as the physical feature of the site (slope, surface water control, etc.) The various design options of the engineered system are evaluated to ensure they are compatible with the hydrogeological system. This section of the report addresses those hydrogeologic factors that influence the design of a landfill.

The objectives of an engineered sanitary landfill are threefold:

1) Minimize the rate of leakage of leachate from the facility.

2) Provide for the collection of leachate during and following the operational life of the facility.

3) Minimize the amount of leachate production following closure of the facility.

For those sites founded on low permeable materials, the first two objectives are addressed in the design of the leachate collection system. Where the integrity of the subgrade materials is questionable, a low permeable surface (liner) may have to be installed at the base of the excavation to minimize the potential for leachate to migrate from the landfill. Clay liners are typically designed to a hydraulic conductivity of 5×10^{-8} cm/sec.

The third objective is addressed by the installation of an engineered cover at closure of the site.

The objective of the engineering for a sanitary landfill is to provide for the collection of leachate which is generated when precipitation percolates through the landfilled materials. This is usually accomplished by providing a drainage layer at the base of the excavation with gravity drainage to a collection point. This drainage layer may consist of a sand blanket, a series of collection pipes or french drains or any combination of the above. This system is designed to control the elevation of leachate within the landfill and to minimize the potential for the leakage of leachate from the landfill. For a low permeable base, the rate of leakage of leachate from the site is low and a less sophisticated drainage layer is feasible. For a more permeable base, the rate of leakage is higher and a more effective leachate control system is required.

The thickness and hydraulic conductivity of the strata immediately underlying the landfill is of critical importance. Materials having a hydraulic conductivity of the order of 1 x 10^{-7} cm/sec or less, and a good capacity to attenuate leachate (e.g. clays) are considered most suitable for landfilling. In general a minimum thickness in the order of 3 to 5 m of low permeable clayey till materials should be maintained below the base of excavation. The thickness of the till allows for some variability in the till lithology while still maintaining a degree of assurance as to the integrity of the unit as a whole.

A.4.0 IMPACT ASSESSMENT

This section addresses the estimated time of travel and anticipated peak concentrations of leachate, which may migrate in the groundwater environment to:

1) Discharge to adjacent surface water and/or,
2) Reach the site boundary and/or,
3) To reach a receptor of groundwater.

It is the intention of an impact assessment to demonstrate that, based on the observed hydrogeologic system and the proposed engineered landfill system, that operation of the landfill will meet accepted criteria regarding groundwater quality at the site boundary.

It should be pointed out, however, that the effects of a failure of the engineered system must also be assessed. This is assessed by assuming that there is an uncontrolled build up of leachate in the site which has the effect of increasing the rates of groundwater flow and reducing the time of arrival of contaminants at the site boundary.

The significance of these effects are assessed in light of the landfill design and the monitoring program and contingency options proposed.

A.5.0 MONITORING PROGRAM

A monitoring program is designed to provide data upon which to assess the performance of both the natural hydrogeologic system and the engineered system.

The intent of the groundwater monitoring program is:

1) To define background water quality to provide a data base against which to assess the significance of any observed groundwater quality changes.

2) To ensure that any change in the groundwater quality in the defined contaminant pathways is readily detected.

3) To assess the significance of any change detected with respect to acceptable groundwater quality criteria.

Monitoring of the engineered component of the landfill is designed to evaluate the effectiveness of the leachate control and collection system.

A.6.0 CONTINGENCY PLANS

A contingency plan is required in order that an unacceptable environmental impact if it occurs can be mitigated. The contingency options assessed are aimed at preventing the continued migration of contaminated groundwater. This prevention may be undertaken by extraction, hydraulic control or physical containment. Design of an effective containment system requires a thorough understanding of the groundwater flow system. In addition the monitoring program must be able to provide an early warning of potentially unacceptable changes in the groundwater quality in order that a contingency system can then be implemented.

PART B: CRITIQUE OF TROW TECHNICAL STUDIES

B.1.0 INTRODUCTION

This review addresses the first two volumes of a three volume report prepared by Trow Hydrology Consultants Limited (Trow) in September 1986. This report was prepared for The Regional Municipality of Halton for the ongoing Environmental Assessment (EA) process. The reports are entitled "Hydrogeologic Report for Site D - Milton, Halton Regional Landfill, Technical Study". Volume 1 (Exhibit H-39) presents the text and drawings, while the appendices are contained in Volume 2 (Exhibit H-39A). Volume 3 (Exhibit H-41) presents the design and operations of a proposed landfill at this site.

Part B of this report provides a critique of volumes 1 and 2 of the above hydrogeologic report by Trow. Specifically CRA reviewed the following:

1) The geologic interpretation as based upon the borehole log records.

2) The hydrostratigraphic sequence at the site with specific reference to the hydraulic conductivity of the low permeable units, the continuity and hydraulic

conductivity of the granular units and the direction of groundwater flow in the strata below the Upper Till.

3) The contaminant migration pathways and arrival times.

4) The hydraulic trap landfill design.

5) The contingency options.

6) The recommended monitoring plan.

CRA agrees with Trow that the site is hydrogeologically suitable for landfilling. However design modifications are recommended by CRA to ensure that the hydraulic trap landfill design proposed by Trow, is effective.

B.2.0 GEOLOGY

B.2.1 INTRODUCTION

As a whole, CRA is in general agreement with Trow's interpretation of the geologic sequence and the site hydrostratigraphy. However, several inconsistencies exist between the descriptive data, the interpretations in the text, and the relevant drawings. CRA concludes that these inconsistencies do not affect the overall conclusions regarding the site geology as determined by Trow (Exhibit H-39).

The bedrock and six discrete overburden units are defined by Trow (p. 29, Exhibit H-39). This sequence, from ground surface is:

1) An Upper Till, consisting of clayey silt with variable silt, sand and gravel content - this unit has wide lateral extent.

2) A very thin, bed of silt with wide lateral extent.

3) A Lower Till, consisting of sandy silt to silty sand with minor clay facies. This till has wide lateral extent.

4) An Upper Granular Deposit consisting of sand and gravel. This unit has limited lateral extent.

5) A Lower Granular Deposit consisting predominantly of silt. This deposit has wide lateral extent.

6) A basal gravelly till with limited lateral extent.

7) Shale bedrock of the Queenston Formation.

This sequence is summarized on Figure B.2.1 (p. 18) which is reproduced from Trow (Figure 1, p. 30; Exhibit H-39).

In order to evaluate the geological sequence, as defined by Trow, the depth and thickness of each stratigraphic horizon, as indicated on borehole logs (Trow, Appendix 2; Exhibit H-39A) was examined by CRA. Additional borehole log information is provided in Geocon (1987 Exhibit M-438). Detailed stratigraphic data has been plotted by CRA on two cross-sections to illustrate the geologic sequence. The locations of these cross-sections and the observation wells are shown on Figure B.2.2 (p. 19) and the geologic cross-sections provided on Figures B.2.3.a and B.2.3.b (p. 20 and 21).

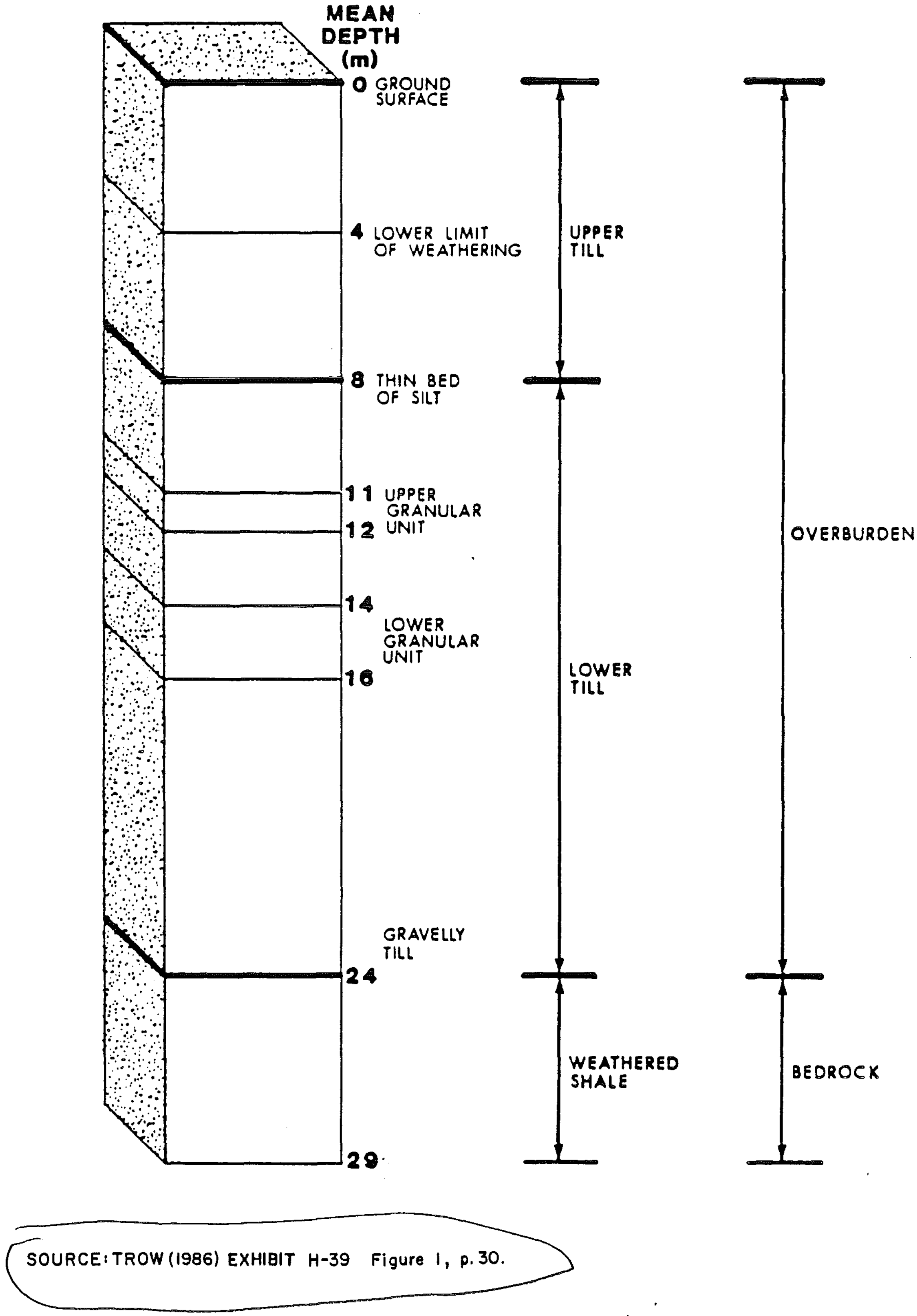

figure B2.1

SCHEMATIC GEOLOGIC SEQUENCE

Site 'D' Hydrogeology – City of Burlington

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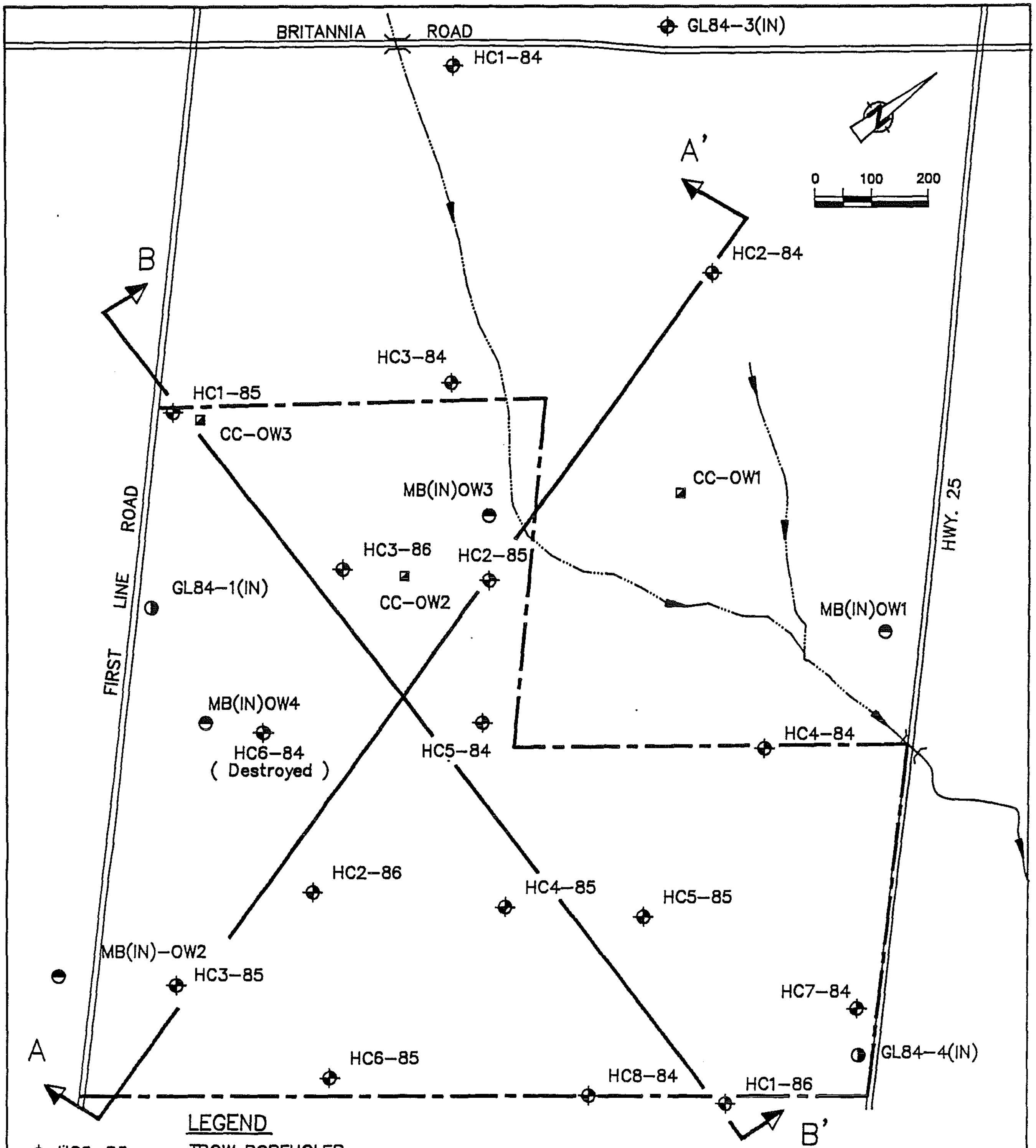

LEGEND

HC6-85	TROW BOREHOLES DRILLED IN 1984, 1985, & 1986
GL84-4(IN)	GARTNER LEE ASSOCIATES LTD. BOREHOLES DRILLED IN 1984
MB(IN)-OW2	MORRISON BEATTY LTD. BOREHOLES DRILLED IN 1984
CC-OW1	COMCOR BOREHOLES DRILLED IN 1985

SOURCE: TROW (1986) DWG. 2
EXHIBIT H-39

figure B2.2

BORHOLE LOCATION MAP

Site 'D' Hydrogeology – City of Burlington

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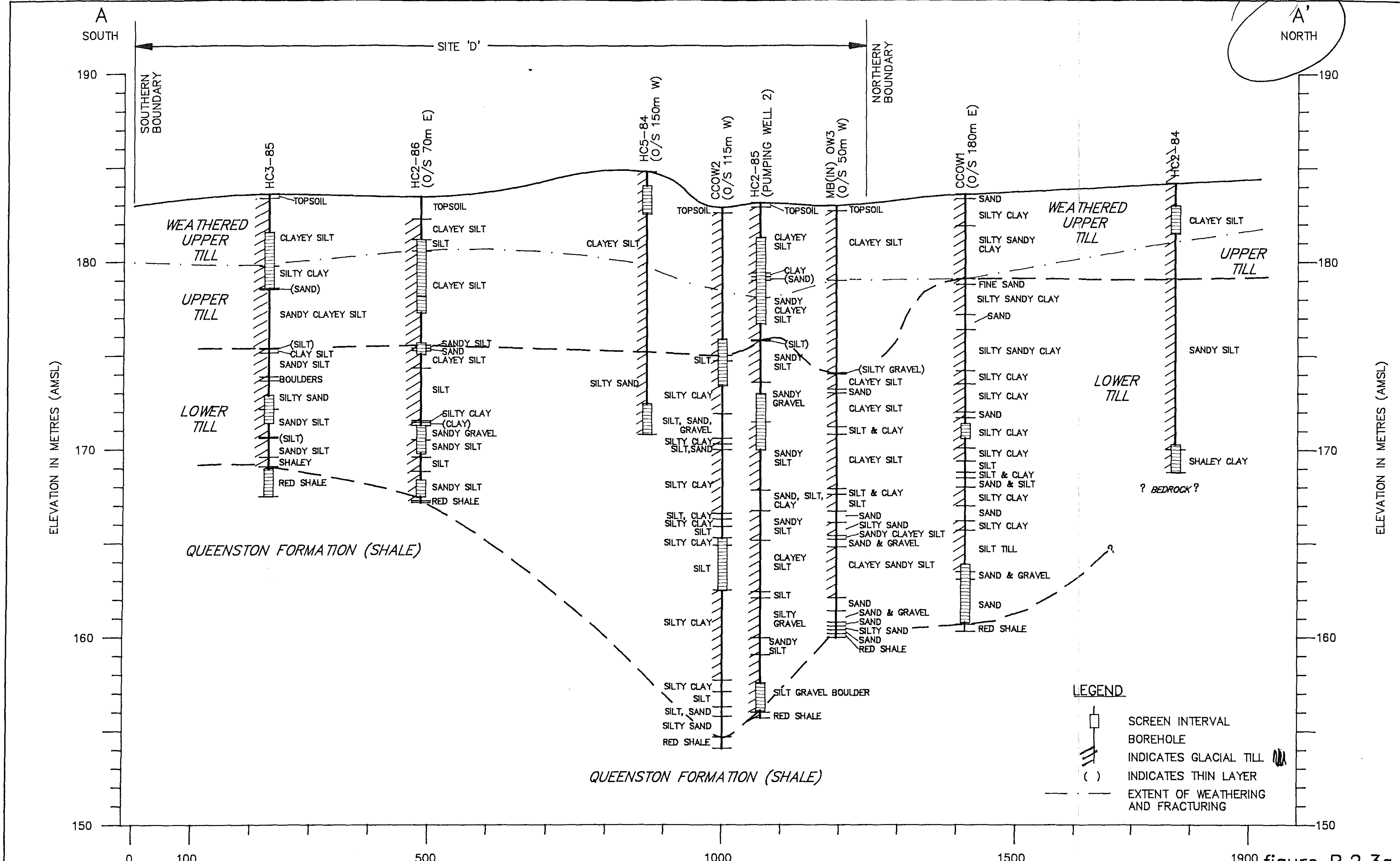

figure B.2.3a

GEOLOGIC CROSS-SECTION A–A'

Site 'D' Hydrogeology – City of Burlington

VERTICAL SCALE 1:200 METRIC
HORIZONTAL SCALE 1:6000 METRIC

SOURCE: TROW (1986) EXHIBIT H-39A

CRA

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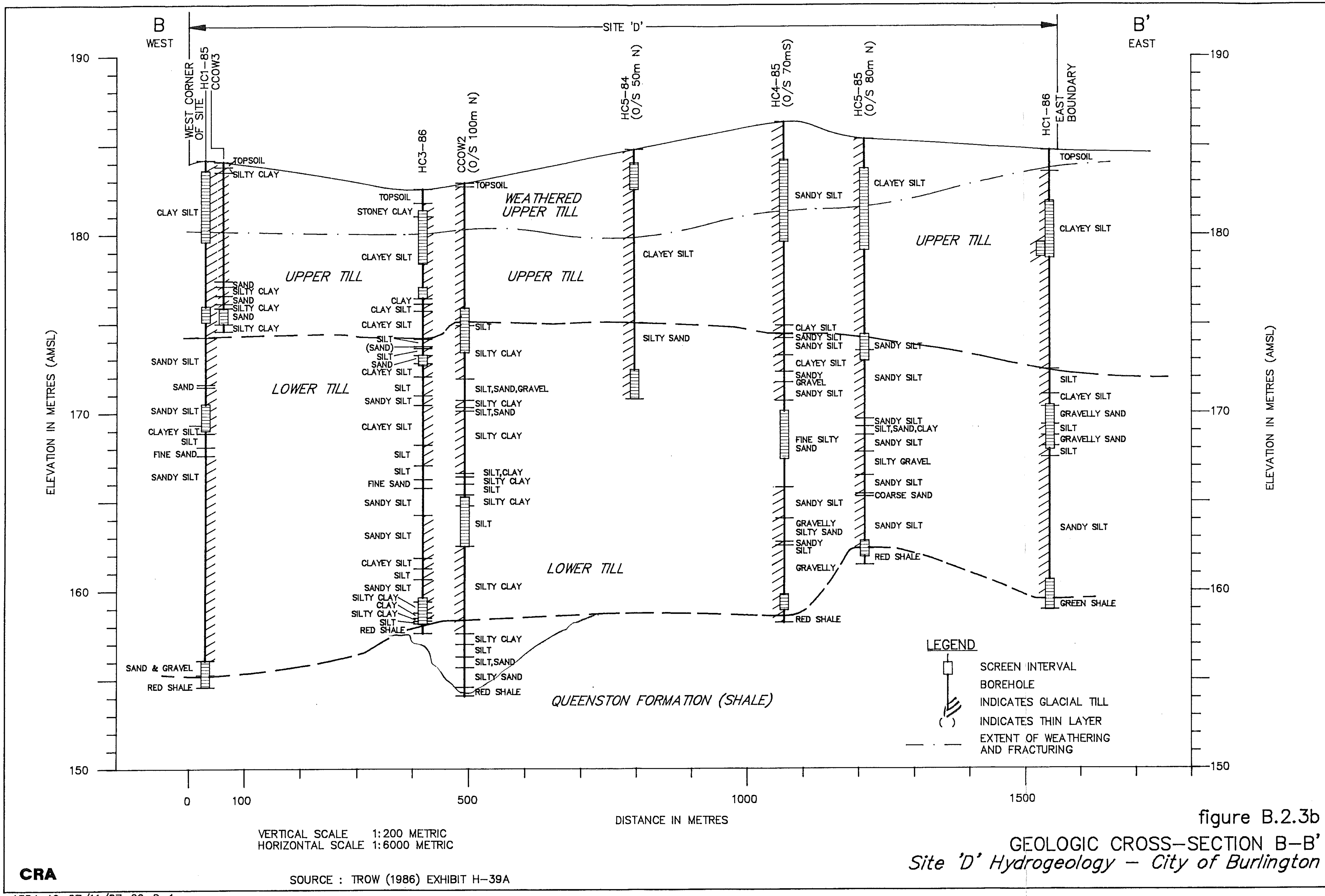


figure B.2.3b

GEOLOGIC CROSS-SECTION B-B'

Site 'D' Hydrogeology - City of Burlington

It should be noted that continuous soil sampling was undertaken in all boreholes drilled in 1985 and 1986. For the 1984 boreholes an intermittent sampling interval was used and thin lithologic variations may have been intersected but not detected.

B.2.2 UPPER TILL UNIT

The Upper Till Unit was encountered near surface in each of the 29 boreholes drilled in the vicinity of Site D. It should be noted that only 27 boreholes are identified on Figure B.2.2 (p. 19). The remaining two boreholes, GL84-5(IN) and GL84-2(IN) are located west and southwest of the site respectively as shown on Plan 1 (backpocket). The thickness of the Upper Till Unit as interpreted by CRA from the borehole logs (Trow, Appendix 2, Exhibit H-39A), was observed to vary between 4.45 m (CC-OW1) located north of the site and 12.2 m (HC1-86). The average thickness using information from all boreholes is 7.74 m. If the 1984 series boreholes are not included due to the uncertainty in defining stratigraphic horizons, the average thickness is 8.1 m. This is consistent with the value of 8 m shown on Trow's schematic cross-section (Figure B.2.1, (p. 18).

The texture of the Upper Till Unit described on the borehole logs by Trow (Appendix 2, Exhibit H-39A) is typically silty clay to clayey silt with variable amounts of sand, gravel and cobbles.

CRA prepared Exhibit B-208 which summarized the available grain size data (Appendix 3, Exhibit H-39A). The data for the Upper Till Unit are reproduced as Table B.2.1. The geometric mean percentage of clay is 20.6 percent, ranging from 12.5 to 35.5 percent. As indicated by Mr. Sobanski (Vol. 34, p. 7318), these grain size data show that this till is relatively uniform.

Silt and sand seams of less than 10 cm in thickness were occasionally encountered within the Unit.

The uppermost portion of the Upper Till Unit is weathered and fractured. The depth of penetration of weathering and frequency of fracturing are not described in equal detail on all borehole logs. The depth of weathering is not shown by Trow for each borehole on the cross-sections, but is shown on the schematic cross-section (Figure B.2.1, p. 18) as being 4 m in depth.

The extent of weathering and fracturing as shown on Figure B.2.3a,b (p. 20, 21), has been determined by CRA from examination of the borehole logs (Trow, Appendix 2,

TABLE B.2.1

SUMMARY OF GRAIN SIZE DISTRIBUTIONS UPPER TILL UNIT

BOREHOLE NUMBER	SAMPLE DEPTH (m)	% GRAVEL	% SAND	% SILT	% CLAY
HC1-85	5.64 - 5.94	27	18	37.5	17.5
HC2-85	4.27 - 4.67	16.5	25.5	40	18
HC3-85	4.94 - 5.24	14	24	41	21
HC4-85	4.11 - 4.42	9.5	29.5	39	22
HC5-85	5.18 - 5.49	16	19	41.5	23.5
HC6-85	5.03 - 5.33	17.5	19.5	44.5	18.5
HC1-84	4.6	6	23.5	43	27.5
HC1-84	6.1	16	27.5	44	12.5
HC2-84	6.1	8	32	42.5	17.5
HC7-84	1.6	0	16.5	48	35.5
GEOMETRIC MEAN		10.2	23.0	42.0	20.6

Source: Trow 1986, Appendix 3, Exhibit H-39A.

Exhibit H-39A). The thickness of the described weathered zone varies between 1.5 m (OW3-86) and 9.5 m (CC-OW3). The average thickness of the weathered and fractured zone is 4.02 m which is consistent with the value of 4 m used by Trow (Figure B.2.1 (p. 17).

It is to be noted that the borehole log for CC-OW3 (Geocon 1987 Exhibit M-438) indicates that the Upper Till at this point contains evidence of weathering and fracturing to a depth of approximately 9.5 m, the total depth of this borehole. Elsewhere on Site D, the occurrence of weathering and fracturing is limited to the upper 4 m or so. This borehole (CC-OW3) is inconsistent with the remaining boreholes and not considered by CRA as representative of the weathered Upper Till.

The lower limit of the Upper Till Unit is described by Trow (p. 32, Exhibit H-39) at either the change in till texture from clayey silt to sandy silt, or at the elevation of a thin silt horizon. This textural change is easily identified on the borehole logs and the core logs examined by CRA. The silt horizon was identified in 10 boreholes. The thickness of this horizon varied from 0.02 to 0.7 m and averaged 0.17 m. At HC5-85, the silt horizon is noticeably thicker and displays a sandy silt texture. The average thickness of the silt horizon, not including this location, is 0.10 m.

B.2.3 LOWER TILL UNIT

The Lower Till Unit comprises a thick sequence of glacial till which overlies bedrock and is in turn overlain by the Upper Till Unit. This Unit was encountered in all boreholes and is assumed to be laterally extensive on a regional scale. The Lower Till Unit is thinnest in the vicinity of HC3-85 (7.8 m) and thickest at CC-OW2 (20.9 m).

As described by Trow (p. 31, Exhibit H-39) the texture of the Lower Till Unit is typically sandy silt with varying amounts of clay and gravel. Fourteen samples of this unit were submitted for grain size distribution analysis by Trow (Appendix 3, Exhibit H-39A). The results of these analyses were tabulated by CRA as Exhibit B-208. The data for the Lower Till Unit are reproduced here as Table B.2.2 (p. 27).

This till shows a greater variation in grain size and contains less clay than the Upper Till.

Textural variability within the Lower Till Unit is very common with several sections of silty gravel or shaley till near the bedrock, and some occurrences of fine grained sediments.

TABLE B.2.2

SUMMARY OF GRAIN SIZE DISTRIBUTIONS
LOWER TILL UNIT

BOREHOLE NUMBER	SAMPLE DEPTH (m)	% GRAVEL	% SAND	% SILT	% CLAY
HC1-85	12.64 - 12.95	24	22	46	8
HC1-85	16.46 - 16.76	20	11	57	12
HC2-85	13.41 - 13.72	15	27.5	45	12.5
HC3-85	9.5 - 9.8	25.5	37	32.5	5
HC4-85	23.16 - 23.47	29	36	31	4
HC5-85	11.28 - 11.58	2.5	27	61.5	9
HC5-85	13.11 - 13.41	20	25.5	41	13.5
HC1-84	12.2	21.5	28.5	46	4
HC4-84	10.7	22	24.5	41	12.5
HC4-84	12.2	12	36.5	42	9.5
HC5-84	12.2	19.5	36.5	38	6
HC6-84	13.7	14	24.5	47.5	14
HC6-84	15.3	0	5	90	5
HC7-84	7.6	14	28.5	43.5	14
GEOMETRIC MEAN		13.4	23.9	45.6	8.4

Source: Trow 1986, Appendix 3, Exhibit H-39A.

Granular horizons are present within the Lower Till Unit as described in Section B.2.4.

B.2.4 GRANULAR UNITS

Stratigraphic descriptions of the boreholes in the vicinity of Site D identify horizons of granular materials of variable thickness within the Lower Till sequence. From inspection of the borehole logs (Appendix 2, Exhibit H-39A) these materials are seen to vary in texture from laminated silt and clays to sands and gravel. Trow (Exhibit H-39) has grouped these strata into the Upper and Lower Granular Units. Based on inspection of the geological cross-sections (Drawings 8-11, Exhibit H-39) Trow has shown that the Upper Granular Unit generally occurs above an elevation of 172 masl, and the Lower Granular Unit at or below an elevation of 170 masl.

B.2.4.1 Upper Granular Unit

The Upper Granular Unit occurs as a relatively thin layer and as described by Trow generally lies between 8 and 16 meters below ground. As determined from the borehole logs provided by Trow, CRA has identified granular (sandy) strata at locations: HC1-85 (0.15 m), HC2-85

(2.1 m), HC3-85 (0.2 m), HC4-85 (0.3 m), HC2-86 (0.76 m), GL84-1(IN) (1.3 m), GL84-4(IN) (0.5 m). In addition, the borehole logs provided by Geocon (Exhibit M-438 show the Upper Granular Unit at CC-OW2 (1.2 m) and MB(IN)-OW4 (1.4 m). The average thickness of the above occurrences is 0.83 m, which approximates the value of 1 m shown by Trow.

Two samples from the Upper Granular Unit at HC2-85 and HC4-85 were submitted for grain size distribution analysis by Trow (Appendix 3, Exhibit H-39A). These samples contained 53-51.5% gravel, 40-23% sand, 7-21.5% silt and 0-4% clay, respectively. These results demonstrate that the texture of the Upper Granular Unit is variable, although Trow reports that this Unit consists of sands and gravels (p. 32, Exhibit H-39).

The interpreted distribution of the Upper Granular Unit is shown by Trow (Drawing 18, Exhibit H-39). This distribution is not consistent with the borehole log data provided above nor the geological cross sections (Trow Exhibit H-39). Additional discussion concerning the distribution of this unit is provided in Part C of this report.

B.2.4.2 Lower Granular Unit

The Lower Granular Unit is interpreted by Trow as a relatively a laterally extensive layer of silt and fine sand which occurs at and below an approximate elevation of 170 m. As determined from the available borehole logs, CRA has identified this unit in 14 boreholes with thickness that varied from 0.25 m (CC-OW2) to 4.9 m (HC4-85). The average thickness of the Lower Granular Unit is approximately 1.68 m. Trow reports an average thickness of 2 m for this unit (Figure B.2.1, p. 18).

Boreholes completed by Trow in 1984 were terminated at depths too shallow to intersect the Lower Granular Unit.

As described by Trow, this unit underlies much of the site.

B.2.5 SUMMARY

CRA is in general agreement with the site geology as defined by Trow. The following summarizes CRA's comments:

1. The Upper Granular Unit is shown to consist of silty sand and gravel, not sand and gravel.

2. The interpreted distribution of the Upper Granular Unit (Trow, Drawing 18, Exhibit H-39) is inconsistent with the available borehole log data and geological cross-sections.

These comments are addressed more fully in Part C of this report.

B.3.0 GROUNDWATER

B.3.1 WATER SUPPLY

Residences in the vicinity of the site obtain domestic water supply from sources in the overburden or bedrock. The inventory completed by Trow (p. 38, Exhibit H-39) indicates that 12 residences obtain water from source aquifers within the overburden and the source for an additional 14 wells is not defined. The remaining 43 domestic wells are completed in bedrock (Trow, p.38; Exhibit H-39).

Trow considers it probable that the overburden water sources are laterally equivalent to or continuous with the Upper or Lower Granular Units identified beneath the site (p. 45, Exhibit H-39).

CRA agrees with this interpretation but points out that the quality of the drillers' logs does leave some room for uncertainty, but Trow's assumption is the conservative approach.

B.3.2 HYDROSTRATIGRAPHY

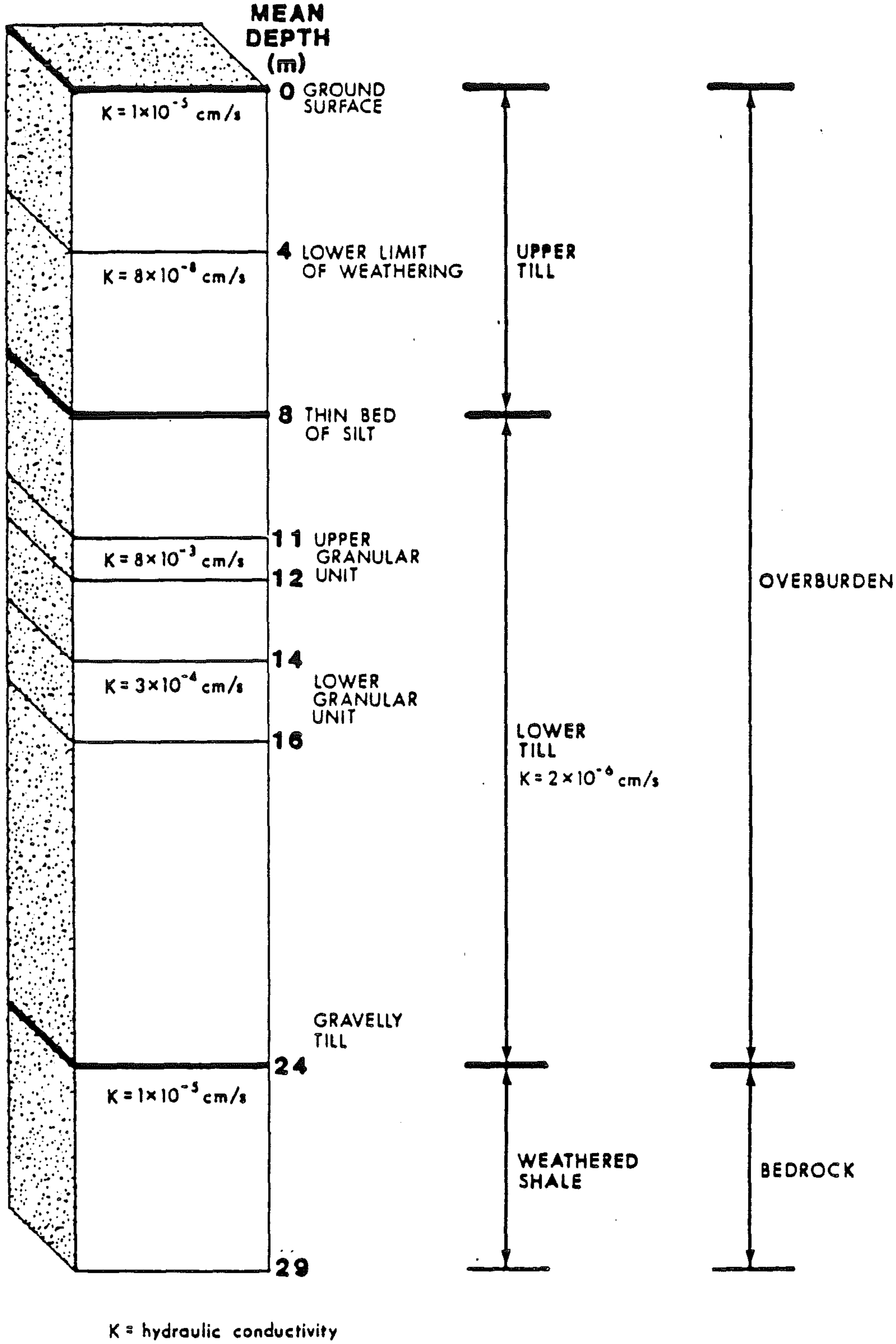
The hydrostratigraphic sequence of this site, as defined by Trow (p. 40, Exhibit H-39) is as follows:

1) the Upper Till (unweathered and weathered);
2) the Upper Granular Unit;
3) the Lower Granular Unit;
4) the Lower Till; and
5) Shale Bedrock.

This sequence is shown schematically on Figure B.3.1. (p. 34).

The hydrostratigraphic units in general coincide with the stratigraphic units described by Trow. The Upper and Lower Till Units have low permeabilities. The Upper and Lower Granular Units have a higher permeability.

The hydraulic conductivity values assigned to the low permeable units by Trow were determined from slug tests while those for the granular units were determined from pumping tests. The hydraulic conductivity of the Weathered Upper Till (1×10^{-5} cm/sec) was assumed by Trow and was not determined from field data generated at the site.



SOURCE: TROW (1986), EXHIBIT H-39 Figure 2, p.41.

figure B3.1

SCHEMATIC HYDROSTRATIGRAPHIC SEQUENCE

Site 'D' Hydrogeology – City of Burlington

CRA

1354-10-30/11/87-29-D-1

The thin bed of silt is identified in the hydrostratigraphic sequence (Figure B.3.1, p. 34). Trow does not assign a hydraulic conductivity to this stratum. CRA estimates a hydraulic conductivity in the order of 10^{-5} cm/sec for this material. Given a thickness of this unit averaging 0.17 m (Section B.2.2, p. 22), and the estimated low hydraulic conductivity CRA does not consider this stratum as hydrogeologically significant.

B.3.2.1 Weathered Upper Till

The base of weathering is not clearly identified by Trow in the borehole logs nor on the accompanying cross-sections.

Trow assigned an assumed hydraulic conductivity of 1×10^{-5} cm/sec to these materials. Trow states that this assumption is "conservative" (p. 47, Exhibit H-39). CRA agrees that this value is indeed conservative.

Recent research referenced by Trow (Dusseault 1985, p. 47, Exhibit H-39) indicates that the presence of fractures in weathered tills in Ontario does not appear to substantially increase the bulk hydraulic conductivity of these materials. The weathering of chlorite to smectite (a swelling clay) is believed by Quigley and Ogunbadejo (1976) to account for this phenomena by effectively sealing the fractures. While smectite was not identified by Trow in clays analyzed at this site, vermiculite (a swelling clay) was identified within the one sample analyzed from the weathered zone at HC2-85 (Trow p. 33, Exhibit H-39). CRA considers that the presence of swelling clays in the weathered till suggests that a bulk hydraulic conductivity of 1×10^{-5} cm/sec is conservative.

A series of piezometers (HCT 86-1 to HCT 86-6) were installed by Trow in order that the tritium profile in the Upper Till could be established. The results presented by Trow (p. 61, Exhibit H-39) show that pre 1952 water has migrated to a depth of 5.4 m below ground surface. Using this data, Trow calculates (p. 62, Exhibit H-39) a hydraulic conductivity of 3×10^{-7} cm/sec for the weathered Upper Till confirming that the assumed hydraulic conductivity (1×10^{-5} cm/sec) is very conservative.

A downward vertical hydraulic gradient employed for the above calculation (0.38) was subsequently supported by a calculation provided by Trow as Exhibit H-181. A review by CRA of this calculation shows, that if the mid-screen elevations are used as being the point at which the water level data are representative, then a lower downward vertical gradient of 0.22 is calculated. For this gradient, the calculated hydraulic conductivity of the weathered Upper Till is 5.2×10^{-7} cm/sec. CRA does not consider this to be significantly different from that value (3×10^{-7} cm/sec) calculated above by Trow.

A value for effective porosity of 0.001 was assigned by Trow (p. 47, Exhibit H-39) for this Unit. Evidence provided by Mr. Feenstra in cross-examination (Exhibit H-245, Vol. 43, P. 9564) showed that for a field experiment recently conducted at Sarnia, an apparent porosity of 0.02 was determined. Mr. Feenstra concluded (Vol. 43, p. 9566) from this value that assumed effective porosity assigned by Trow is quite conservative. An effective porosity higher than 0.001 has the effect of lowering the groundwater velocity for the weathered Upper Till and increasing the travel time to the site boundary. CRA agrees that the assigned effective porosity (0.001) is conservative.

As discussed by Trow (p. 63, Exhibit H-39), the rate of tritium advance indicates that the weathered and unweathered portions of the Upper Till have a similar effective porosity. Trow (p. 46, Exhibit H-39) estimate an effective porosity of 0.25 for the unweathered Upper Till.

However, in order to be conservative, Trow assigns values of 1×10^{-5} cm/sec and 0.001 for the hydraulic conductivity and effective porosity, respectively, of the weathered Upper Till.

CRA agrees that these assigned values are indeed conservative.

B.3.2.2 Unweathered Upper Till

The hydraulic conductivity of this unit was determined by Trow from single well response tests. The results of these tests yielded a geometric mean hydraulic conductivity of 8.1×10^{-8} cm/sec (p. 46, Exhibit H-39). Inspection of the data (Appendix 12, Exhibit H-39A) show that by including HC1-85-3 with a calculated hydraulic conductivity of 7.9×10^{-6} cm/sec a geometric mean of 2.4×10^{-7} cm/sec results.

CRA considers that the mean percent clay size (20.8%, Table B.2.1, p. 24) suggests that the hydraulic conductivity of this till is unlikely to exceed 1×10^{-7} cm/sec.

CRA considers that single well response tests are not the most appropriate method for determining the hydraulic conductivity of low permeable materials. Laboratory determinations of the vertical hydraulic conductivity would have aided in assessing the hydraulics of this unit.

B.3.2.3 Lower Till

The Lower Till Unit is continuous beneath the site and contains the granular units.

CRA has reviewed the grain size data provided by Trow (Appendix 3, Exhibit H-39A) and concludes that the Lower Till has a lower clay content than the Upper Till (8.4% compared to 20.6%; Tables B.2.2 (p. 27) and B.2.1 (p. 24) respectively). It is expected therefore that the hydraulic conductivity of the Lower Till would be somewhat greater than that of the Upper Till.

The mean hydraulic conductivity of the Lower Till as presented by Trow (p. 42, Exhibit H-39) is 2×10^{-6} cm/sec. This value was determined from analysis of slug test results and is somewhat greater than the value determined using the same procedure for the Upper Till (8×10^{-8} cm/sec).

The hydraulic conductivity values determined from slug tests may be somewhat inaccurate. CRA considers that laboratory hydraulic conductivity determinations would provide a better measure of the permeability of these materials.

B.3.2.4 Upper Granular Unit

This Unit is discontinuous in its distribution beneath the site and as indicated by CRA in Section B.2.4.1 generally consists of silty sands and gravels.

The slug test data provided by Trow (Appendix 12, Exhibit H-39A) show the following values for the hydraulic conductivity of this unit:

HC2-85-2	1.1×10^{-6} cm/sec
HC2-86-2	4.0×10^{-5} cm/sec

The values of the hydraulic conductivity are lower than expected for sands and gravelly sands and suggest, as indicated by the grain size data from HC4-85 (4% clay, Table B.2.2, p. 27), that these materials may contain a significant amount of fine grained material.

The distribution of the Upper Granular Unit is shown by Trow on Drawing 18 (Exhibit H-39). During cross-examination, it was indicated by Mr. Sobanski (Volume 22, p. 5025 - 5027) that Trow's Drawing 18 (Exhibit H-39) showed the distribution of the "significant" or "water bearing" portions of the Upper Granular Unit. It was recognized by Mr. Sobanski that thin silty horizons were encountered at an elevation similar to that of the Upper Granular Unit; e.g. at HC6-85, 'silt interbedded with clay, minor pebbles', was encountered between 172.7 and 173.0 m (Appendix 2, Exhibit H-39A). This could be a lateral extension of the Upper Granular Unit, but because of its poor water yielding characteristics, Mr. Sobanski does not consider this hydrogeologically significant. Therefore, Mr. Sobanski concluded that only the permeable granular materials encountered can be included in either of the granular hydrostratigraphic units. CRA agrees with this interpretation.

A pumping test of 49 hours duration was conducted by Trow on PW2 which is screened in the Upper Granular Unit and located adjacent to HC2-85. The calculated drawdown data for this test are not provided. The following interpretation undertaken by CRA is based upon the time-drawdown, time-recovery and distance-drawdown graphs presented by Trow (Appendix 10, Exhibit H-39A).

CRA agrees with Trow (p. 44, Exhibit H-39) that these test results indicate that the Upper Granular Unit is discontinuous eastwards from the pumping well.

A transmissivity of 2.5×10^{-4} m^2/sec and a hydraulic conductivity of 8.2×10^{-3} cm/sec was determined by Trow for this Unit (p. 46, Exhibit H-39).

Given the grain size variations encountered, it is probable that this hydraulic conductivity is representative of the more permeable portions of this unit.

The hydraulic conductivity as calculated by Trow is therefore considered by CRA as conservative.

The time-recovery graph for PW2 (Appendix 10, Exhibit H-39A) shows that this well may not have fully recovered following pumping. Examination of this graph by CRA indicates that recovery data appear to have been collected from the pumping well for a four hour period only, following a pumping test of 49 hours duration.

Some recovery data was collected for the observation wells monitored during this test and are presented on the Theis drawdown plot (Appendix 10, Exhibit H-39A). For two of the wells, (OW3 and OW4), recovery data appear to have been collected for an estimated 6660 minutes (111 hours) after pumping stopped. OW3 recovered only about half of the approximately 1.75 m of drawdown achieved during pumping. At OW4, only 1 cm of recovery followed the 16 cm of drawdown. At OW1 and OW2 recovery data appear to have been collected for only 500 minutes and it cannot be ascertained from the data provided if these wells will recover to their original static level.

The apparent lack of complete recovery is of significance in characterizing the hydraulics of this unit. CRA considers the incomplete recovery to indicate that the Upper Granular Unit does not comprise a continuous permeable layer under the western portion of the site but rather an isolated lense of granular material embedded within the Lower Till. This is discussed further in Part C of this report.

B.3.2.5 Lower Granular Unit

Only two observation wells are fully screened in this Unit, while HC1-85-2 is partially screened in the Unit. Slug test data (Trow, Appendix 12, Exhibit H-39A) show a hydraulic conductivity of 1.0×10^{-6}, 1.2×10^{-6} and 1.7×10^{-4} cm/sec at HC1-85-2, HC4-85-2 and HC1-86-2, respectively. The geometric mean of these values as calculated by CRA is 5.9×10^{-6} cm/sec. There are no grain size data for this Unit.

It should be noted that the hydraulic conductivity at HC1-86-2 (1.7×10^{-4}cm/sec) is the highest value obtained by slug testing at this site (Trow, Appendix 12, Exhibit H-39A).

An aquifer transmissivity of 9.7×10^{-6} m^2/sec was determined by Trow (p. 46,

Exhibit H-39) from a pumping test conducted at a test well (PW-1) located adjacent to HC4-85. Using an aquifer thickness of 4.1 m at HC4-85, CRA calculates a hydraulic conductivity of 2 x 10^{-4} cm/sec. This is consistent with the value calculated by Trow for this Unit (3.3 x 10^{-4} cm/sec. p. 46, Exhibit H-39).

It is noted in Appendix C (Exhibit H-84) that the water level in an observation well (OW-2) rose during the pumping test interval. In addition, the water level in the pumping well recovered to above its original static level (Appendix 10, Exhibit H-39A). This suggests that the water levels were not stable prior to testing and indicates that the cone of influence developed during this test may be more extensive than that interpreted by Trow (p. 43, Exhibit H-39).

As indicated in Appendix C (Exhibit H-84) the pumping well drewdown a total of 6.6 m. Examination of the recovery plot for PW1 (Appendix 10, Exhibit H-19A) shows that within approximately 0.5 minutes after the pump shut down, the water level had risen to a point 0.985 m below original static. CRA concludes that the pumping well is inefficient. A more efficient well could be pumped at a greater rate and produce a more extensive cone of depression.

B.3.3 HYDRAULIC GRADIENTS

B.3.3.1 Horizontal Hydraulic Gradients

The lateral component of groundwater flow in the weathered Upper Till is directed both southwest and eastwards to the adjacent surface water courses as shown by Trow (Drawing 17, Exhibit H-39). The horizontal gradient as reported by Mr. Beechinor in cross examination (Vol. 29, p. 6123) had a mean value of 0.0052 (Exhibit H-170), while those reported by Geocon averaged 0.008 (Exhibit M-168). CRA does not consider this difference as significant. However, CRA does not consider the method that Trow utilized to calculate the gradients as inappropriate.

Trow calculates a mean eastwards hydraulic gradient in the Upper Granular Unit as 0.001 from their Drawing 18 (p. 50, Exhibit H-39). However, one of the wells shown on this drawing, PW-1, is completed in the Lower Granular Unit. Given the uncertainty regarding the distribution of this Unit and the few piezometers screened within it, CRA considers that a flow direction and gradient can not be determined with confidence.

CRA considers that insufficient data are available to determine a flow direction and horizontal gradient in the Lower Granular Unit.

The potentiometric distribution at the overburden/bedrock interface is shown by Trow (Drawing 16, Exhibit H-39). There is little range in the values presented and an average horizontal hydraulic gradient of .001 is calculated by Trow (p. 49, Exhibit H-39). CRA reviewed this drawing and considers an average gradient of 0.003 may be more representative.

The contoured distribution shows a general groundwater flow direction to the south and southeast. CRA expects a similar pattern of groundwater flow in the Lower Till and Granular units.

B.3.3.2 Vertical Hydraulic Gradients

The vertical hydraulic gradients summarized by Trow (p. 51, Exhibit H-39) show that steep downward gradients of 0.26 exist across the Upper Till with a significantly lower gradient of 0.01 directed downwards between the Upper Granular Unit and the bedrock. It is not clear which wells nor which set(s) of water level data were used by Trow to calculate these gradients.

In order to examine the vertical hydraulic gradients at the site the available water level data (Appendix 5, Exhibit H-39A and Exhibit H-85) was reviewed.

Vertical gradients were calculated by CRA using the mid-screen elevations for each piezometer and the elevation of the water table for the standpipe piezometers. The calculated gradients are provided in Appendix I. A review of these data show:

1) Strong downward gradients ranging from 0.014 to 0.421 occur between the unweathered Upper Till and underlying strata. These values average approximately 0.2.

2) Downward gradients ranging from 0.004 to 0.046 are found within the underlying strata. Upward gradients of 0.021 occur locally within the Lower Till Unit at HC4-85. Transient upward gradients occur at several other locations reflecting seasonal variations in piezometric elevations. The mean gradient at these locations is directed downwards. In general, the vertical gradients beneath the Upper Till are low.

B.3.4 GROUNDWATER FLOW SYSTEM

CRA is in general agreement with Trow that groundwater flow at this site is predominantly directed downwards with the bedrock being the receptor of the bulk of the infiltration at the site.

The water balance presented by Trow (Figure 3, p. 66, Exhibit H-39) indicates that 22.8 percent of infiltration at the site migrates laterally off site, while 71.5 percent migrates down to the bedrock.

This calculation was based on the assumption that the Upper Granular Unit comprised a continuous strata. However, as shown by Trow, (Drawing 18, Exhibit H-39) the Upper Granular Unit is not continuous beneath the whole site, which thus has the effect of reducing the amount of lateral off-site flow with a resulting increase in the percentage of infiltration that reaches the lower units.

Hydraulic gradients, both vertical and horizontal, are generally low indicating the slow movement of groundwater flow.

calculated. CRA considers that the infiltration value used by Trow (9.6 mm/yr) is low. However, CRA considers that this value may reasonably represent the infiltration rate through the unweathered Upper Till.

B.3.5 SUMMARY

CRA is in general agreement with the site hydrogeology as provided by Trow. However, there are some areas of differing interpretations, as follows:

1) The hydraulic characterization of the weathered Upper Till is based on assumed values and is not supported by the available field data. The assumed values are very conservative. Based on the tritium results, Trow calculates a hydraulic conductivity of 3.0×10^{-7} cm/sec for this unit. CRA consider that the results from the tritium data provide a more representative value than that (1×10^{-5} cm/sec) assumed by Trow.

2) The use of slug tests alone may not provide a reliable estimate of the hydraulic conductivity of low permeable materials. This is of concern given that the unweathered Upper Till is the base upon which the proposed landfill is to be sited. CRA would recommend, and has completed a laboratory determination of the hydraulic conductivity of this Till as reported in Section C.2.2.2, (p. 87) of this report. The resulting mean value is 1.4×10^{-8} cm/sec which is significantly lower than the 8×10^{-8} cm/sec reported by Trow.

3) The apparent lack of complete recovery following the pumping test of the Upper Granular Unit indicates that this unit comprises an isolated lense and not a continuous layer extending westward from the site.

4) For the Lower Granular Unit, a more efficient pumping well could produce a greater yield and hence a more extensive cone of depression.

These points are addressed in more detail in Part C of this report.

B.4.0 EVALUATION OF CONTAMINANT MIGRATION

This evaluation is based on the potential contaminant pathways as defined by Trow (Figure 7, p. 94, Exhibit H-39) as follows:

1) For the leachate collection system in operation diffusion downward into the unweathered Upper Till represents the only contaminant loss from the landfill into the subsurface.

2) For the condition where the leachate collection system or a portion thereof has failed, contaminants can migrate
   i) laterally in the weathered Upper Till,
   ii) vertically downward through the unweathered Upper Till and Lower Till, and thence laterally in the granular units and the bedrock.

For the landfill operating as designed, the only contaminant pathway is migration via diffusion into the underlying unweathered Upper Till. This pathway was evaluated by Trow, and as detailed in Exhibit H-86A, (Figure 1, p. 7) shows that chloride can potentially migrate a total distance of 3 m into the unweathered Upper Till below the base of the landfill.

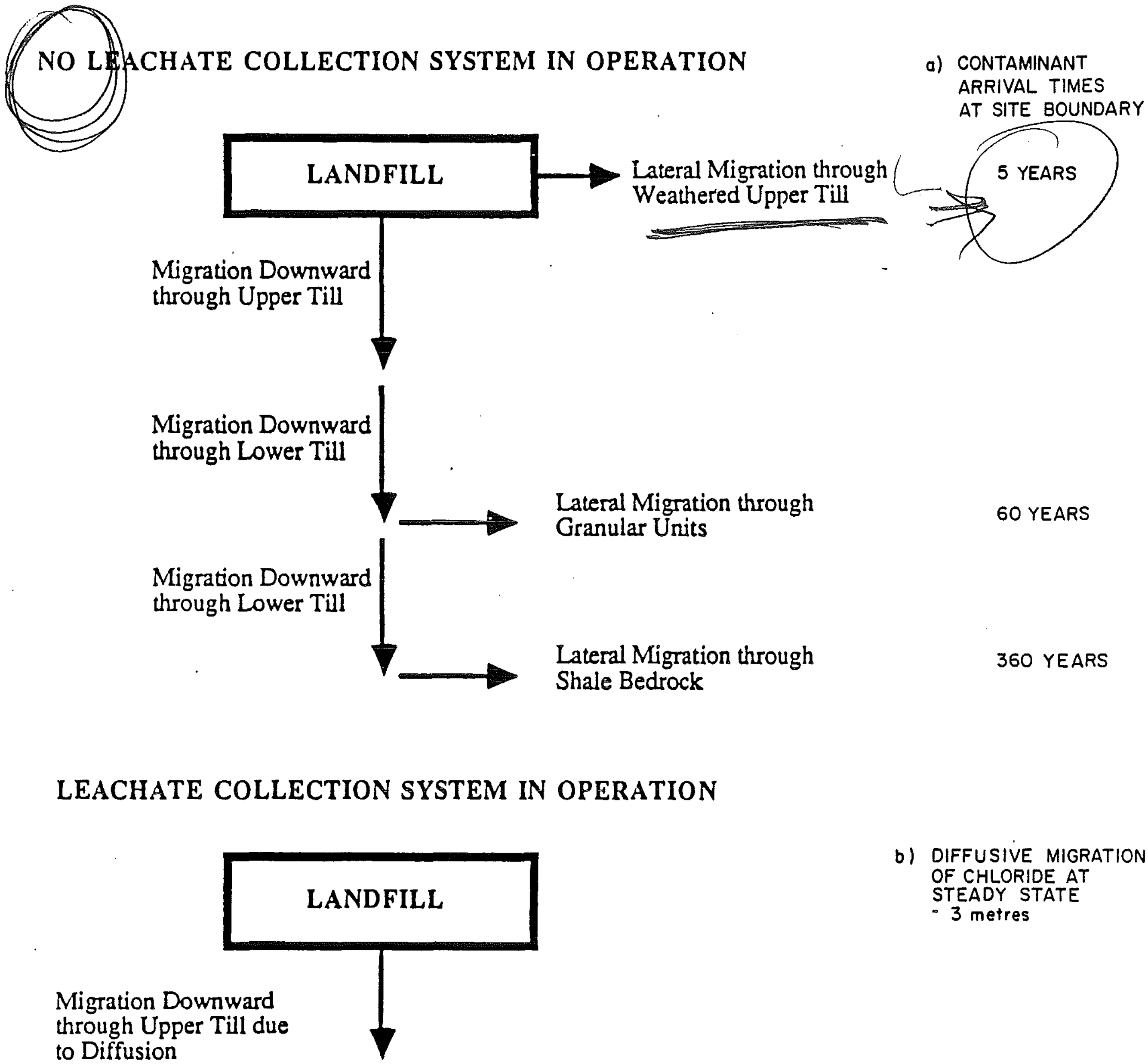
For the condition of a failed landfill, the contaminant arrival times were determined by Trow by coupling a series of one-dimensional transport equations. These equations describe flow in each of the hydrostratigraphic units encountered along a contaminant pathway. These pathways and the resulting arrival times are summarized on Figure B.4.1 (p. 53). The following addresses each of these contaminant pathways.

B.4.1 <u>WEATHERED UPPER TILL</u>

As shown on Figure B.4.1 (p. 53) Trow concludes that contaminants can migrate to the site boundary in five years. An arrival time of five years is considered by CRA as unreasonable.

Trow indicates (p. ix, Exhibit H-39) that experience gained at other similarly sited landfills in Ontario shows that rapid migration through the weathered zone has not been detected. However, it is recognized that the hydrogeologic conditions governing flow in such zones are not fully understood.

With respect to landfilling in fractured clays, the uncertainty regarding the hydraulics of these materials can be addressed by:



SOURCE: TROW (1986), Figure 7, p.94. EXHIBIT H-39

a) CONTAMINANT ARRIVAL TIMES FROM TROW (1986) p.102 EXHIBIT H-39

b) FROM EXHIBIT H-86A, Figure 1, p. 7

figure B4.1

SCHEMATIC OF CONTAMINANT MIGRATION PATHWAYS

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1) Recompacting the sidewalls of the excavation to provide a low permeable barrier.

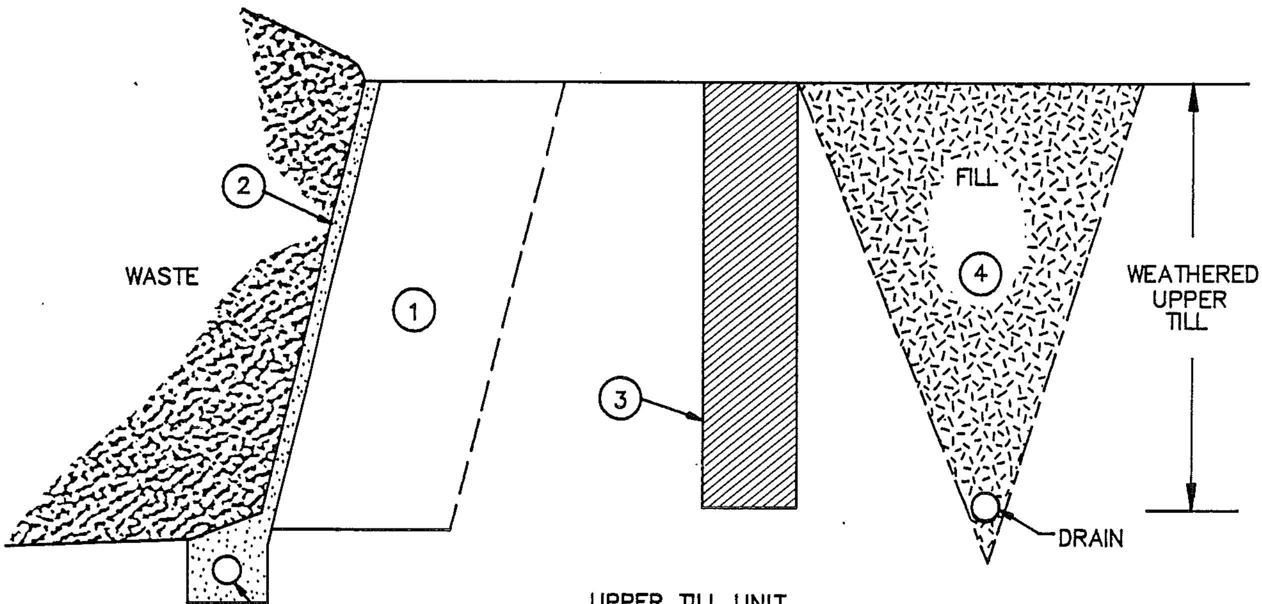
2) Providing a permeable drainage layer with connection to the leachate collection system.

3) Installing a cut-off wall around the outside of a completed excavation.

4) Installing a perimeter drain around the outside of a completed excavation.

These engineering alternatives are shown schematically on Figure B.4.2 (p. 55). A similar figure (Exhibit B-212) was discussed by Mr. Sobanski in cross-examination (Volume 34, p. 7355) who considered that such options could be considered for Site D. He pointed out that for 1 and 2 above the side wall slope of the excavation would probably have to be reduced. He also believed that one of the options shown, the perimeter drain, has been selected for this site (Vol. 34, p. 7361).

It should be pointed out that the need to implement any of the above alternatives would be based upon the observation of extensive fracturing on the side slope of an excavation. Local fracture zones could be over excavated and recompacted.



NOT TO SCALE

LEGEND

1. EXCAVATE AND REMOULD WEATHERED UPPER TILL – DURING CONSTRUCTION
2. CONSTRUCT DRAINAGE LAYER – DRAINS TO LEACHATE COLLECTION SYSTEM – DURING CONSTRUCTION
3. CONSTRUCT CLAY CUT–OFF WALL
4. INSTALL PERIMETER DRAIN

MODIFIED FROM : EXHIBIT B–212

figure B4.2

ENGINEERED SOLUTIONS
UPPER WEATHERED TILL
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B.4.2 GRANULAR UNITS

Trow considered the Upper Granular Unit as the most significant pathway for off site groundwater flow and evaluated contaminant arrival times at the site boundary in this granular unit only.

These evaluations were performed on the assumption that:

1) The UGU is continuous under and beyond the western half of the site.

2) The hydraulic conductivity determined from the pumping test provides an average value for this unit.

CRA considers that for the purpose of assessing potential impact these assumptions are quite conservative. CRA would agree it would be prudent to use this assumption given that nearby domestic wells exploit the overburden as a water supply source. This assumption provides a worst case scenario.

The impact assessment conducted by Trow (Exhibit H-39) shows that for the proposed landfill operating as designed, there will be no groundwater quality impact at the site boundary in the granular units (Exhibit B-259).

For the condition where the proposed landfill fails to perform as designed and further, that no corrective action is implemented, a period of 60 years will elapse before a groundwater quality impact is registered at the site boundary in the granular units.

For lower hydraulic conductivities in either of the till units or the granular unit, the travel time will be longer.

While CRA is in general agreement with the results of the impact assessment, the assumptions used by Trow lead to the overestimation of the groundwater velocity and an underestimation of the time of arrival.

B.5.0 LANDFILL DESIGN CONSIDERATIONS

Trow does not discuss in this section addressing landfill design considerations (p. 119, Exhibit H-39), which portions, if any, of the site are hydrogeologically preferred for landfilling. During cross-examination it was implied by Mr. Sobanski (Vol. 34, p. 7445), that uniform hydrogeologic conditions are encountered across the site. However, the western two-thirds was preferred by Mr. Sobanski because of the larger data base for this portion of the site.

On the basis of this review undertaken by CRA, the whole of the original site is considered as hydrogeologically suitable for landfilling.

The landfill design as proposed by Trow, is based on the "hydraulic trap" concept. This concept is shown schematically on Exhibit H-39B. The principle of this system, as put forward by Trow (p. 123, Exhibit H-39), is to control the leachate level at an elevation below the potentiometric head (water level) of the underlying granular units and the bedrock. Thus, groundwater flow is inwards to the landfill which hydraulically isolates the underlying strata.

The hydrogeologic elements of the hydraulic trap as considered by Trow (p. 125, Exhibit H-39) are as follows:

1) Maintain a maximum leachate level of 1.5 m above the landfill floor.

2) Allow for an additional seasonal piezometric fluctuation of 0.4 m, so the floor elevation should lie 1.9 m below the piezometric elevation of the underlying granular units and bedrock.

It is to be noted that Trow indicates that the thickness of unweathered Upper Till underlying the landfill will be 4 m (Figure 22, p. 128, Exhibit H-39).

The proposed hydraulic trap design of Trow was evaluated by CRA. In order to complete this evaluation the base elevation of the unweathered Upper Till as interpreted by CRA was plotted in plan view (Figure B.5.1, p. 60). The April 1986 water levels are also plotted on this figure, as are the five landfill cells are taken from Drawing 2 (Trow, Exhibit H-39B).

For each cell, the minimum piezometric elevation in the underlying strata was determined. This value was then compared to the design leachate elevation as

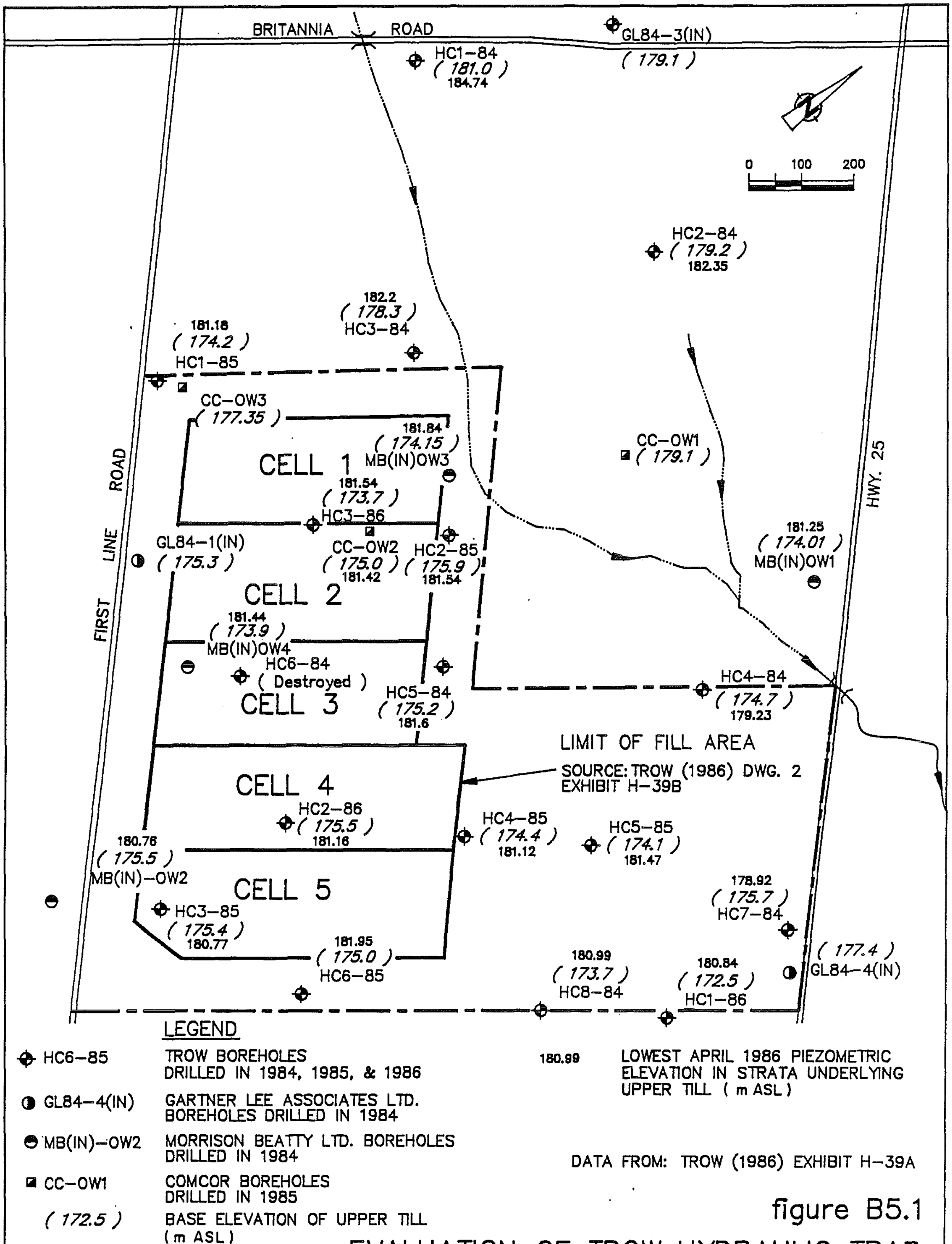

figure B5.1

EVALUATION OF TROW HYDRAULIC TRAP
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inferred by CRA by taking the lowest floor elevation from Trow's Drawing 2 (Exhibit H-39B) and adding 1.5 m, the designed leachate mounding between tiles. As determined by Trow (p. 125, Exhibit H-39) a 0.4 m head difference is required between the design leachate elevation and the April 1986 piezometric heads in the granular strata or bedrock to provide an adequate safety margin to ensure for the operation of the hydraulic trap.

The results of this evaluation are summarized on Table B.5.1 (p. 62) which shows that for cells 1 and 5, the criteria of a 0.4 m safety margin established by Trow for the hydraulic trap are not met. Some minor redesign may be required.

Also the minimum thickness of unweathered Upper Till underlying each cell as interpreted by CRA varies from 2.6 to 3.6. m. This contrasts with the 4 m used by Trow for the impact assessment.

The design leachate elevation was calculated by Trow (p. 125, Exhibit H-39) using a hydraulic conductivity of 1 x 10^{-4} cm/sec for the refuse. The hydraulic conductivity of refuse is quite variable but typically is expected to range from 10^{-2} to 10^{-4} cm/sec. CRA considers that a value of 1 x 10^{-4} cm/sec is conservative and provides a realistic assessment of the magnitude of leachate mounding.

TABLE B.5.1

EVALUATION OF PROPOSED HYDRAULIC TRAP DESIGN

Cell No.	Maximum Base of Upper Till (m)	Base[4] Elevation Landfill (m)	Minimum Upper Till Thickness (m)	Design[1] Maximum Leachate Level (m)	Piezometric[2] Elevation (m)	Minimum[3] Hydraulic Trap Head (m)
1	176	179.5	3.5	181.0	181.2	0.2
2	175.9	178.5 - 179.5	2.6	181.5	181.5	0.5
3	175.2	178.0 - 179.0	2.8	181.5	181.5	1.0
4	175.5	179.0	3.5	181.5	181.5	0.7
5	175.4	179.0	3.6	180.5	180.8	0.3

Notes:

1) Design maximum leachate level is minimum base of landfill plus designed leachate mound of 1.5 m.

2) Piezometric elevation is equal to the lowest measured piezometric elevation in strata below the upper till, as measured in April 1986.

3) Minimum hydraulic head is determined by subtracting the design maximum leachate level from the piezometric elevation. A value less than 0.4 m indicates that the trap design criteria has not been met.

4) From Trow Drawing 2, Exhibit H-39B.

Trow examined the effects that the inflow of groundwater into the hydraulic trap could have on adjacent groundwater levels (p. 127, Exhibit H-39). The calculated groundwater inflow is reported to be 3.6 L/min (0.8 gpm) (Trow Appendix 16, Exhibit H-39A). This rate of inflow is approximately equal to the yield of an average domestic well.

CRA concludes that extraction of groundwater at a rate of 3.6 L/min (0.8 gpm) to maintain the hydraulic trap will have a negligible impact on groundwater levels in the area.

CRA is in general agreement that a hydraulic trap landfill design can be implemented at this site. However a modified design will have to be considered in order to achieve the hydraulic trap design in a portion of the site. This is discussed in more detail in Part C of this report.

B.6.0 CONTINGENCIES

Contingency options are required in the event that the landfill system fails to perform as designed. The monitoring program designed by Trow as discussed in Section B.7 (p. 70) of this report is suitable to provide an early warning of groundwater quality changes. These changes can be monitored in order to evaluate the need, if any, to implement contingency options.

It is assumed here that regular maintenance of the engineered components of the landfill will be undertaken to ensure that the hydraulic trap is functioning correctly.

Should excess leachate heads develop within the landfill, then the hydraulic gradient will be directed downwards across the unweathered Upper Till. In such a situation, the hydraulic trap will have failed and leachate will begin to migrate into the underlying unweathered Upper Till.

Contingency measures can be implemented to reduce the level of leachate mounding within the landfill and restore the hydraulic trap. These measures were not discussed in the Trow report. However, Mr. Sobanski indicated in cross-examination (Vol. 28, p. 5939) that purge wells could be put into the landfill to extract leachate in order to reduce leachate mounding and restore the hydraulic trap.

However, in the most unlikely event that no contingency measures are implemented to restore a failed hydraulic trap, then leachate may migrate from the landfill via the following pathways:

1) Laterally in the weathered Upper Till.
2) Downwards to the granular units and thence laterally.

B.6.1 LATERAL MIGRATION IN WEATHERED UPPER TILL

Migration in this zone would be restricted to the weathered horizon which is limited to approximately a 4 m depth below ground surface. This migration can be effectively controlled by the installation of a perimeter drain.

The perimeter drain as described by Trow (p.131, Exhibit H-39) is expected to collect 100 percent of any contaminated water potentially migrating in the weathered Upper Till.

As discussed in Section B.4.1 (p. 52) of this report a cut off-wall could also be considered for the weathered Upper Till.

In cross-examination Mr. Sobanski considered that the potential for contaminant migration in this zone is not a concern because of the engineering contingencies available (Vol. 34, p. 7365). CRA agrees with the above and points out, as indicated by Mr. Sobanski (Vol. 34, p. 7431), that determining the linear groundwater velocity in this zone is not all that critical given the contingency options available.

B.6.2 LATERAL MIGRATION IN THE GRANULAR UNITS

As demonstrated by the pumping test, groundwater flow in the UGU can be controlled by pumping.

The required pumping rate is expected to approximately equal the infiltration to the landfill. Trow calculate a rate of 12.6 L/m for infiltration into this unit (p. 133, Exhibit H-39). A hydraulic gradient of 0.5 was used in this calculation to reflect the effects of leachate mounding. In an earlier section addressing contaminant arrival times, Trow used a gradient of 0.85 to reflect the effects of leachate mounding (Table 10, p. 88, Exhibit H-39).

Under this gradient, an infiltration rate of 21.4 L/m (4.7 gpm) to the Upper Granular Unit is calculated. This rate is approximately equal to the yield of about four domestic wells and as such is not expected to have any discernible effect on groundwater levels in the area. It should be noted that at present there are four domestic wells on Site D. It is expected that pumping from these wells will be discontinued should landfill development proceed. Therefore CRA concludes that the operation of a purge well system will not impact present water levels.

Trow had calculated the long-term impact on water levels resulting from purge well operation. They concluded that water levels at domestic wells to the west of the site would be lowered by about 1.7 m (p. 133, Exhibit H-39) after 27 years of continuous pumping.

Implicit in this calculation (Appendix 16, Exhibit H-39A) is the assumption that all of the pumped water was drawn from within the Upper Granular Unit and that infiltration was nil. This is unreasonable when examining the effects of pumping on a scale of years.

The effects of purge well operation at Site D were examined by CRA using the Theis equation. For the following variables:

$T = 21.6\ m^2/day$ (p. 46, Exhibit H-39)

$Q = 30.8\ m^3/day$ (21.4 L/min)

$S = 2.7 \times 10^{-4}$ (p. 46, Exhibit H-39)

r = 150 m (Appendix 16, Exhibit H-39A)

t = 100 days

a drawdown of 0.76 m was calculated.

In addition it was also assumed that the Upper Granular Unit beneath the proposed landfill extends westward to beyond First Line Road. CRA considers that the Upper Granular Unit is not continuous beneath and westward from the site.

Given the above calculated drawdown, and the assumed abandoning of the four domestic wells currently on site, CRA concludes that operation of a contingency purge well system for the Upper Granular Unit will not have a discernible impact on the present groundwater levels adjacent to the site.

A purge well(s) operating at the above rate (21.4 L/min) would be required only in the event of a total failure of the landfill system. A much reduced pumping rate would be required for a partial failure of one cell. For such a failure, estimated at say 10 percent of the area of the landfill, the pumping rate would reduce to $3.08\ m^3$/day (2.14 L/min). The calculated drawdown thus reduces to 0.076 m.

The same arguments apply to the potential effects of pumping from a purge well system completed in the Lower Granular Unit. Because of the lower transmissivity more pumping wells may be required than for the Upper Granular Unit to control a totally failed landfill. However the lower transmissivity results in a lower calculated drawdown at the nearby domestic wells.

CRA concludes that contaminant migration, were it to occur in the granular units, can be effectively controlled by operation of a purge well system without interfering with groundwater levels in the area.

B.7.0 MONITORING PROGRAM

A monitoring program is discussed by Trow and Drawing 24 (Exhibit H-39) locates the monitoring points, both existing and proposed. The details of this program were provided during cross-examination of Mr. Sobanski (Vol. 34, p. 7406 and Exhibit H-213). The following summarizes the recommended monitoring program as it is understood by CRA:

1) Monitoring at 4 existing observation well nests for a total of 11 piezometers.

2) The installation of as many as 57 additional piezometers at 15 locations around the perimeter of the proposed landfill.

3) Monitoring both pumping wells (PW-1 and PW-2).

4) Monitoring the on-site farm well located on the northwest side of the property.

5) Monitoring 5 existing off-site domestic wells, four located along First Line Road and one to the north of the site.

This comprises a potential total of 76 groundwater quality monitoring points and implies a large amount of uncertainty associated with the hydrogeologic characterization of this site.

This is considered by CRA as an excessive number of monitoring points. Section C.4.2.2 (p. 102) of this report provides CRA's recommended monitoring program which consists of 24 groundwater monitoring points.

There is no discussion addressed by Trow (Exhibit H-39) to monitoring the performance of the hydraulic trap. In cross-examination it was indicated by Mr. Sobanski (Volume 34, p. 7426) that hydraulic monitoring (i.e. water levels) would be undertaken at existing and proposed monitoring installations. It is not known how leachate levels within the landfill are to be monitored.

The available groundwater quality as provided by Trow (Appendix 11, Exhibit H-39A) and Geocon (Exhibit M-438) show in general elevated levels of chloride and sulphate. Values of chloride range up to 1000 mg/L for on site wells and up to 600 mg/L from adjacent domestic wells (Table 1, p. 5-18, Exhibit M-438). As discussed in testimony by Dr. Charlesworth, chloride levels at this site can show fluctuations of up to 100 percent. CRA recognizes that for this site chloride may not be a useful indicator of contamination given the present levels which may exceed MOE drinking water objectives (250 mg/L) and the apparent seasonal variation. CRA would recommend that a more extensive groundwater sampling program be implemented at the initiation of landfilling to establish background water quality and trends at the site.

A suite of target parameters for future monitoring would be identified following characterization of the leachate.

B.8.0 SUMMARY

CRA is in general agreement with the hydrostratigraphic sequence, groundwater flow system, conceptual landfill design and contingencies as detailed by Trow.

The following summarizes where CRA differs from Trow in the assessment of Site D:

1) The weathered Upper Till is most unlikely to comprise a pathway of significant contaminant migration. A first arrival time of five years from a failed landfill system is overly conservative and inconsistent with experience gained at similar sites elsewhere in Ontario. Alternative engineering designs can be considered during the construction phase if significant fracturing is identified during excavation. In addition, the contingency plan proposed by Trow can be expeditiously implemented, if warranted, and is expected to control 100 percent of leachate migrating in this unit.

2) Slug tests do not provide the most meaningful determination of the hydraulic conductivity of low permeable strata. The hydraulic conductivity of the unweathered Upper Till, the primary layer restricting contaminant migration at this site, is not well

supported. Laboratory permeability tests would have provided a more reliable value. CRA undertook such tests, the results of which are reported in Part C of this report.

3) The incomplete recovery observed following the pumping test conducted in the Upper Granular Unit indicates that this unit does not comprise a continuous permeable blanket underlying much of western portion of the site. CRA considers the value of the hydraulic conductivity calculated by Trow as conservative (high) given that this unit is not continuous.

4) The water level recovery following pumping to above original static level and the inefficiency of the pumping well suggests that a purge well could be constructed in the lower granular unit and pumped at a greater rate and create a greater cone of influence than that implied by Trow.

5) Purge wells could be constructed into the waste and pumped to control excessive leachate mounding. The number and placement of such wells would be determined as needed. This therefore would provide the primary contingency option available at this site.

6) Operation of a purge well system to control contaminant migration in the granular units will not have a discernible influence on groundwater levels in the area adjacent to the site.

7) The landfill design as proposed does not effectively provide for a hydraulic trap everywhere across the site. However a minor modification to the existing design can ensure that the hydraulic trap can be effectively implemented.

8) The recommended monitoring program consists of as many as 76 groundwater quality monitoring points. This is considered as an overly extensive monitoring program. In addition, the recommended program does not address monitoring of the elevation of the leachate mound within the landfill.

9) The level and variation in chloride concentrations indicates that chloride is probably not a useful indicator parameter for this site. A suite of indicator parameters will have to be developed from additional background sampling and characterization of the leachate.

PART C: INTERPRETATION OF SITE D HYDROGEOLOGY AND SUITABILITY FOR LANDFILLING

C.1.0 INTRODUCTION

In Part B of this report, the technical study reports of Trow were critiqued. This critique identified a number of differing interpretations as listed on pp. 73-75.

In Part C of this report CRA reviews the above concerns. The criteria regarding the suitability of landfilling as presented in Part A of this report are evaluated herein with respect to Site D. CRA concludes that the site is hydrogeologically suitable for landfilling.

C.2.0 HYDROGEOLOGY

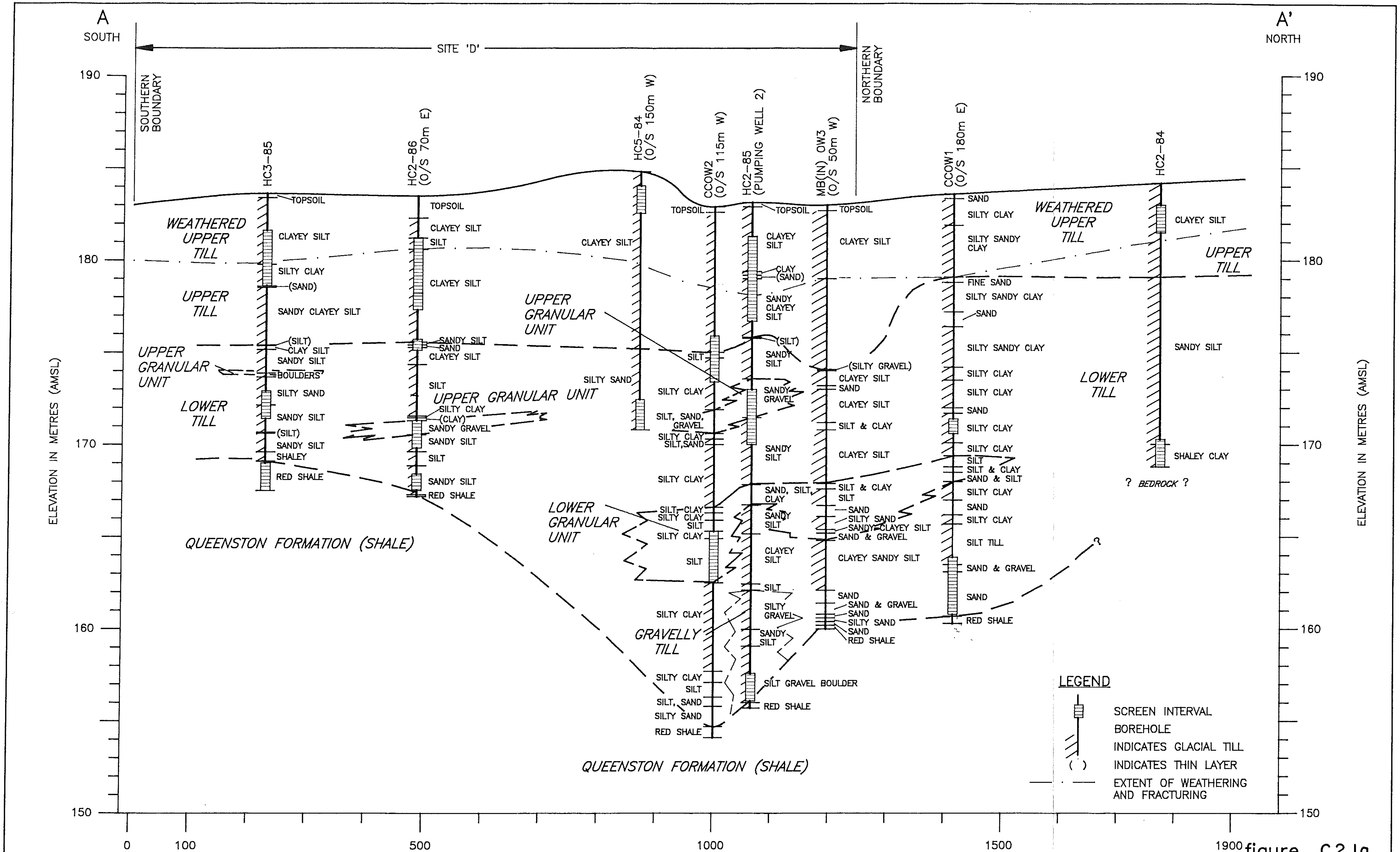
C.2.1 GEOLOGY

CRA is in general agreement with the geologic interpretation of the site as put forward by Trow with the exception of the distribution of the Upper Granular Unit.

C.2.1.1 Upper Granular Unit

From a review of the available borehole logs, CRA has interpreted that the Upper Granular Unit is present at the thickness indicated at each of the following borehole locations: HC1-85 (0.15 m), HC2-85 (2.1 m), HC3-85 (0.2 m), HC4-85 (0.3 m), HC2-86 (0.76 m), GL84-1(IN) (1.3 m), GL84-4(IN) (0.5 m), CC-OW2 (1.2 m) and MB(IN)-OW4 (1.4 m). The average thickness of these occurrences if 0.83 m, which approximates the value of 1 m shown by Trow (p. 30 Exhibit H-39).

The interpreted geologic sequence of the site is presented as geologic cross-sections on Figures C 2.1a and b (p. 78 and 79).



VERTICAL SCALE 1:200 METRIC
HORIZONTAL SCALE 1:6000 METRIC

SOURCE: TROW (1986) EXHIBIT H39A

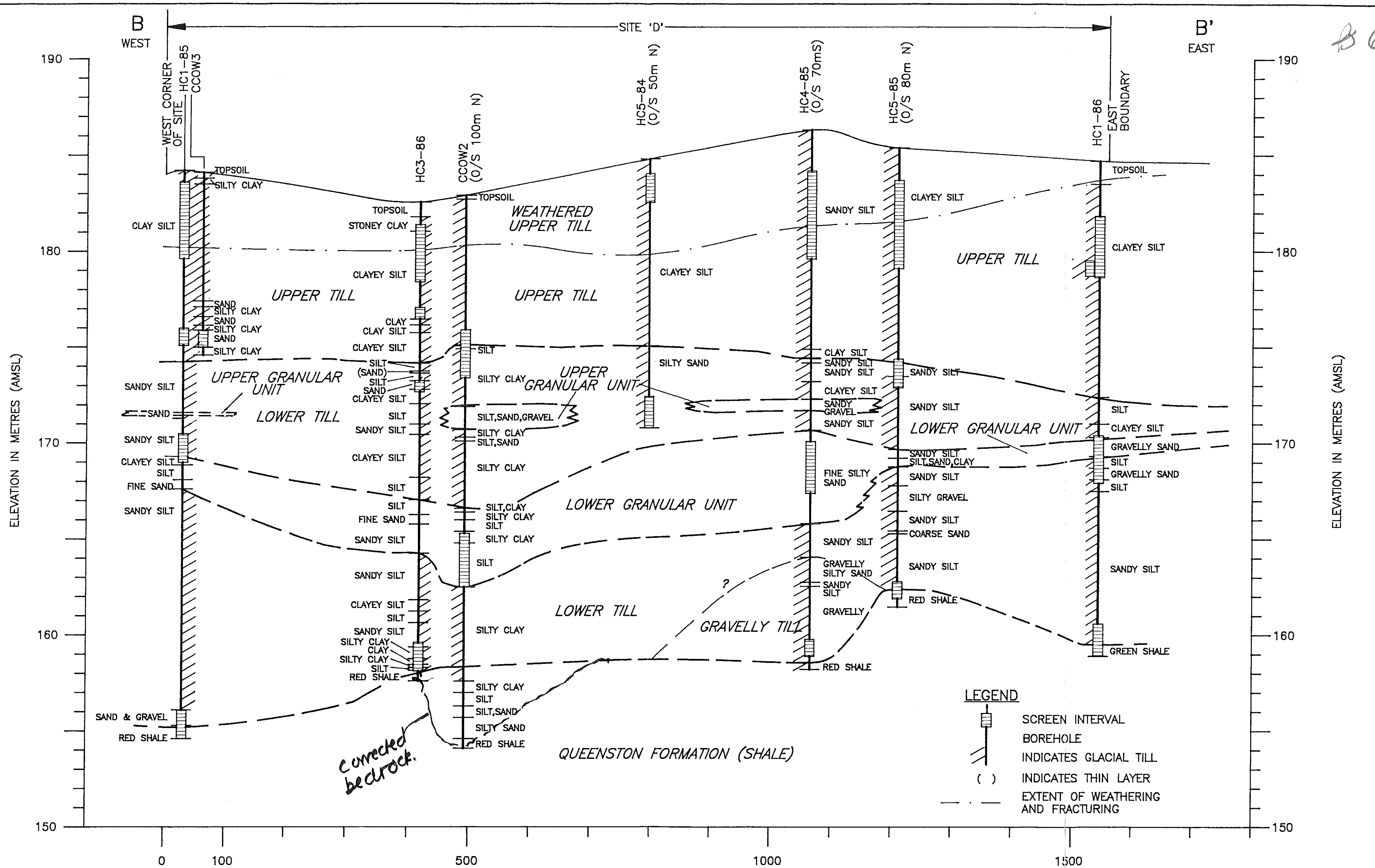
CRA

figure C2.1a

GEOLOGIC CROSS-SECTION A–A'

Site 'D' Hydrogeology- City of Burlington

1354-10-27/11/87-29-D-1



VERTICAL SCALE 1:200 METRIC
HORIZONTAL SCALE 1:6000 METRIC

SOURCE:TROW (1986) EXHIBIT H39A

CRA

figure C2.1b

GEOLOGIC CROSS-SECTION B-B'

Site 'D' Hydrogeology-City of Burlington

1354-10-27/11/87-29-D-1

The distribution of the UGU is shown on plan view as Figure C2.2 (p. 81). In addition the distribution shown by Trow (Drawing 18 Exhibit H-39) is also shown.

As shown on Figure C.2.2 (p. 81), CRA interprets that this unit is laterally discontinuous beneath the site and consists of two lenticular shaped bodies, the western one of which is interpreted to extend off site to the west. This interpretation is confirmed by the results of the pumping tests as discussed in B.3.2.4 (p. 40) of this report.

CRA concludes that the UGU does not provide a continuous permeable horizon from beneath the site to the western property boundary. This unit has a more restricted distribution than that interpreted by Trow.

C.2.1.2 Lower Granular Unit

The distribution of the Lower Granular Unit, as interpreted by CRA, is provided on Figure C.2.3 (p. 82). This figure shows that the LGU is continuous beneath the site in an east-west direction. However, this unit has a limited north-south distribution.

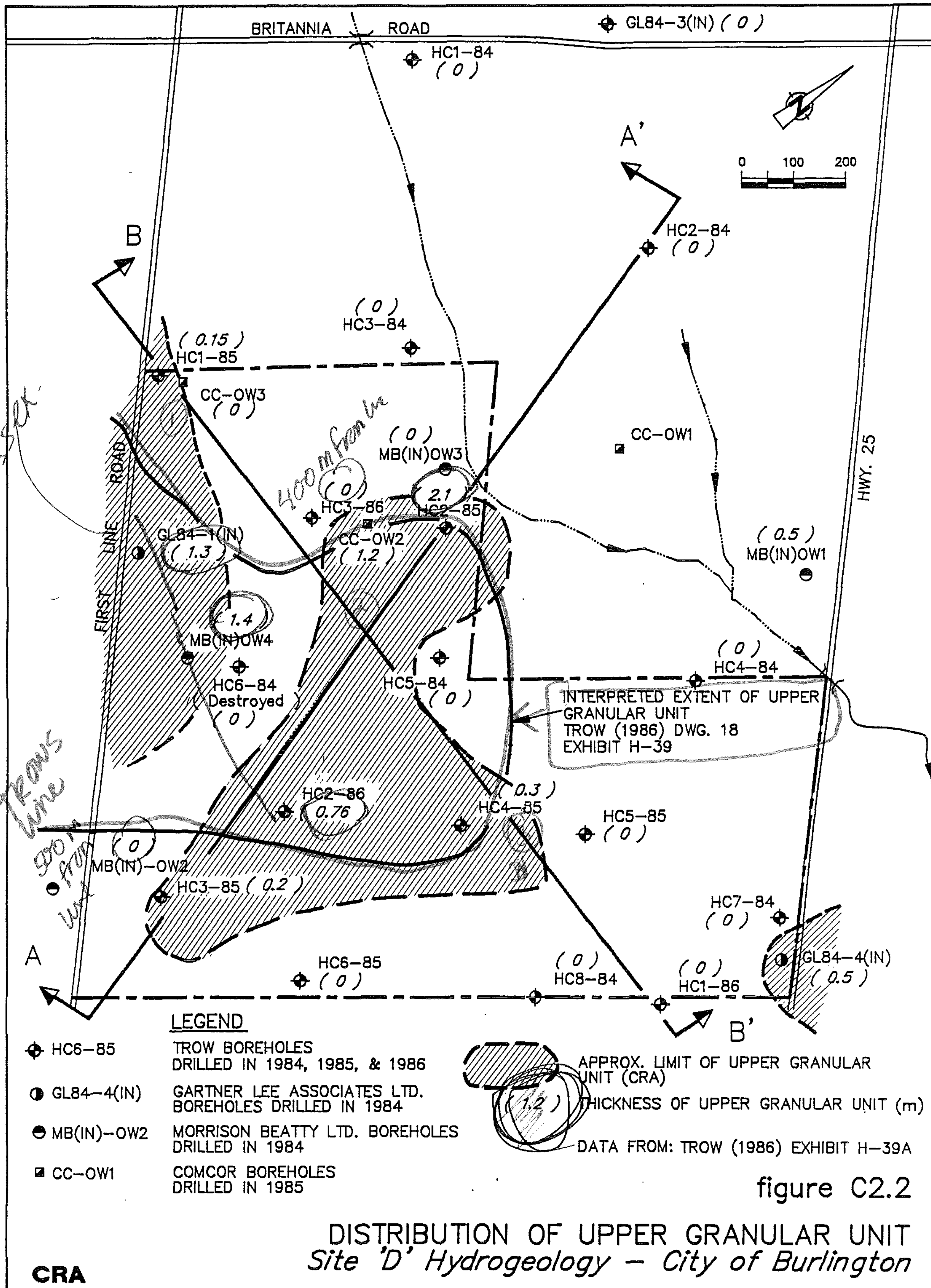
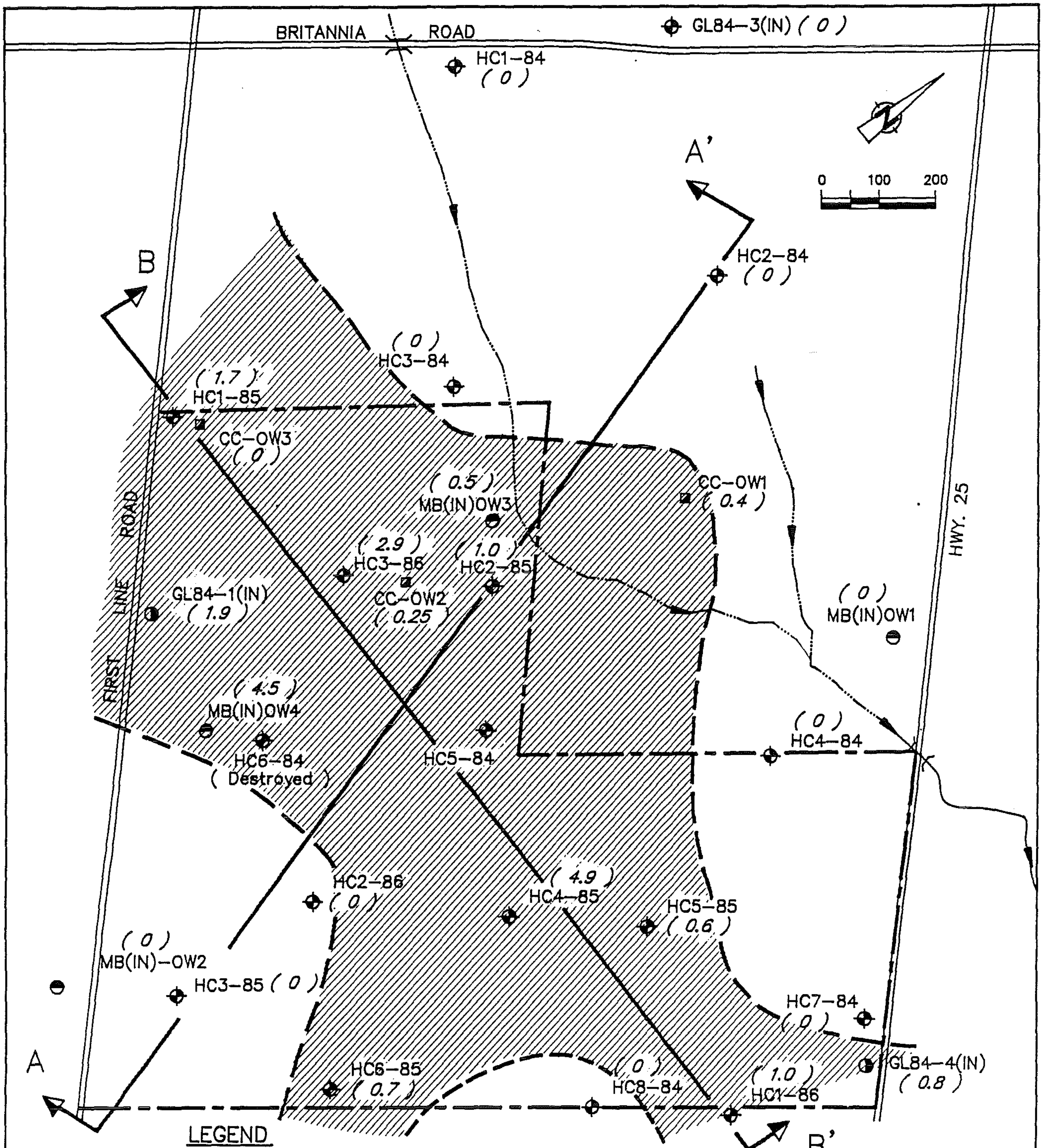


figure C2.2

DISTRIBUTION OF UPPER GRANULAR UNIT

Site 'D' Hydrogeology – City of Burlington

1354-10-27/11/87-29-D-1



LEGEND

HC6–85	TROW BOREHOLES DRILLED IN 1984, 1985, & 1986
GL84–4(IN)	GARTNER LEE ASSOCIATES LTD. BOREHOLES DRILLED IN 1984
MB(IN)–OW2	MORRISON BEATTY LTD. BOREHOLES DRILLED IN 1984
CC–OW1	COMCOR BOREHOLES DRILLED IN 1985

APPROX. LIMIT OF LOWER GRANULAR UNIT (CRA)

(4.5) THICKNESS OF LOWER GRANULAR UNIT (m)

DATA FROM: TROW (1986) EXHIBIT H–39A

figure C2.3

DISTRIBUTION OF LOWER GRANULAR UNIT

Site 'D' Hydrogeology – City of Burlington

CRA

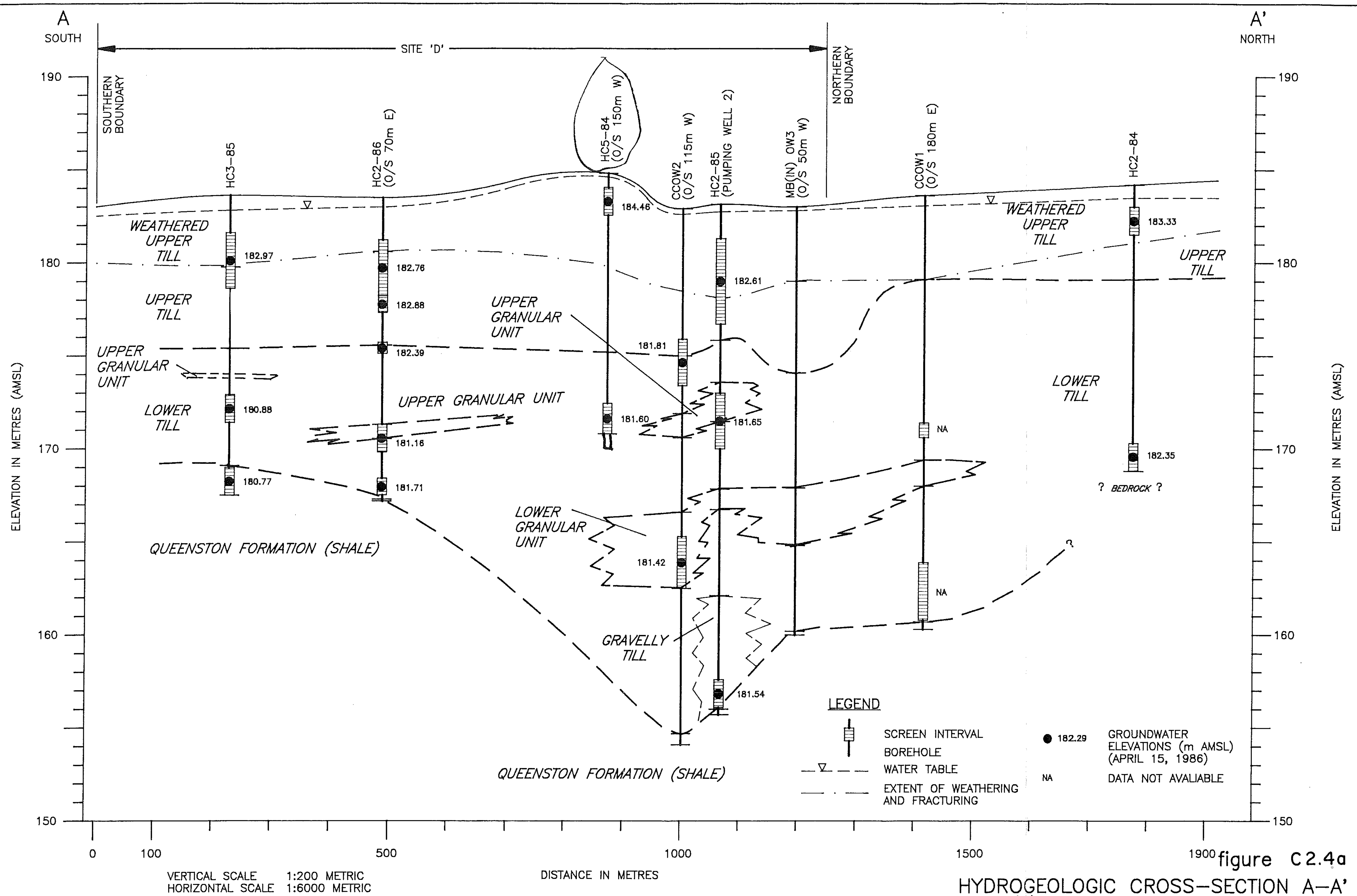
1354–10–27/11/87–29–D–1

C.2.2 HYDROSTRATIGRAPHY

The hydrostratigraphic sequence, as interpreted by CRA, is shown on Figure C.2.4a and b. These cross-sections show the distribution of the hydrostratigraphic units and the April 1986 water levels. These water levels indicate the downward flow of groundwater across the unweathered Upper Till and the less steep gradients beneath.

C.2.2.1 Weathered Upper Till

One sample from within the weathered Upper Till was obtained by CRA from the core samples retained by Trow and was submitted to Golders Associates for laboratory permeability determinations. The results of this testing and other test data from samples of the unweathered Upper Till are presented on Table C.2.1 (p. 86) and the report provided by Golder Associates is included as Appendix II. The hydraulic conductivity of the sample from the weathered zone at HC1-86 was determined to be 1.11×10^{-7} cm/sec. This result indicates that a value of 1×10^{-5} cm/sec as assumed by Trow for the weathered Upper Till, is conservative.



CRA

SOURCE: TROW (1986) EXHIBIT H 39A

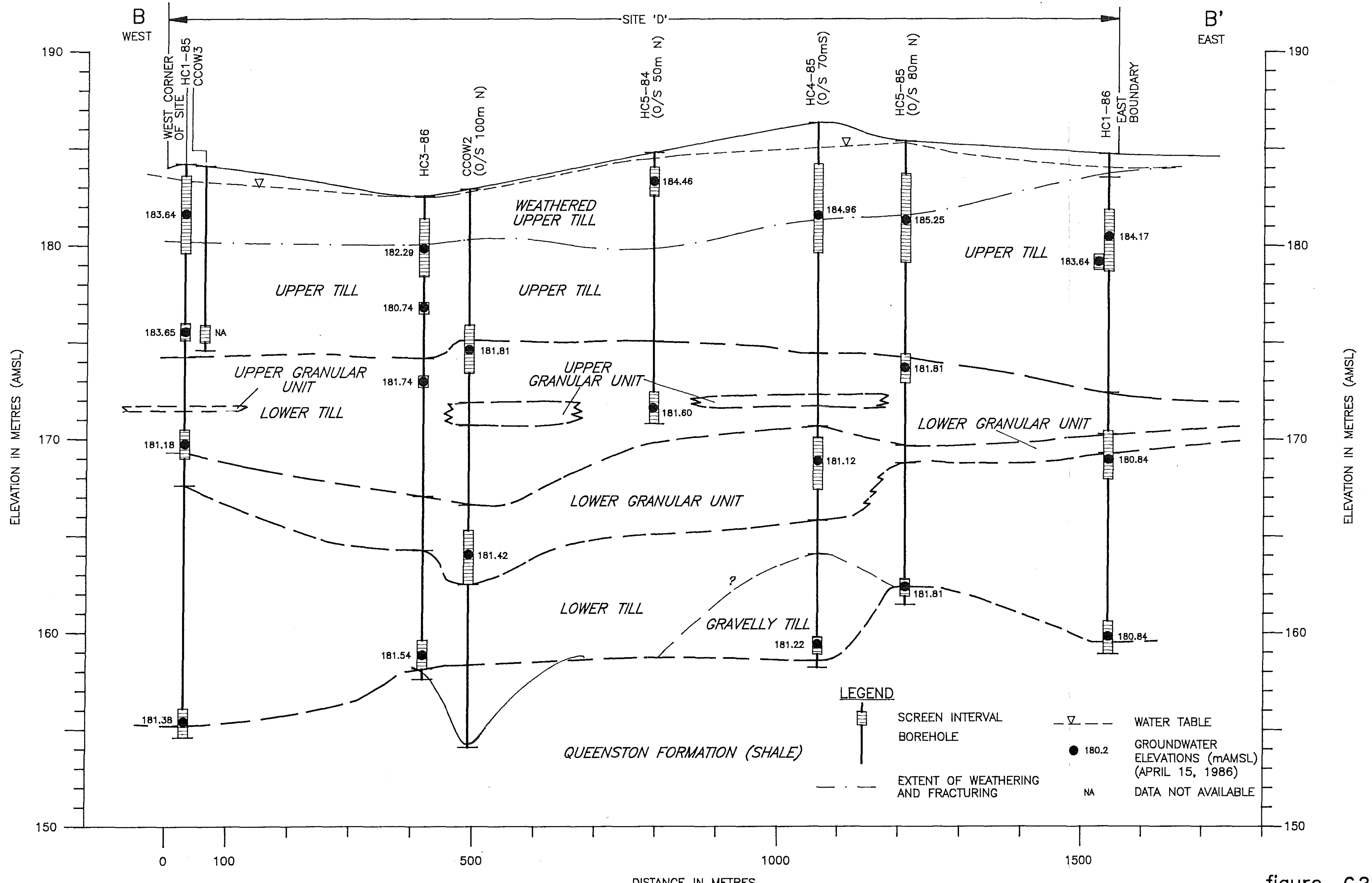
POTENTIOMETRIC ELEVATIONS APRIL 1986.
(TROW – Appendix 5)

figure C2.4a

HYDROGEOLOGIC CROSS–SECTION A–A'

Site 'D' Hydrogeology– City of Burlington

1354–10–27/11/87–29–D– I



VERTICAL SCALE 1:200 METRIC
HORIZONTAL SCALE 1:6000 METRIC

CRA

SOURCE:TROW (1986) EXHIBIT H39A

POTENTIOMETRIC ELEVATIONS APRIL 1986.
(TROW - Appendix 5)

figure C2.4b

HYDROGEOLOGIC CROSS-SECTION B-B'

Site 'D' Hydrogeology - City of Burlington

1354-10-27/11/87-29-D-0

86R

TABLE C.2.1

SUMMARY OF PHYSICAL PROPERTIES
LABORATORY HYDRAULIC CONDUCTIVITY TESTS

Borehole No.	Sample No.	Hydrostratigraphic Unit	Depth (m)	Water Content-Trimmings (%)	Water Content-Final (%)	Dry Unit Weight (kN/m³)	Vertical Hydraulic Conductivity (cm/s)	Per Cent Clay (%)	Per Cent Clay and Silt (%)	Liquid Limit (%)	Plasticity Index (%)
HC 5-85	CRA 1	(2)*	4.72-5.18	13.7	12.9	19.42	6.83×10^{-9}	20.0	53.5	25.9	8.9
										27.4*	9.6*
HC 5-85	CRA 2	(2)	8.08-8.53	8.4	11.3	20.80	6.95×10^{-9}	19.5	59.8	25.0*	8.4*
HC 2-86	CRA 3	(2)	4.57-5.33	3.9	10.4	19.93	1.45×10^{-8}	20.0	62.0		
HC 2-86	CRA 4	(2)	7.62-8.38	6.2	14.7	18.35	2.59×10^{-8}	26.0	79.0		
HC 1-86	CRA 5	(1)	2.29-3.05	1.4	14.2	19.68	1.11×10^{-7}	26.0	67.0	~~[illegible]~~	~~[illegible]~~
HC 2-86	CRA 6	(2)	6.86-7.62					26.0	75.5	28.~~5~~*	~~[illegible]~~ 9.8*

(samples 2,3,4 included)

GEOMETRIC MEAN VERTICAL HYDRAULIC CONDUCTIVITY - UNWEATHERED UPPER TILL = 1.38×10^{-8} cm/sec#

*CRA 1-88	ST2	(2)	4.27-4.88	16.3	16.1	17.88	9.21×10^{-9}	29.5	69.5	28.8	10.8

Notes:
(1) Weathered Upper Till
(2) Unweathered Upper Till
* Sample remoulded
\# Not including remoulded sample

* Reported 9/03/88

For a conservative hydraulic conductivity of 1×10^{-6} cm/sec, an effective transport porosity of 0.02 and a hydraulic gradient of 0.005, an average linear groundwater velocity of 0.079 m/yr is calculated.

C.2.2.2 Unweathered Upper Till

In order to provide additional data for the hydraulic conductivity of this till, laboratory permeability determinations were completed on four samples of unweathered Upper Till. These samples were obtained by CRA from the existing borehole core samples retained by Trow and forwarded to Golder Associates for testing. The test procedures and results as provided by Golder Associates are presented in Appendix II.

As shown on Table C.2.1 (p. 86), for three samples of undisturbed unweathered till, the geometric mean vertical hydraulic conductivity is 1.38×10^{-8} cm/sec. In addition, one sample was remoulded and yielded a hydraulic conductivity of 6.83×10^{-9} cm/sec. These values are significantly lower than those determined from the slug tests conducted by Trow.

Sample CRA-3 was obtained from within the screen elevation of piezometers 4 and 5 at well nest HC2-86.

The hydraulic conductivity at HC2-86-4 as determined by slug testing is 1.7×10^{-7} cm/sec (Appendix 12, Exhibit H-39A). This value is to be compared to the much lower value of 1.45×10^{-8} cm/sec as determined for CRA-3 from the laboratory testing.

It is to be noted from the grain size distribution of each sample tested, (Table C.2.1, p. 86) that the percentage of clay lies within the range of 19.5 to 26.0 percent which is consistent with the grain size data provided by Trow and summarized on Table B.2.1 (p. 24).

These hydraulic conductivity tests provide a more meaningful representation of the vertical hydraulic conductivity than that provided by the single well response test data. A mean vertical hydraulic conductivity of 1.4×10^{-8} cm/sec is considered by CRA as representative of the unweathered Upper Till.

For an unremediated failure of the engineered landfill a downward velocity of 0.015 m/yr across this Unit is calculated.

C.2.2.3 Upper Granular Unit

The apparent incomplete recovery of the observation wells following test pumping indicates that this Unit does not comprise a continuous permeable strata beneath much of the western portion of the site as interpreted by Trow. CRA concludes from the incomplete recovery that the portion of the UGU which was pumped comprises a lens and not a continuous blanket. This interpretation is consistent with the geologic interpretation provided in Figure C.2.2 (p. 81) and demonstrates that it is conservative to consider, as Trow does, that this Unit provides a continuous permeable blanket beneath and west of the site.

C.2.3 GROUNDWATER FLOW SYSTEM

The pattern of groundwater flow at the site is controlled to a large extent by the unweathered Upper Till. This unit comprises a thick, uniform, low permeable layer which mantles the site. Within this Unit, hydraulic gradients are directed downwards.

Within the strata beneath the Upper Till the downward gradients are less steep. Locally gradients are subhorizontal with some upward gradients encountered within this sequence.

CRA considers that the direction of groundwater flow in the strata beneath the Upper Till at this site will be strongly influenced by the pattern of flow in the bedrock. As demonstrated by Trow (Drawing 16, Exhibit H-39) flow at the bedrock contact is towards the south and southeast.

CRA has interpreted the UGU as consisting of two lenses beneath the site. The rate of lateral groundwater flow within this unit will be controlled for the most part by the permeability of the strata enveloping these lenses.

The enveloping strata generally consist of the Lower Till. Locally however, thin low permeable granular strata may represent the lateral continuation of the UGU. As discussed in Part B of this report (Section B.3.2.4, p. 40) the 0.3 m of 'silt' interbedded with clay, minor pebbles' encountered at HC6-85 for example, may represent the geological equivalent of the UGU. However, CRA considers such materials to have similar hydraulic conductivity to that of the Lower Till. Because of the lensoid distribution of the UGU, groundwater flow in this unit will parallel that of the enveloping Lower Till. CRA conclude that the horizontal component of groundwater flow in both granular units is to the south and southeast at a low gradient, paralleling the direction shown by Trow (Drawing 16, Exhibit H-39) for the bedrock/overburden contact.

C.2.4 EVALUATION OF CONTAMINANT MIGRATION

The evaluation undertaken by Trow (p. 91, Exhibit H-39) was for the situation in which the hydraulic trap has failed and no remedial measures are implemented to restore the trap. For the condition where the hydraulic trap is operating as designed, there will be some contaminant loss from the landfill via the mechanism of diffusion. As shown by Trow (Exhibit H-86A, Figure 1, p. 7), the diffusion halo will migrate a distance of as much as 3 m into the unweathered Upper Till. For volatile organic compounds (VOCs) and other attenuated compounds, the diffusion front will advance a shorter distance.

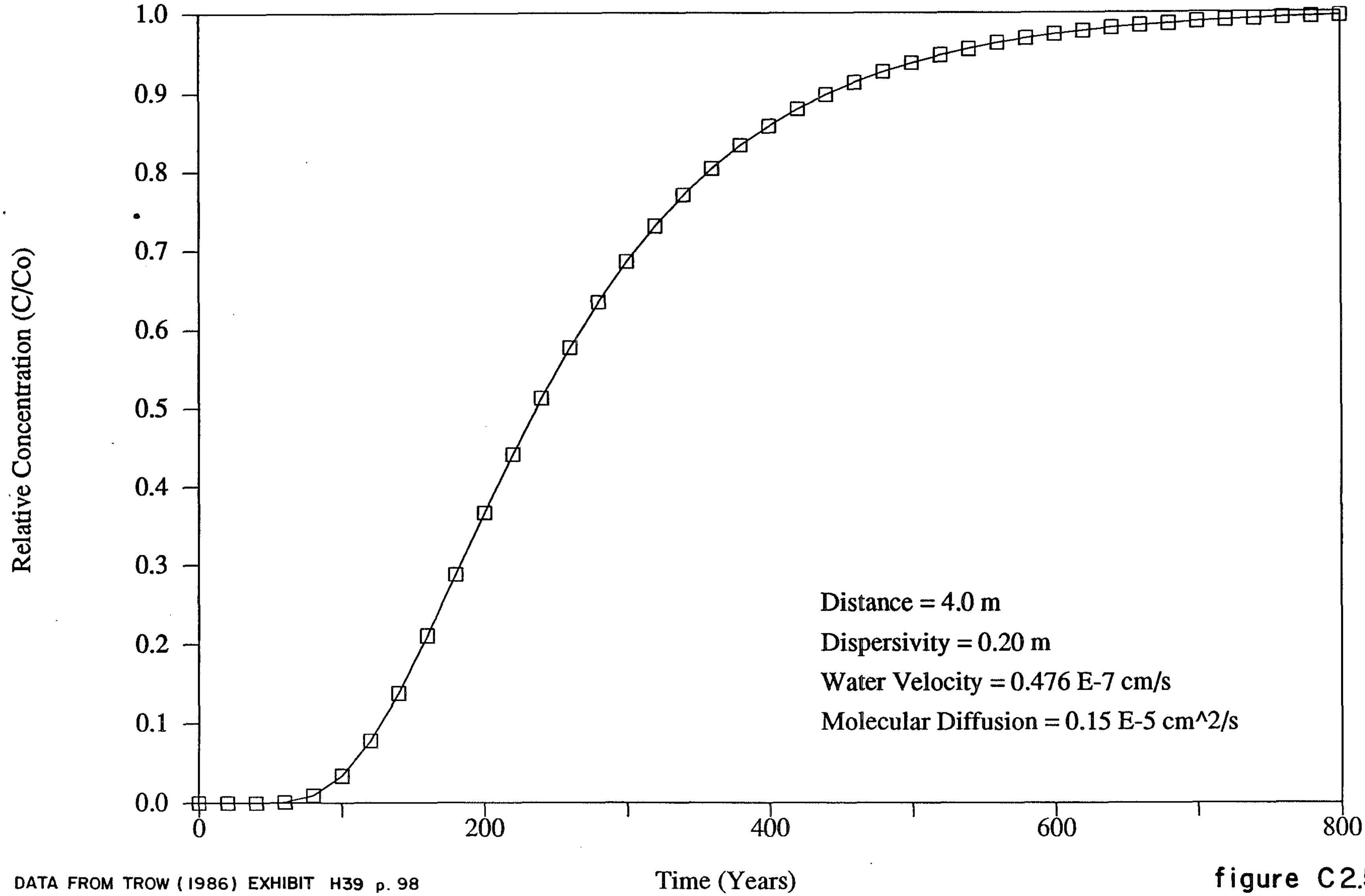
In the case of long term failure of the hydraulic trap, contaminants may migrate from the landfill downward through the unweathered Upper Till, downward through the Lower Till and thence laterally in either of the granular units and/or the bedrock. Also for long term failure of the trap, contaminants may migrate laterally from the landfill through the weathered upper till. The following discussion addresses downward migration through the unweathered Upper Till.

C.2.4.1 Downward Migration Through Unweathered Upper Till

The rate of any contaminant migration to depth at this site will be strongly controlled by the hydraulic properties of the unweathered Upper Till.

As discussed herein, a geometric mean of 1.4×10^{-8} cm/sec was determined from laboratory constant head tests for the vertical hydraulic conductivity of the unweathered Upper Till. For the given gradient and effective porosity values used by Trow, an average linear groundwater velocity of 0.015 m/yr is calculated. This is to be compared to the value of 0.09 m/yr calculated by Trow (Table 10, p. 88, Exhibit H-39).

In order to determine the first arrival times of conservative contaminants migrating downwards through 4 m of unweathered Upper Till, the Ogata-Banks 1-dimensional contaminant transport model was applied by CRA. The input parameters for this model are the same as those used by Trow (Figure 9, p. 98, Exhibit H-39) except that the groundwater velocity of 4.7×10^{-8} cm/sec, which incorporates a vertical hydraulic conductivity of 1.4×10^{-8} cm/sec, was used. The results of this simulation are shown on Figure C.2.5 (p. 93).



DATA FROM TROW (1986) EXHIBIT H39 p. 98
EXCEPT Kv = 1.4 x 10^{-8} cm/sec.

figure C2.5

BREAKTHROUGH CURVE
- UNWEATHERED UPPER TILL
- TROW DESIGN

Site 'D' Hydrogeology – City of Burlington

CRA

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As shown, the initial break through time for conservative contaminants is in the order of 80 years with a relative concentration (C/CO) of 0.1 being reached in approximately 125 years. This demonstrates the significant degree of protection for the underlying strata provided by the unweathered Upper Till.

In addition, approximately 3 m of the Lower Till separates the base of the Upper Till from the uppermost pathway potentially providing for lateral off-site groundwater flow - the Upper Granular Unit. The breakthrough time determined by Trow for migration across the Lower Till is approximately 25 years (p. 99, Exhibit H-39). This indicates that in the event of a failure of the proposed landfill, approximately 150 years are required for contaminants at one-tenth the concentration as that found in the leachate to migrate from the base of the landfill to the top of the uppermost granular unit.

It must be recognized that contaminants will reach the Upper Granular Unit where this unit is present, in the event that the landfill fails and no remedial measures are implemented for this period. Restoration of the hydraulic trap would reverse the direction of groundwater flow and any contaminants that had migrated into the underlying tills would in time migrate back towards the landfill.

C.3.0 CONCEPTUAL LANDFILL DESIGN

The principle features of the hydrogeology to be considered in designing a landfill at this site are as follows:

1) A weathered Upper Till on the order of 4 m thick through which lateral groundwater flow from the landfill may occur.

2) A thick uniform unweathered Upper Till with a mean vertical hydraulic conductivity of 1.4×10^{-8} cm/sec overlies the entire site between a depth of approximately 4 to 8 metres below ground and comprises a suitable base upon which to landfill.

3) The mean vertical hydraulic gradients of 0.2 are directed downwards across this till.

4) The base elevation of the Upper Till varies from 174 to 176 masl across the site.

5) Downward hydraulic gradients in the underlying Lower Till are less steep and there is potential for off-site lateral flow in the granular units as well as the underlying shale bedrock.

6) Nearby domestic wells exploit the overburden and the bedrock as a water supply source.

As discussed in Section B.5.0 (p. 58), CRA considers that a hydraulic trap landfill design can be implemented at this site. The principal elements of this design are as follows:

1) Maintain a maximum leachate level of 0.4 m below April 1986 piezometric elevations for the underlying granular units and bedrock to provide for the hydraulic trap.

2) Maintain a maximum thickness of the unweathered Upper Till underlying the base of the landfill.

CRA undertook a complete evaluation of the landfill design proposed by Trow. An alternative design which provides for the hydraulic trap and a maximum thickness of unweathered Upper Till is proposed by CRA in a separate report entitled "Evaluation of Halton Region Landfill Technical Studies Site D - Milton, Design and Operations Report".

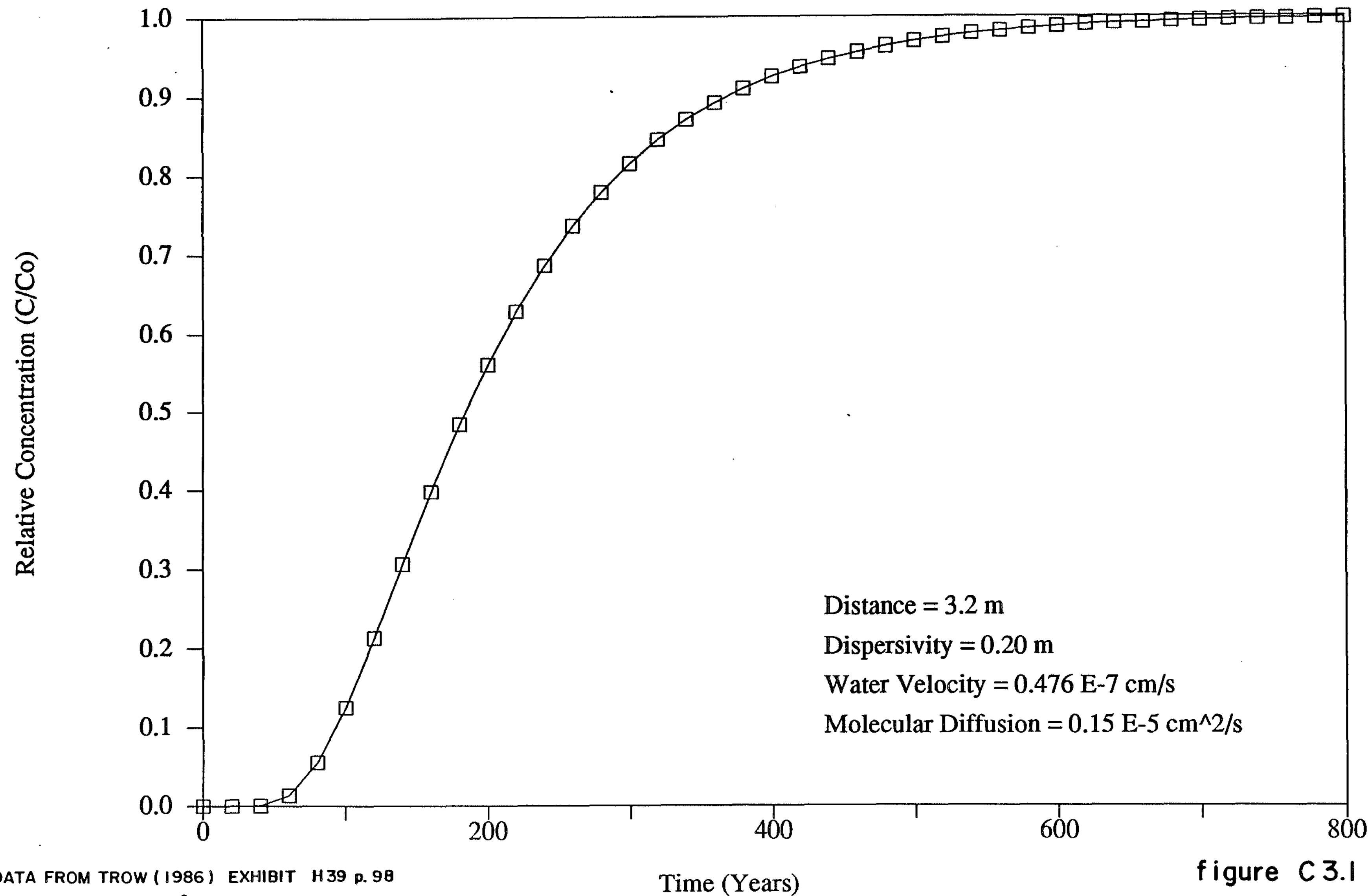
This alternative design incorporates a minimum unweathered Upper Till thicknesses of 3.2 m. The till thickness ranges up to 6.6 m and averages 4.5 m. The

Ogata-Banks solution was again applied by CRA to estimate breakthrough times for contaminant transport through this till layer. The same dispersivity and molecular diffusion values as previously used by Trow were used while the groundwater velocity term incorporated the 1.4×10^{-8} cm/sec vertical hydraulic conductivity for the unweathered Upper Till. The resulting breakthrough curve is shown on Figure C.3.1 (p. 98). Again, this evaluation assumes that the hydraulic trap has failed and that no remedial measures are implemented.

Initial breakthrough occurs within 60 years while a relative concentration (C/Co) of 0.1 is reached in approximately 95 years.

By including the travel time for migration across the Lower Till as determined by Trow (25 years) (p. 99, Exhibit H-39) a total travel time of approximately 120 years is required for contaminants migrating downwards from the landfill at a concentration of one-tenth of that encountered within the landfill to reach the Upper Granular Unit.

As stated before, it must be recognized that contaminants can migrate to the base of the Upper Till only if the hydraulic trap fails and no restorative measures are implemented for a number of years.



DATA FROM TROW (1986) EXHIBIT H39 p. 98
EXCEPT Kv = 1.4 x 10^{-8} cm / sec.

figure C3.1

REVISED BREAKTHROUGH CURVE
- UNWEATHERED UPPER TILL
- CRA DESIGN

Site 'D' Hydrogeology – City of Burlington

CRA

1354-10-27/11/87-29-D-1

CRA concludes that in the event of failure of the hydraulic trap, sufficient lead time is provided by the extremely slow rate of groundwater flow within the underlying unweathered Upper Till, such that remedial measures, aimed at restoring the hydraulic trap, can be implemented.

C.4.0 MONITORING

As discussed in Part B of this report, the number of groundwater quality monitoring wells (Section B.7.0, p. 70) as recommended by Trow is considered excessive. In addition insufficient attention was paid to the monitoring of the leachate mound within the landfill. Given that the hydraulic trap is the primary means of protecting the groundwater environment at this site, the monitoring program should be directed to ensure that this trap is maintained.

The following discussion initially addresses hydraulic monitoring and then the monitoring of groundwater quality.

C.4.1 HYDRAULIC MONITORING

CRA recommended that this portion of the monitoring program be designed to demonstrate that the elevation of the leachate mound within the landfill does not exceed the elevation of the piezometric surface of the underlying granular units or bedrock.

It is recommended therefore that in each landfill cell four piezometers be installed at the base of the excavation midway between a pair of collection pipes. These installations should ideally consist of flexible tubing laid across the floor of the excavation and up the side slope. This would ensure that they would not be damaged during landfilling. In the event that one of the piezometers becomes inoperable it could be replaced by drilling through the landfilled refuse and installing a piezometer at the floor of the landfill. Every effort should then be made to ensure that this installation is not destroyed during continued landfilling.

It is to be emphasized that these installations are for the monitoring of leachate levels only and not for the collection of leachate samples.

Adjacent to each cell, at least one monitoring nest, complete with piezometers set at the top of the bedrock, and at the elevation of the Upper and Lower Granular Units, should be monitored to determine the lowest piezometric elevation in these strata. Existing installations can be used where practical.

Evaluation of this monitoring data should be conducted on an ongoing basis to ensure that the hydraulic trap is performing as designed.

C.4.2 WATER QUALITY MONITORING

C.4.2.1 Leachate Characterization

Samples for leachate characterization should be collected from the leachate collection system. This characterization is required to identify target parameters for the groundwater monitoring program.

Initial characterization from each cell should include a complete suite of organic compounds including PCBs, pesticides and VOCs along with general chemistry parameters and metals.

Annual characterizations thereafter should be focussed on a limited suite of constituents including the more mobile and the more toxic species. Included within this list would be those parameters targeted for the groundwater monitoring program.

C.4.2.2 Groundwater Quality Monitoring

It is recognized that for the hydraulic trap in operation, the need for comprehensive groundwater quality monitoring is reduced. However a more ~~intensive monitoring~~ program must be implemented in the event that a failure occurs in the hydraulic trap. Following successful implementation of remedial measures to restore the hydraulic trap the frequency of groundwater quality monitoring could then be reduced.

The suggested location of the groundwater quality monitoring wells is as follows:

1) 3 nests along First Line Road. * SW prop boundary

2) 1 nest on each of the north-west and south-east property boundaries.

3) 2 nests along the north-east perimeter of the landfilled area.

For the alternative landfill design proposed by CRA, a second well nest at the south-east property boundary is recommended.

Where appropriate, existing monitors could be used. In addition, selected wells in the above network could be used for the regular water level (hydraulic) monitoring as discussed in the previous section (Section C.4.2.1, p. 102).

Each well nest should consist of four piezometers set in the bedrock, the granular units and the weathered till, respectively. If granular strata are not encountered screens should be set at the appropriate elevations. Existing installations should be used where practical.

In addition to the above on-site wells, the four domestic wells along First Line Road should be monitored on a continuing basis along with any of the on-site domestic wells that will not be destroyed by landfilling.

It is recommended that background water quality at all these monitoring wells should be determined prior to landfilling. These data then provide the background against which future groundwater quality changes, if any, can be assessed.

From a review of the leachate characterization and the additional background data recommended above, a suite of indicator parameters can be developed for the ongoing monitoring program.

C.5.0 CONTINGENCIES

The hydraulic trap provides the primary protection for groundwater quality at this site. The monitoring program is designed to collect sufficient water level data to ensure that the effectiveness of the hydraulic trap can be evaluated. The first level of contingency options at this site should therefore be focussed on remedying any excessive leachate mounding within the landfill that may occur. Additional contingency options were evaluated by Trow for the situation in which an uncontrolled leachate build up occurs and contaminants migrate from the landfill cells.

As shown by the evaluation of contaminant migration, for a failed hydraulic trap, it will take a period of in excess of 100 years in order for contaminants migrating downward across the unweathered Upper Till and the Lower Till to reach the Upper Granular Unit (where present). During this time contingency measures could be implemented to restore the hydraulic trap. If however, the contingency measures are not effective, contaminated groundwater may egress from the landfill by:

1) Lateral migration in weathered Upper Till.
2) Downward migration to the granular units and/or bedrock and thence lateral flow off site.

The following discussion addressed initially the contingency measures to be implemented to control excessive leachate mounding. Subsequently, contingency measures for each of the above two contaminant migration pathways are discussed.

C.5.1 LEACHATE PURGE WELLS

Purge wells drilled directly into the landfilled materials can be used to control leachate levels within the landfill. The number and spacing of such leachate purge wells is dependent on the hydraulics of the landfilled materials, the area over which control is required as well as the amount of head reduction required. Leachate would be pumped directly into the nearest operating leachate collection system.

This option could be implemented readily and could be expected to provide the required control. Monitoring would be required to verify the effectiveness of purge well operation.

C.5.2 CONTAMINANT MIGRATION CONTROL IN WEATHERED UPPER TILL

Trow has proposed a perimeter drain designed to intercept any potentially contaminated groundwater migrating in this zone. CRA expects that such a system will capture 100 percent of the groundwater in this zone.

Trow concluded that within 5 years of a failure of the hydraulic trap contaminant migrating in this zone could reach the site boundary. Based on this scenario it could be concluded that such perimeter drains should be installed at the same time the landfill cells are excavated.

CRA does not consider this appropriate for the following reasons:

1. The development of extensive contaminant plumes within weathered clay horizons is inconsistent with the experience gained at other similarly sited Ontario landfills.

2. An apparent transport porosity of 0.02, as discussed by Mr. Feenstra (Vol. 43, p. 9566) results in a contaminant travel velocity of 0.63 m/yr. This is to be compared to a groundwater velocity of 13 m/yr determined by Trow (p. 88, Exhibit H-39). If a more realistic hydraulic conductivity of 1 x 10^{-6} cm/sec is used the calculated groundwater velocity reduces to 0.063 m/yr.

CRA concludes that the weathered Upper Till can be monitored effectively. Groundwater transport times in this Unit are such that sufficient lead time exists in order to implement any necessary contingency measures. The perimeter drainage contingency measure, proposed by Trow, is expected to control 100 percent of the groundwater in this zone.

C.5.3 GRANULAR UNIT PURGE WELLS

As demonstrated by the pumping tests conducted by Trow on both the Upper and Lower Granular Units, lateral migration of potentially contaminated groundwater in these units can be controlled by purging.

The required pumping rate will approximately equal the infiltration to these units. Trow calculated this rate as 12.6 L/min (2.8 gpm). Using a hydraulic conductivity of 1.4 x 10^{-8} cm/sec and a hydraulic gradient of 0.85 (consistent with that employed by Trow in the contaminant migration computer simulations) an infiltration rate of 2.14 L/min (0.5 gpm) is calculated.

CRA considers that effective purging can be implemented in the discontinuous Upper Granular Unit.

Because of the potential to dewater this unit, the pumping rate is expected to be lower than that suggested above.

As discussed in Part B of this report, CRA concluded that operation of a purge well system at the higher rate determined by Trow would have no discernible impact on water levels beyond the site.

Purge wells can be constructed in either the Upper Granular Unit and/or the Lower Granular Unit if required.

C.6.0 **SUITABILITY FOR LANDFILLING**

C.6.1 INTRODUCTION

As described in Part A of this report, for a site to be considered suitable for landfilling, it must meet three criteria. These are:

1) Migration of contaminants from the landfill must be predictable and the impact from this migration must be determined to be acceptable.

2) The site must be able to be adequately monitored in order to verify the predictions on the behaviour of the contaminant migration.

3) Feasible contingency plans must be developed such that if unacceptable contaminant migration results, as determined from the monitoring, this migration can be mitigated.

C.6.2 PREDICTABILITY

In order to ensure that unacceptable groundwater quality impacts will not occur in the event of an uncontrolled landfill failure at this site, contaminant transport times are evaluated for each of the potential contaminant pathways defined. This evaluation requires that those parameters which govern the rate of groundwater flow along the defined contaminant pathway(s) be defined.

Groundwater flow at this site is most strongly controlled by the unweathered Upper Till. This Unit limits the rate of exfiltration from the landfill and provides for slow groundwater movement downwards to the underlying strata. Sufficient data are available to accurately predict the rate and direction of groundwater flow in this Unit.

The granular units comprise the pathway through which lateral off-site groundwater movement may occur. The hydraulic gradient and direction of flow in these units are imprecisely defined.

However, a reasonable value for the hydraulic gradient is provided by Trow for the failed landfill and the direction of groundwater flow is assumed to be towards the domestic wells along First Line Road. This provides a reasonable and conservative prediction of contaminant arrival times at the site boundary.

Should groundwater contamination reach levels that potentially are unacceptable, then contingency options, as discussed in Section C.4.6 would be implemented.

CRA believes that ~~a good hydrogeologic~~ understanding has been established at this site, and further that this site does meet the criteria of predictability.

C.6.3 MONITORING

In order to demonstrate that the landfill is performing as predicted, a monitoring program must be implemented.

The success of a monitoring program requires that:

1) The potential contaminant pathways be delineated.

2) Background water quality be defined against which quality changes can be assessed.

3) A suitable landfill derived indicator parameter must be identified with which to establish the extent of groundwater contamination.

The contaminant pathways have been reliably delineated. In addition, contaminant transport along these flow paths has been modelled in order to develop estimates of arrival times.

There is a concern that background water quality within the granular units at this site has not been adequately defined. This inadequacy can be addressed by the installation and sampling of the proposed monitoring wells prior to or during the initial development of the landfill site. This provides for the development of a data base prior to the disposal of refuse at the site.

It is recognized that chloride alone may not be the most appropriate indicator of landfill derived contamination at this site. It is expected, however, that a suite of leachate indicator parameters can readily be developed following initial characterization of the leachate.

The monitoring program as recommended by CRA is designed to address the following:

1) Water level monitoring to determine the piezometric elevations in the strata underlying the site.

2) Leachate level monitoring which, in conjunction with the above, will allow assessment of the performance of the hydraulic trap.

3) Groundwater quality in the granular units and bedrock at various points along the site perimeter.

4) Groundwater quality in the weathered Upper Till at each of the above perimeter nested monitoring wells.

5) Groundwater quality of the adjacent domestic water supply wells.

CRA concludes that this site can be monitored adequately.

C.6.4 CONTINGENCIES

The engineered contingencies, considered by Trow consist of the following:

1) perimeter drains to capture migrating contaminants in the unweathered Upper Till.

2) a purge well system to capture migrating contaminants in the Upper Granular Unit and/or the Lower Granular Unit.

These contingency plans can provide for effective control of contaminant migration in the defined contaminant pathways in the event of an unremediated build-up of leachate in the landfill and unacceptable contaminant migration.

In addition, CRA recommends that

1) Leachate purge wells be considered as the primary contingency measure at this site. This measure would be designed to control the leachate elevation within the landfill to ensure the continued operation of the hydraulic trap.

2) The supply of piped water to local residents if detrimental off-site contaminant migration occurs.

CRA concludes that the Site meets the criteria of implementation of an effective contingency plan.

C.6.5 CONCLUSIONS

CRA concludes that Site D is hydrogeologically suitable for landfilling. The potential for contaminant migration can be predicted, and the site can be monitored effectively. In addition, effective contingency measures can be implemented if contamination is detected by monitoring in the weathered Upper Till and/or the granular units.

All of which is respectfully submitted,

CONESTOGA-ROVERS & ASSOCIATES

John M. Petrie, M. Sc.

REGISTERED PROFESSIONAL ENGINEER
A. J. CRUTCHER
PROVINCE OF ONTARIO

Anthony J. Crutcher, P. Eng.

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APPENDIX I

VERTICAL HYDRAULIC GRADIENTS

VERTICAL HYDRAULIC GRADIENTS

Well Number	Hydrostratigraphic Unit	Top of Screen	Bottom Of Screen	Mid Point	Water Levels 07-Jun-84	12-Jun-84	15-Jun-84	26-Jun-84	01-Mar-85	12-Mar-85	01-Apr-85	16-Apr-85	06-May-85	15-Jun-85	15-Jul-85	20-Aug-85	29-Aug-85	05-Sep-85
HC1-84-d	Bedrock/Lower Till	172.50	171.00	171.75														
HC1-84-s	Upper Till (w?)	184.00	182.50	183.25	185.80		185.83	185.98		186.28	186.43	186.20	185.96	185.69	185.60	185.60	185.59	185.77
		Vertical Gradient:(d-s)																
HC3-84-d	Lower Till	170.40	168.90	169.65	182.50		182.49	182.47	181.85	182.02	182.18	182.30	182.34	182.42	182.50	182.31	182.83	182.81
HC3-84-s	Upper Till	181.80	180.30	181.05	181.49		182.15	183.26	183.23	183.25	183.41	183.26	183.10	183.22	182.49	182.92	182.93	183.06
		Vertical Gradient:(d-s)			0.09		0.03	-0.07	-0.12	-0.11	-0.11	-0.08	-0.07	-0.07	0.00	-0.05	-0.01	-0.02
HC4-84-d	Lower Till	166.90	165.40	166.15		179.48	179.44	179.34	179.24	179.38	179.54	179.57	179.67	179.23	179.39	178.84	179.05	179.05
HC4-84-s	Upper Till (w)?	178.60	177.10	177.85		179.85	179.77	179.87	180.17	180.40	180.55	180.20	180.05	179.67	179.59	178.82	179.09	179.32
		Vertical Gradient:(d-s)				-0.03	-0.03	-0.05	-0.08	-0.09	-0.09	-0.05	-0.03	-0.04	-0.02	0.00	-0.00	-0.02
HC7-84-1	Lower Till(Bedrock?)	171.50	170.00	170.75		178.46	178.31	178.37	178.30	178.50	178.62	178.61	178.37	178.12	178.24	177.78	178.03	178.07
HC7-84-2	Upper Till	177.40	175.90	176.65		180.86	180.58	180.62	181.31	181.42	181.19	181.32	180.38	180.52	180.41	179.97	180.23	180.81
HC7-84-3	Upper Till (w)?	179.70	178.20	178.95		181.22	181.11	181.02	182.03	182.12	182.09	181.71	181.25	180.74	180.54	180.20	180.69	181.17
		Vertical Gradient:(1-2)				-0.41	-0.38	-0.38	-0.51	-0.49	-0.44	-0.46	-0.34	-0.41	-0.37	-0.37	-0.37	-0.46
		(1-3)				-0.34	-0.34	-0.32	-0.45	-0.44	-0.42	-0.38	-0.35	-0.32	-0.28	-0.30	-0.32	-0.38
		(2-3)				-0.16	-0.23	-0.17	-0.31	-0.30	-0.39	-0.17	-0.38	-0.10	-0.06	-0.10	-0.20	-0.16
HC8-84-d	Lower Till	169.20	167.70	168.45		180.78	180.98	181.08			181.35	181.61	181.65	181.20	181.04	180.86	181.13	181.11
HC8-84-s	Upper Till	180.70	179.20	179.95		179.94	180.23	181.84			182.91	182.54	182.35	181.92	181.84	181.59	181.95	182.11
		Vertical Gradient:(1-2)				0.07	0.07	-0.07			-0.14	-0.08	-0.06	-0.06	-0.07	-0.06	-0.07	-0.09

Well Number	Hydrostratigraphic Unit	Top of Screen	Bottom Of Screen	Mid Point	Water Levels													
					24-Sep-85	25-Sep-85	26-Sep-85	27-Sep-85	01-Oct-85	07-Oct-85	17-Oct-85	18-Oct-85	31-Oct-85	18-Nov-85	20-Nov-85	04-Dec-85	22-Dec-85	03-Jan-86
HC1-84-d	Bedrock/Lower Till	172.50	171.00	171.75														
HC1-84-s	Upper Till (w?)	184.00	182.50	183.25	185.69					185.57		185.63	185.93	186.42		186.42	186.05	185.86
		Vertical Gradient: (d-s)																
HC3-84-d	Lower Till	170.40	168.90	169.65	182.74					182.86		182.90	183.10	182.42		182.51	182.52	182.49
HC3-84-s	Upper Till	181.80	180.30	181.05	182.99					183.14		183.22	183.21	183.54		183.62	183.56	183.51
		Vertical Gradient: (d-s)			-0.02					-0.02		-0.03	-0.01	-0.10		-0.10	-0.09	-0.09
HC4-84-d	Lower Till	166.90	165.40	166.15	178.99					179.30		179.27	179.24	179.45		179.55	179.53	179.07
HC4-84-s	Upper Till (w)?	178.60	177.10	177.85	179.25					179.53		179.59	179.88	180.25		179.91	180.15	180.06
		Vertical Gradient: (d-s)			-0.02					-0.02		-0.03	-0.05	-0.07		-0.03	-0.05	-0.08
HC7-84-1	Lower Till (Bedrock?)	171.50	170.00	170.75	178.46					178.51		178.55	178.39	178.76		178.85	178.80	178.42
HC7-84-2	Upper Till	177.40	175.90	176.65	180.80					180.91		181.00	181.19	181.54		181.47	181.23	180.96
HC7-84-3	Upper Till (w)?	179.70	178.20	178.95	181.01					181.33		181.62	181.75	181.97		181.78	181.63	181.41
		Vertical Gradient: (1-2)			-0.40					-0.41		-0.42	-0.47	-0.47		-0.44	-0.41	-0.43
		(1-3)			-0.31					-0.34		-0.37	-0.41	-0.39		-0.36	-0.35	-0.36
		(2-3)			-0.09					-0.18		-0.27	-0.24	-0.19		-0.13	-0.17	-0.20
HC8-84-d	Lower Till	169.20	167.70	168.45	181.17					181.21		181.23	181.32	181.16		181.43	181.30	181.30
HC8-84-s	Upper Till	180.70	179.20	179.95	182.05					182.03		182.25	182.24	182.81		182.88	182.81	182.74
		Vertical Gradient: (1-2)			-0.08					-0.07		-0.09	-0.08	-0.14		-0.13	-0.13	-0.13

Well Number	Hydrostratigraphic Unit	Top of Screen	Bottom Of Screen	Mid Point	Water Levels 18-Jan-86	06-Feb-86	19-Feb-86	09-Mar-86	24-Mar-86	15-Apr-86	09-Jun-87	07-Aug-87	15-Aug-87	21-Aug-87	28-Aug-87
HC1-84-d	Bedrock/Lower Till	172.50	171.00	171.75	184.57	184.57	184.57	184.57	184.54	184.74					
HC1-84-s	Upper Till (w?)	184.00	182.50	183.25	185.97	185.81	185.97	186.01	186.32	186.05					
		Vertical Gradient: (d-s)			-0.12	-0.11	-0.12	-0.13	-0.15	-0.11					
HC3-84-d	Lower Till	170.40	168.90	169.65	182.44	182.39	182.30	182.17	182.26	182.20					
HC3-84-s	Upper Till	181.80	180.30	181.05	183.34	183.34	183.40	183.49	183.67	183.88					
		Vertical Gradient: (d-s)			-0.08	-0.08	-0.10	-0.12	-0.12	-0.15					
HC4-84-d	Lower Till	166.90	165.40	166.15	179.24	179.23	179.13	178.97	179.24	179.23					
HC4-84-s	Upper Till (w)?	178.60	177.10	177.85	179.83	179.87	179.87	179.88	180.37	180.18					
		Vertical Gradient: (d-s)			-0.05	-0.05	-0.06	-0.08	-0.10	-0.08					
HC7-84-1	Lower Till (Bedrock?)	171.50	170.00	170.75	178.44	178.34	178.37	178.41	178.42	178.92					
HC7-84-2	Upper Till	177.40	175.90	176.65	180.95	180.93	180.89	180.83	181.23	181.01					
HC7-84-3	Upper Till (w)?	179.70	178.20	178.95	181.48	181.40	181.40	181.42	181.68	181.52					
		Vertical Gradient: (1-2)			-0.43	-0.44	-0.43	-0.41	-0.48						
		(1-3)			-0.37	-0.37	-0.37	-0.37	-0.40						
		(2-3)			-0.23	-0.20	-0.22	-0.26	-0.20						
HC8-84-d	Lower Till	169.20	167.70	168.45	181.18	181.07	181.08	181.11	181.10	180.99					
HC8-84-s	Upper Till	180.70	179.20	179.95	182.50	182.78	182.78	182.78	183.01	183.01					
		Vertical Gradient: (1-2)			-0.11	-0.15	-0.15	-0.15	-0.17	-0.18					

Well Number	Hydrostratigraphic Unit	Top of Screen	Bottom Of Screen	Mid Point	Water Levels													
					24-Sep-85	25-Sep-85	26-Sep-85	27-Sep-85	01-Oct-85	07-Oct-85	17-Oct-85	18-Oct-85	31-Oct-85	18-Nov-85	20-Nov-85	04-Dec-85	22-Dec-85	03-Jan-86
HC1-85-1	Lower Till	156.10	154.60	155.35	180.89	181.06	181.25	181.35		181.84		181.94	181.90		181.27	181.66	182.74	182.52
HC1-85-2	Lower Till	170.50	169.00	169.75	182.09	182.11	182.12	182.12		182.28		181.97	181.41		180.78	181.56	183.68	183.38
HC1-85-3	Upper Till	176.00	175.10	175.55	182.49	182.45	182.52	182.59		182.65		182.60	182.87		182.30	183.28	183.45	183.24
HC1-85-4	Upper Till (w?)	183.60	179.60	w.t.	182.49	182.48	182.53	182.59		182.65		182.60	182.87		182.61	183.30	183.43	183.21
		Vertical Gradient:		(1-2)	-0.08	-0.07	-0.06	-0.05		-0.03		-0.00	0.03		0.03	0.01	-0.07	-0.06
				(1-3)	-0.08	-0.07	-0.06	-0.06		-0.04		-0.03	-0.05		-0.05	-0.08	-0.04	-0.04
				(1-4)	-0.06	-0.05	-0.05	-0.05		-0.03		-0.02	-0.04		-0.05	-0.06	-0.02	-0.02
				(2-3)	-0.07	-0.06	-0.07	-0.08		-0.06		-0.11	-0.25		-0.26	-0.30	0.04	0.02
				(2-4)	-0.03	-0.03	-0.03	-0.04		-0.03		-0.05	-0.11		-0.14	-0.13	0.02	0.01
				(3-4)	0.00	-0.00	-0.00	0.00		0.00		0.00	0.00		-0.04	-0.00	0.00	0.00
HC2-85-1	Lower Till	157.60	156.10	156.85							181.76		181.72		181.45	181.91	181.95	181.95
HC2-85-2	Upper Granular	173.00	170.00	171.50							181.75		181.86		181.22	182.03	182.09	182.05
HC2-85-3	Upper Till (w?)	181.30	176.70	w.t.							182.55		182.63		181.40	182.09	182.15	182.09
		Vertical Gradient:		(1-2)							0.00		-0.01		0.02	-0.01	-0.01	-0.01
				(1-3)							-0.03		-0.04		0.00	-0.01	-0.01	-0.01
				(2-3)							-0.07		-0.07		-0.02	-0.01	-0.01	-0.00
HC3-85-1	Bedrock	169.00	167.50	168.25	180.11	180.16	180.22	180.25	180.11		180.25		180.97		180.54	181.17	180.89	182.74
HC3-85-2	Lower Till	172.90	171.40	172.15	180.36	180.40	180.46	180.52	180.38		180.42		181.11		180.62	181.33	181.16	180.75
HC3-85-3	Upper Till (w?)	181.60	178.60	w.t.	182.70	182.79	182.82	182.86	182.63		182.89		183.07		182.60	183.09	182.99	180.61
		Vertical Gradient:		(1-2)	-0.06	-0.06	-0.06	-0.07	-0.07		-0.04		-0.04		-0.02	-0.04	-0.07	0.51
				(1-3)	-0.18	-0.18	-0.18	-0.18	-0.18		-0.18		-0.14		-0.14	-0.13	-0.14	0.17
				(2-3)	-0.22	-0.22	-0.22	-0.22	-0.21		-0.23		-0.18		-0.19	-0.16	-0.17	0.02
HC4-85-1	Lower Till	159.80	158.90	159.35						181.54	181.63		181.22		180.97	181.51	181.50	181.52
HC4-85-2	Lower Granular	170.10	167.40	168.75						181.02	181.21		181.00		180.62	181.46	181.46	181.34
HC4-85-3	Upper Till (w?)	184.20	179.60	w.t.						184.15	184.26		184.05		183.42	184.56	184.59	184.45
		Vertical Gradient:		(1-2)						0.06	0.04		0.02		0.04	0.01	0.00	0.02
				(1-3)						-0.11	-0.11		-0.11		-0.10	-0.12	-0.12	-0.12
				(2-3)						-0.20	-0.20		-0.20		-0.19	-0.20	-0.20	-0.20
HC5-85-1	Lower Till	162.80	161.90	162.35							181.04		181.07		180.49	181.36	181.42	181.35
HC5-85-2	Upper/Lower Till	174.40	172.90	173.65							181.69		181.72		181.13	181.96	182.09	181.93
HC5-85-3	Upper Till (w?)	183.70	179.10	w.t.							184.95		185.17		184.57	185.05	184.82	184.54
		Vertical Gradient:		(1-2)							-0.06		-0.06		-0.06	-0.05	-0.06	-0.05
				(1-3)							-0.17		-0.18		-0.18	-0.16	-0.15	-0.14
				(2-3)							-0.29		-0.30		-0.32	-0.27	-0.24	-0.24

VERTICAL HYDRAULIC GRADIENTS

Well Number	Hydrostratigraphic Unit	Top of Screen	Bottom Of Screen	Mid Point	Water Levels 18-Jan-86	06-Feb-86	19-Feb-86	09-Mar-86	24-Mar-86	15-Apr-86	09-Jun-87	07-Aug-87	15-Aug-87	21-Aug-87	28-Aug-87
HC1-85-1	Lower Till	156.10	154.60	155.35	181.69	181.64	181.59	181.52	181.57	181.38	181.66	181.63	181.67	181.67	181.68
HC1-85-2	Lower Till	170.50	169.00	169.75	181.55	181.41	181.44	181.46	181.36	181.18	181.34	181.39	181.43	181.43	181.44
HC1-85-3	Upper Till	176.00	175.10	175.55	182.84	182.97	183.15	183.38	183.63	183.65	183.32	183.35	183.37	183.32	183.27
HC1-85-4	Upper Till (w?)	183.60	179.60	w.t.	182.93	183.06	183.18	183.33	183.63	183.64	183.42	183.44	183.46	183.41	183.36
		Vertical Gradient:		(1-2)	0.01	0.02	0.01	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02
				(1-3)	-0.06	-0.07	-0.08	-0.09	-0.10	-0.11	-0.08	-0.09	-0.08	-0.08	-0.08
				(1-4)	-0.04	-0.05	-0.06	-0.06	-0.07	-0.08	-0.06	-0.06	-0.06	-0.06	-0.06
				(2-3)	-0.22	-0.27	-0.29	-0.33	-0.39	-0.43	-0.34	-0.34	-0.33	-0.33	-0.32
				(2-4)	-0.10	-0.12	-0.13	-0.14	-0.16	-0.18	-0.15	-0.15	-0.15	-0.14	-0.14
				(3-4)	-0.01	-0.01	-0.00	0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01
HC2-85-1	Lower Till	157.60	156.10	156.85	181.66	181.79	181.79	181.79	181.68	181.54	181.65	181.78	181.83	181.84	181.86
HC2-85-2	Upper Granular	173.00	170.00	171.50	181.76	181.87	181.86	181.82	181.81	181.65	181.75	181.84	181.87	181.87	181.87
HC2-85-3	Upper Till (w?)	181.30	176.70	w.t.	181.80	181.93	181.97	182.02	182.52	182.61	181.85	182.03	182.05	182.00	181.95
		Vertical Gradient:		(1-2)	-0.01	-0.01	-0.00	-0.00	-0.01	-0.01	-0.01	-0.00	-0.00	-0.00	
				(1-3)	-0.01	-0.01	-0.01	-0.01	-0.03	-0.04	-0.01	-0.01	-0.01	-0.01	
				(2-3)	-0.00	-0.01	-0.01	-0.02	-0.06	-0.09	-0.01	-0.02	-0.02	-0.01	
HC3-85-1	Bedrock	169.00	167.50	168.25	180.61	180.65	180.69	180.77		180.77					180.77
HC3-85-2	Lower Till	172.90	171.40	172.15	180.80	180.81	180.87	180.92		180.88					180.88
HC3-85-3	Upper Till (w?)	181.60	178.60	w.t.	182.61	182.66	182.63	182.60	183.01	182.97					182.97
		Vertical Gradient:		(1-2)	-0.05	-0.04	-0.05	-0.04		-0.03					-0.03
				(1-3)	-0.14	-0.14	-0.13	-0.13		-0.15					-0.15
				(2-3)	-0.17	-0.18	-0.17	-0.16		-0.19					-0.19
HC4-85-1	Lower Till	159.80	158.90	159.35		181.39	181.39	181.39	181.22	181.22	181.08	181.18	181.22	181.21	181.20
HC4-85-2	Lower Granular	170.10	167.40	168.75		181.31	181.22	181.15	181.08	181.12	180.91	181.01	181.05	181.04	181.02
HC4-85-3	Upper Till (w?)	184.20	179.60	w.t.	184.31	184.44	184.39	184.34	184.81	184.96	185.31	185.39	185.36	185.30	185.22
		Vertical Gradient:		(1-2)		0.01	0.02	0.03	0.01	0.01	0.02	0.02	0.02	0.02	0.02
				(1-3)		-0.12	-0.12	-0.12	-0.14	-0.15	-0.16	-0.16	-0.16	-0.16	-0.16
				(2-3)		-0.20	-0.20	-0.20	-0.23	-0.24	-0.27	-0.26	-0.26	-0.26	-0.26
HC5-85-1	Lower Till	162.80	161.90	162.35	181.28	181.28	181.32	181.39	181.48	181.47					
HC5-85-2	Upper/Lower Till	174.40	172.90	173.65	181.82	181.81	181.80	181.78	181.71	181.81					
HC5-85-3	Upper Till (w?)	183.70	179.10	w.t.	184.45	184.50	184.42	184.33	185.19	185.25					
		Vertical Gradient:		(1-2)	-0.05	-0.05	-0.04	-0.03	-0.02	-0.03					
				(1-3)	-0.14	-0.15	-0.14	-0.13	-0.16	-0.17					
				(2-3)	-0.24	-0.25	-0.24	-0.24	-0.30	-0.30					

APPENDIX II

LABORATORY HYDRAULIC CONDUCTIVITY TEST REPORT - GOLDER ASSOCIATES

Rec'd CRA

NOV 24 1987

Golder Associates

CONSULTING GEOTECHNICAL AND MINING ENGINEERS

November 23, 1987 Our ref: 871-1418

Conestoga-Rovers & Associates Limited
651 Colby Drive
WATERLOO, Ontario
N2V 1C2

ATTENTION: Mr. Lloyd A. Lemon, B.Sc.

RE: HYDRAULIC CONDUCTIVITY TESTING
Your Project 1354-10

Dear Sirs:

This letter reports the factual results of Constant Head Hydraulic Conductivity tests which have been carried out on five core samples from the above project. These samples were delivered to our laboratory on September 21, 1987.

The Constant Head Hydraulic Conductivity tests were carried out using the triaxial constant head mercury/water apparatus. This test procedure is outlined in the attached Appendix.

The test core which was labelled as Borehole HC 5-85, Cample CRA 1, was in a dry state and was not considered to be in a suitable condition for testing. It was agreed with CRA that this sample would be broken up, wetted to approximately 14 per cent water content and compacted into a standard Proctor mould at standard Proctor effort. The sample was then extruded, trimmed to a length of 9.74 cm and tested, using the above-mentioned Constant Head Hydraulic Conductivity test procedure.

The remaining core samples were trimmed to a nominal size of 5 cm diameter x 7 cm height, in the wetted condition as received, and tested. The hydraulic conductivity test results are summarized on Table 1.

The laboratory data obtained during the saturation, consolidation and constant head hydraulic conductivity stages of testing are shown on Figures 1 to 10, inclusive. This report presentation was requested by Conestoga-Rovers & Associates Limited.

GOLDER ASSOCIATES (EASTERN CANADA) LTD. • 3151 WHARTON WAY, MISSISSAUGA, ONTARIO, CANADA L4X 2B6 • TELEPHONE (416) 625-0094 • TELEX 06-961136

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We were also requested to carry out the grain size distribution for each sample according to ASTM D 422-63. The results of these tests are shown on Figures 11 to 16, inclusive, and summarized on Table 1 along with the Atterberg Limit determinations, ASTM D 4318.

We trust that this information is sufficient for your immediate purposes. If, however, there are any questions please contact us.

Yours truly

GOLDER ASSOCIATES

F. A. Rydgren

Leo R. Lahti, P. Eng.

FAR/LRL/jm

Enc: Table 1
Figures 1 to 16, inclusive
Appendix

TABLE 1

SUMMARY OF PHYSICAL PROPERTIES
LABORATORY HYDRAULIC CONDUCTIVITY TESTS

Borehole No.	SA. No.	Water Content-Trimmings (%)	Water Content-Final (%)	Dry Unit Weight (kN/m^3)	Hydraulic Conductivity (cm/s)	Per Cent Clay (%)	Per Cent Clay and Silt (%)	Liquid Limit (%)	Plasticity Index (%)
HC 5-85	CRA 1	13.7	12.9	19.42	6.83×10^{-9}	20.0	53.5	25.9	8.9
HC 5-85	CRA 2	8.4	11.3	20.80	6.95×10^{-9}	19.5	59.8		
HC 2-86	CRA 3	3.9	10.4	19.93	1.45×10^{-8}	20.0	62.0		
HC 2-86	CRA 4	6.2	14.7	18.35	2.59×10^{-8}	26.0	79.0		
HC 1-86	CRA 5	1.4	14.2	19.68	1.11×10^{-7}	26.0	67.0		
HC 2-86	CRA 6					26.0	75.5		

HYDRAULIC CONDUCTIVITY TEST

SHEET 1 OF 2

FIGURE 1

BOREHOLE NUMBER HC 5-85
SAMPLE NUMBER CRA 1
SAMPLE LOCATION 4.72-5.18 m
SAMPLE TYPE Grey Silty Clay to Clayey Silt Some Fine Gravel

Project 871-1418
CRA / Hydraulic Conductivity / 1354-18

ORIGINAL: LENGTH cm	9.74	CONSOLIDATED: AREA cm2	78.23	WET WEIGHT gm	1757.9
DIAMETER cm	10.10	LENGTH cm	9.62	DRY WEIGHT gm	1532.2
AREA cm2	80.154	PRESSURE kPA	206.70	VOLUME WATER cc	225.7
VOLUME cc	780.364	HYDRAULIC GRADIENT (p/l)	19.51		

WATER CONTENT initial %	13.70	SPECIFIC GRAVITY	2.700 assumed	LIQUID LIMIT %	25.9
WATER CONTENT final %	12.90	VOLUME SOLIDS cc	567.481	PLASTIC INDEX %	8.9
UNIT WEIGHT kN/m3	22.08	VOLUME VOIDS cc	212.883	CLAY FRACTION (.002mm) %	20.0
DRY UNIT WEIGHT kN/m3	19.42	VOID RATIO	0.375	SILT FRACTION (.06mm) %	53.5
lb/ft3	123.63	SATURATION %	106.021	UNIT WEIGHT kN/m3 (received	22.49

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value
482.3	475.4	3070	8.50	0.96

HYDRAULIC CONDUCTIVITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
700.7	494.0	475.4	28.1	18.61	14856.85	206.7	225.3

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	OUTFLOW Vc cc	trns.#1 aVc cc	INFLOW Vc cc	trns.#28 aVc cc	DAILY HYDRAULIC CONDUCTIVITY RESULTS OUTFLOW cm/s	INFLOW cm/s
87-09-27	09:24	0	0	33.0	0.00	16.5	0.00		
87-09-28	08:37	1393	83580	31.9	1.10	16.1	0.40	8.52E-09	3.10E-09
87-09-29	08:31	2827	169620	30.7	2.30	15.5	1.00	9.03E-09	4.51E-09
87-09-30	09:00	4296	257760	29.4	3.60	14.8	1.70	9.55E-09	5.14E-09
87-10-01	08:10	5686	341160	28.3	4.70	14.0	2.50	8.54E-09	6.21E-09

HYDRAULIC CONDUCTIVITY, cm/s

TOTAL FLOW

MINUTES		
5686	OUTFLOW,cm/s	8.91E-09
	INFLOW,cm/s	4.74E-09
	AVERAGE,cm/s	6.83E-09

PART 1

MINUTES			
2859	OUTFLOW,	9.06E-09	cm/s
	INFLOW,	5.66E-09	cm/s
	AVERAGE,	7.36E-09	cm/s

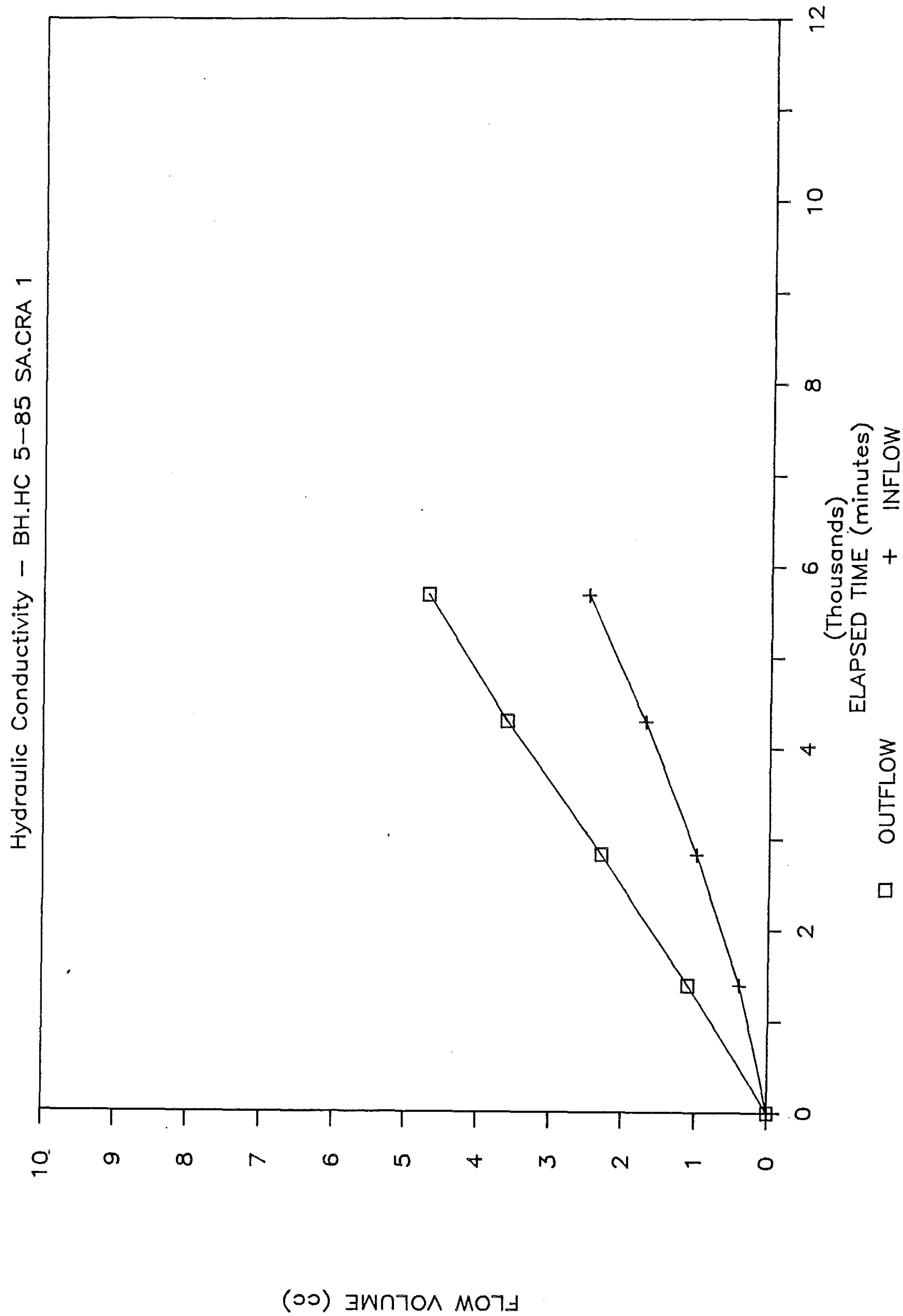
PART 2

MINUTES			
5686	OUTFLOW,	8.92E-09	cm/s
	INFLOW,	4.74E-09	cm/s
	AVERAGE,	6.83E-09	cm/s
	AVERAGE, USE FOR ANALYSES	6.83E-09	cm/s

NOTES

Membrane sealed onto sample with vacuum grease,
Compacted to 100% Standard Proctor effort,
@ time 2890 minutes into hyd. conductivity run.
Data by F.A.R.

Golder Associates



Hydraulic Conductivity — BH.HC 5-85 SA.CRA 1
FLOW VOLUME (cc)
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
(Thousands)
ELAPSED TIME (minutes)
□ OUTFLOW
+ INFLOW

HYDRAULIC CONDUCTIVITY TEST

SHEET 1 OF 2

FIGURE 3

BOREHOLE NUMBER HC 5-85
SAMPLE NUMBER CRA 2
SAMPLE LOCATION 8.08-8.53 m
SAMPLE TYPE Grey Silty Clay to Clayey Silt Some Fine Gravel

Project 871-1418

CRA / Hydraulic Conductivity / 1354-10

ORIGINAL: LENGTH cm	8.93	CONSOLIDATED: AREA cm2	19.92	WET WEIGHT gm	414.7
DIAMETER cm	5.07	LENGTH cm	8.87	DRY WEIGHT gm	382.5
AREA cm2	20.191	PRESSURE kPA	124.71	VOLUME WATER cc	32.2
VOLUME cc	180.307	HYDRAULIC GRADIENT (p/l)	19.68		

WATER CONTENT initial %	8.40	SPECIFIC GRAVITY	2.700 assumed	LIQUID LIMIT %	
WATER CONTENT final %	11.30	VOLUME SOLIDS cc	141.667	PLASTIC INDEX %	
UNIT WEIGHT kN/m3	22.55	VOLUME VOIDS cc	38.641	CLAY FRACTION (.002mm) %	19.5
DRY UNIT WEIGHT kN/m3	20.80	VOID RATIO	0.273	SILT FRACTION (.06mm) %	59.8
lb/ft3	132.40	SATURATION %	83.358		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value
551.2	544.3	8640	19.40	0.96

HYDRAULIC CONDUCTIVITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
686.2	561.5	544.3	3.7	17.22	3500.039	124.7	141.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	OUTFLOW Vc cc	trns.#1 aVc cc	INFLOW Vc cc	trns.#2B aVc cc	DAILY HYDRAULIC CONDUCTIVITY RESULTS OUTFLOW cm/s	INFLOW cm/s
87-10-10	12:32	0	0	59.8	0.00	12.2	0.00		
87-10-11	10:41	1329	79740	59.6	0.20	12.1	0.10	6.36E-09	3.18E-09
87-10-12	10:42	2770	166200	59.3	0.50	11.8	0.40	8.79E-09	8.79E-09
87-10-13	09:36	4144	248640	59.0	0.80	11.6	0.60	9.22E-09	6.15E-09
87-10-14	08:34	5522	331320	58.8	1.00	11.4	0.80	6.13E-09	6.13E-09
87-10-15	08:56	6984	419040	58.5	1.30	11.2	1.00	8.67E-09	5.78E-09

HYDRAULIC CONDUCTIVITY, cm/s

TOTAL FLOW
MINUTES 6984
OUTFLOW,cm/s 7.83E-09
INFLOW,cm/s 6.00E-09
AVERAGE,cm/s 6.92E-09

PART 1
MINUTES 2840
OUTFLOW, 7.44E-09 cm/s
INFLOW, 5.95E-09 cm/s
AVERAGE, 6.69E-09 cm/s

PART 2
MINUTES 5522
OUTFLOW, 7.86E-09 cm/s
INFLOW, 6.05E-09 cm/s
AVERAGE, 6.95E-09 cm/s

AVERAGE, USE FOR ANALYSES 6.95E-09 cm/s

NOTES

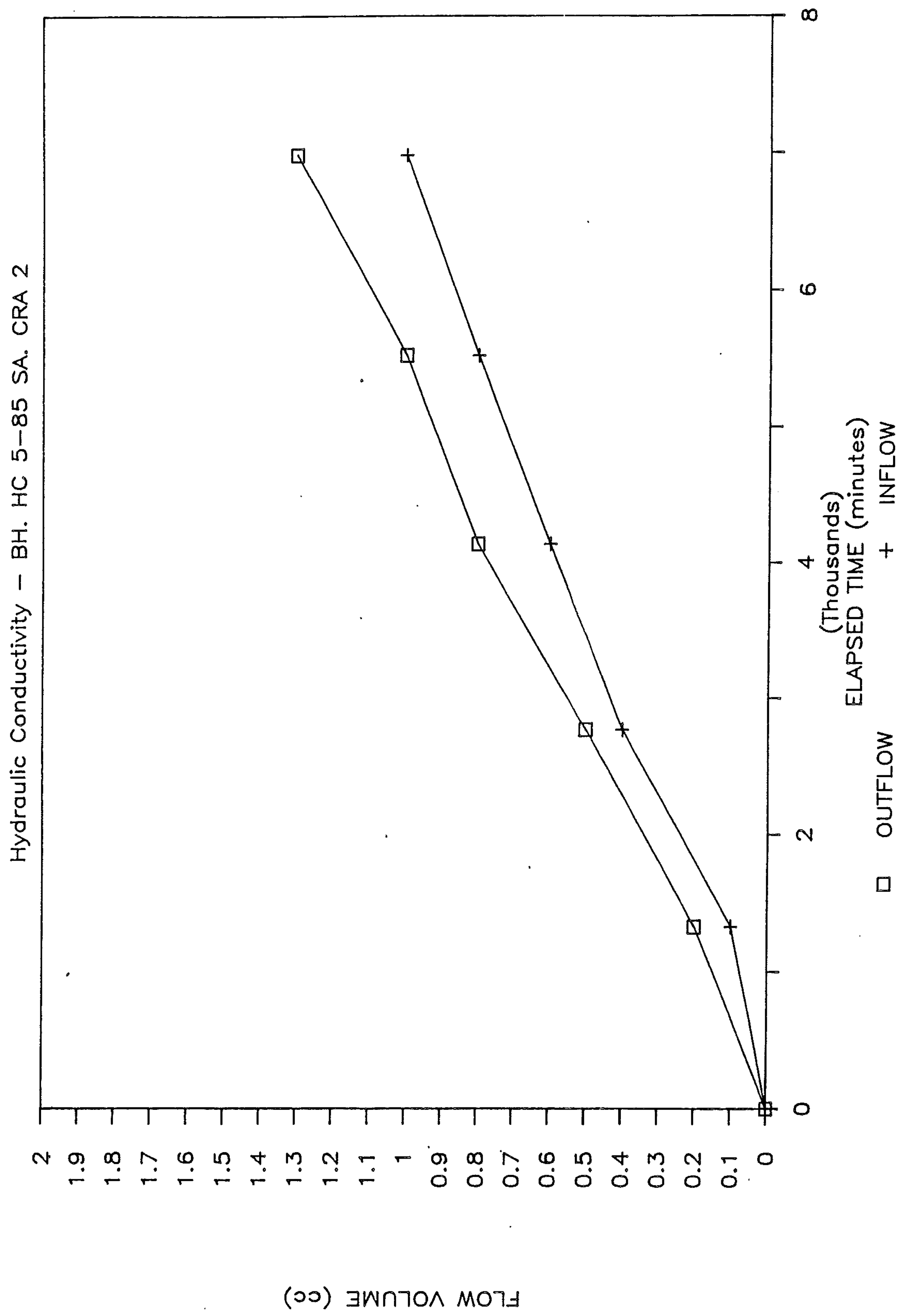
Membrane sealed onto sample with vacuum grease,
Sample consolidated at 124 kPa prior to hyd.conductivity run,
0 time 2880 minutes into hydraulic conductivity run.
Data by F.A.R.

Golder Associates

HYDRAULIC CONDUCTIVITY TEST

SHEET 2 OF 2

FIGURE 4



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HYDRAULIC CONDUCTIVITY TEST

FIGURE 5

SHEET 1 OF 2

BOREHOLE NUMBER HC 2-86
SAMPLE NUMBER CRA 3
SAMPLE LOCATION 4.57-5.33
SAMPLE TYPE Grey Silty Clay to Clayey Silt,Some Fine Gravel

Project 871-1418

CRA / Hydraulic Conductivity / 1354-10

ORIGINAL: LENGTH cm	7.31	CONSOLIDATED: AREA cm2	20.28	WET WEIGHT gm	318.0
DIAMETER cm	5.12	LENGTH cm	7.25	DRY WEIGHT gm	228.9
AREA cm2	20.591	PRESSURE kPA	74.41	VOLUME WATER cc	89.1
VOLUME cc	150.523	HYDRAULIC GRADIENT (p/l)	20.19		

WATER CONTENT initial %	3.90	SPECIFIC GRAVITY	2.700 assumed	LIQUID LIMIT %	
WATER CONTENT final %	10.40	VOLUME SOLIDS cc	84.778	PLASTIC INDEX %	
UNIT WEIGHT kN/m3	20.71	VOLUME VOIDS cc	65.745	CLAY FRACTION (.002mm) %	20.0
DRY UNIT WEIGHT kN/m3	19.93	VOID RATIO	0.775	SILT FRACTION (.06mm) %	62.0
lb/ft3	126.89	SATURATION %	135.553		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value
413.4	406.5	4320	21.80	0.96

HYDRAULIC CONDUCTIVITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
495.4	421.0	406.5	3.4	14.47	2994.122	74.4	88.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	OUTFLOW #7B Vc cc	OUTFLOW #7B aVc cc	INFLOW #7H Vc cc	INFLOW #7H aVc cc	DAILY HYDRAULIC CONDUCTIVITY RESULTS OUTFLOW cm/s	DAILY HYDRAULIC CONDUCTIVITY RESULTS INFLOW cm/s
87-10-21	08:41	0	0	70.2	0.00	10.9	0.00		
87-10-22	08:43	1442	86520	69.8	0.40	10.3	0.60	1.12E-08	1.68E-08
87-10-23	08:36	2875	172500	69.2	1.00	9.9	1.00	1.69E-08	1.13E-08
87-10-24	16:30	4789	287340	68.7	1.50	9.2	1.70	1.05E-08	1.48E-08
87-10-25	10:53	5892	353520	68.3	1.90	9.7	2.20	1.46E-08	1.83E-08
87-10-26	07:55	7154	429240	68.0	2.20	10.4	2.90		

HYDRAULIC CONDUCTIVITY, cm/s

TOTAL FLOW
MINUTES 7154
OUTFLOW,cm/s 1.33E-08
INFLOW,cm/s 1.53E-08
AVERAGE,cm/s 1.43E-08

PART 1
MINUTES 1103
OUTFLOW, 1.46E-08 cm/s
INFLOW, 1.83E-08 cm/s
AVERAGE, 1.65E-08 cm/s

PART 2
MINUTES 5712
OUTFLOW, 1.27E-08 cm/s
INFLOW, 1.63E-08 cm/s
AVERAGE, 1.45E-08 cm/s

AVERAGE, USE FOR ANALYSES 1.45E-08 cm/s

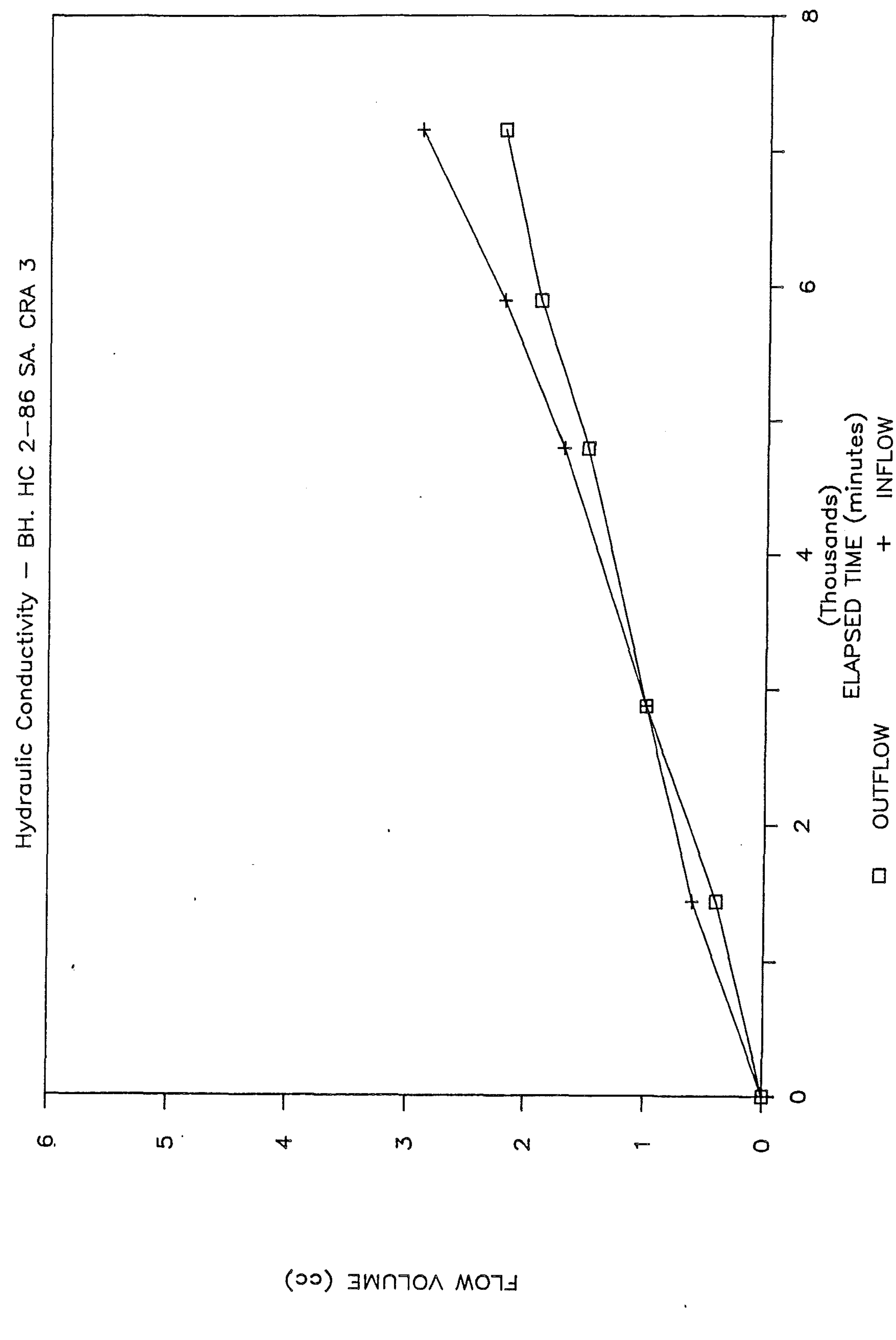
NOTES

Membrane sealed onto sample with vacuum grease,
Sample consolidated at 124 kPa prior to hyd. conductivity run,
0 time 1440 minutes into hydraulic conductivity run.
Data by F.A.R.

HYDRAULIC CONDUCTIVITY TEST

SHEET 2 OF 2

FIGURE 6



HYDRAULIC CONDUCTIVITY TEST

FIGURE 7

BOREHOLE NUMBER HC 2-86 — Project 871-1418
SAMPLE NUMBER CRA 4
SAMPLE LOCATION 7.62-8.38 m — CRA / Hydraulic Conductivity / 1354-18
SAMPLE TYPE Irregular Layered Grey Silty Clay ,Fine Gravel, Red Silt

ORIGINAL: LENGTH cm	6.23	CONSOLIDATED: AREA cm2	19.42	WET WEIGHT gm	256.9
DIAMETER cm	5.00	LENGTH cm	6.20	DRY WEIGHT gm	228.9
AREA cm2	19.637	PRESSURE kPA	106.79	VOLUME WATER cc	28.0
VOLUME cc	122.342	HYDRAULIC GRADIENT (p/l)	20.31		

WATER CONTENT initial %	12.20	SPECIFIC GRAVITY	2.700 assumed	LIQUID LIMIT %	
WATER CONTENT final %	14.70	VOLUME SOLIDS cc	84.778	PLASTIC INDEX %	
UNIT WEIGHT kN/m3	20.58	VOLUME VOIDS cc	37.564	CLAY FRACTION (.002mm) %	26.0
DRY UNIT WEIGHT kN/m3	18.35	VOID RATIO	0.443	SILT FRACTION (.06mm) %	79.0
lb/ft3	116.78	SATURATION %	74.513		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value
413.4	406.5	5760	8.30	0.96

HYDRAULIC CONDUCTIVITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
525.7	418.9	406.5	2	12.40	2457.827	106.8	119.2

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	OUTFLOW #3 Vc cc	OUTFLOW #3 aVc cc	INFLOW #4B Vc cc	INFLOW #4B aVc cc	DAILY HYDRAULIC CONDUCTIVITY RESULTS OUTFLOW cm/s	DAILY HYDRAULIC CONDUCTIVITY RESULTS INFLOW cm/s
87-10-15	08:56	0	0	23.4	0.00	2.4	0.00		
87-10-16	08:36	1420	85200	24.4	1.00	3.4	1.00	2.96E-08	2.96E-08
87-10-17	08:24	2848	170880	25.2	1.80	4.3	1.90	2.35E-08	2.65E-08
87-10-18	12:43	4547	272820	26.3	2.90	5.4	3.00	2.72E-08	2.72E-08
87-10-19	08:52	5756	345360	26.8	3.40	6.1	3.70	1.74E-08	2.43E-08

HYDRAULIC CONDUCTIVITY, cm/s

TOTAL FLOW

MINUTES		
5756	OUTFLOW,cm/s	2.44E-08
	INFLOW,cm/s	2.69E-08
	AVERAGE,cm/s	2.57E-08

PART 1

MINUTES			
1209	OUTFLOW,	1.74E-08	cm/s
	INFLOW,	2.43E-08	cm/s
	AVERAGE,	2.08E-08	cm/s

PART 2

MINUTES			
5756	OUTFLOW,	2.48E-08	cm/s
	INFLOW,	2.70E-08	cm/s
	AVERAGE,	2.59E-08	cm/s

AVERAGE, USE FOR ANALYSES 2.59E-08 cm/s

NOTES

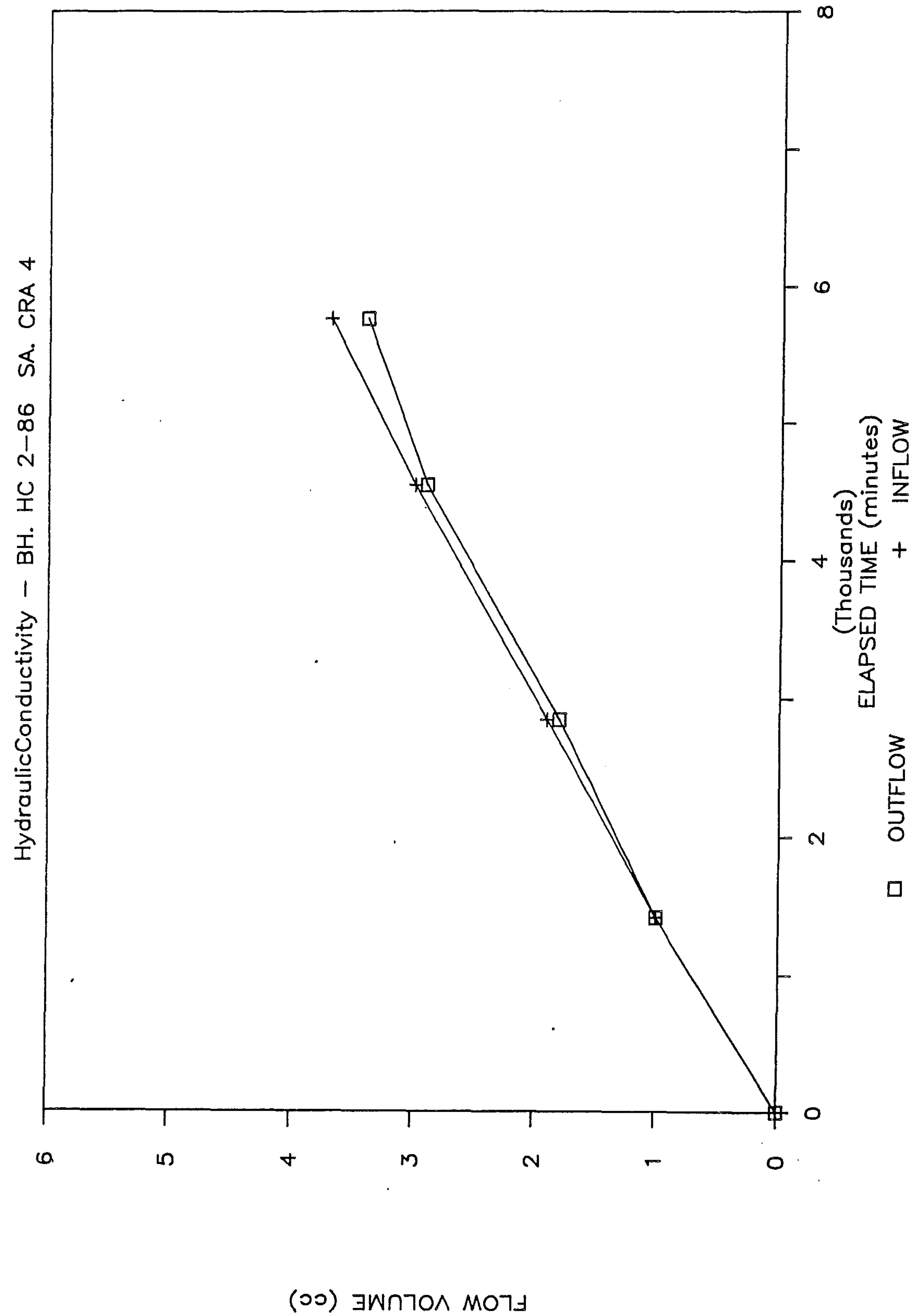
Membrane sealed onto sample with vacuum grease,
Sample consolidated at 124 kPa prior to hyd. conductivity run,
0 time 1440 minutes into hydraulic conductivity run.
Data by F.A.R.

Golder Associates

HYDRAULIC CONDUCTIVITY TEST

SHEET 2 OF 2

FIGURE 8



HYDRAULIC CONDUCTIVITY TEST

FIGURE 9

SHEET 1 OF 2

BOREHOLE NUMBER HC 1-86
SAMPLE NUMBER CRA 5
SAMPLE LOCATION 2.29-3.05 m
SAMPLE TYPE Grey Silty Clay ,Some Fine Gravel

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CRA / Hydraulic Conductivity / 1354-10

ORIGINAL: LENGTH cm	5.77	COSOLIDATED: AREA cm2	20.21	WET WEIGHT gm	239.9
DIAMETER cm	5.10	LENGTH cm	5.74	DRY WEIGHT gm	236.7
AREA cm2	20.431	PRESSURE kPA	44.10	VOLUME WATER cc	3.2
VOLUME cc	117.886	HYDRAULIC GRADIENT (p/l)	19.49		

WATER CONTENT initial %	1.40	SPECIFIC GRAVITY	2.700 assumed	LIQUID LIMIT %	
WATER CONTENT final %	14.20	VOLUME SOLIDS cc	87.667	PLASTIC INDEX %	
UNIT WEIGHT kN/m3	19.95	VOLUME VOIDS cc	30.219	CLAY FRACTION (.002mm) %	26.0
DRY UNIT WEIGHT kN/m3	19.68	VOID RATIO	0.345	SILT FRACTION (.06mm) %	67.0
lb/ft3	125.25	SATURATION %	10.688		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value
482.3	475.4	4500	34.70	0.96

HYDRAULIC CONDUCTIVITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
530.5	486.4	475.4	1.9	11.02	2273.351	44.1	55.1

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	OUTFLOW #3 Vc cc	OUTFLOW #3 aVc cc	INFLOW #40 Vc cc	INFLOW #40 aVc cc	DAILY HYDRAULIC CONDUCTIVITY RESULTS OUTFLOW cm/s	DAILY HYDRAULIC CONDUCTIVITY RESULTS INFLOW cm/s
87-10-25	10:52	0	0	20.8	0.00	1.5	0.00		
87-10-26	07:55	1263	75780	25.1	4.30	5.9	4.40	1.43E-07	1.47E-07
87-10-27	08:35	2743	164580	29.7	8.90	10.3	8.80	1.31E-07	1.25E-07
87-10-28	08:40	4188	251280	33.4	12.60	14.2	12.70	1.08E-07	1.14E-07
87-10-29	08:41	5629	337740	36.8	16.00	17.6	16.10	9.93E-08	9.93E-08
87-10-30	08:37	7065	423900	39.9	19.10	19.8	18.30	9.08E-08	6.45E-08

HYDRAULIC CONDUCTIVITY, cm/s

TOTAL FLOW
MINUTES 7065
OUTFLOW,cm/s 1.14E-07
INFLOW,cm/s 1.10E-07
AVERAGE,cm/s 1.12E-07

PART 1
MINUTES 2077
OUTFLOW, 9.51E-08 cm/s
INFLOW, 8.19E-08 cm/s
AVERAGE, 8.85E-08 cm/s

PART 2
MINUTES 7065
OUTFLOW, 1.14E-07 cm/s
INFLOW, 1.09E-07 cm/s
AVERAGE, 1.11E-07 cm/s

AVERAGE, USE FOR ANALYSES 1.11E-07 cm/s

NOTES

Membrane sealed onto sample with vacuum grease,
Sample consolidated at 124 kPa prior to hyd. conductivity run,
0 time 1440 minutes into hydraulic conductivity run.
Data by F.A.R.

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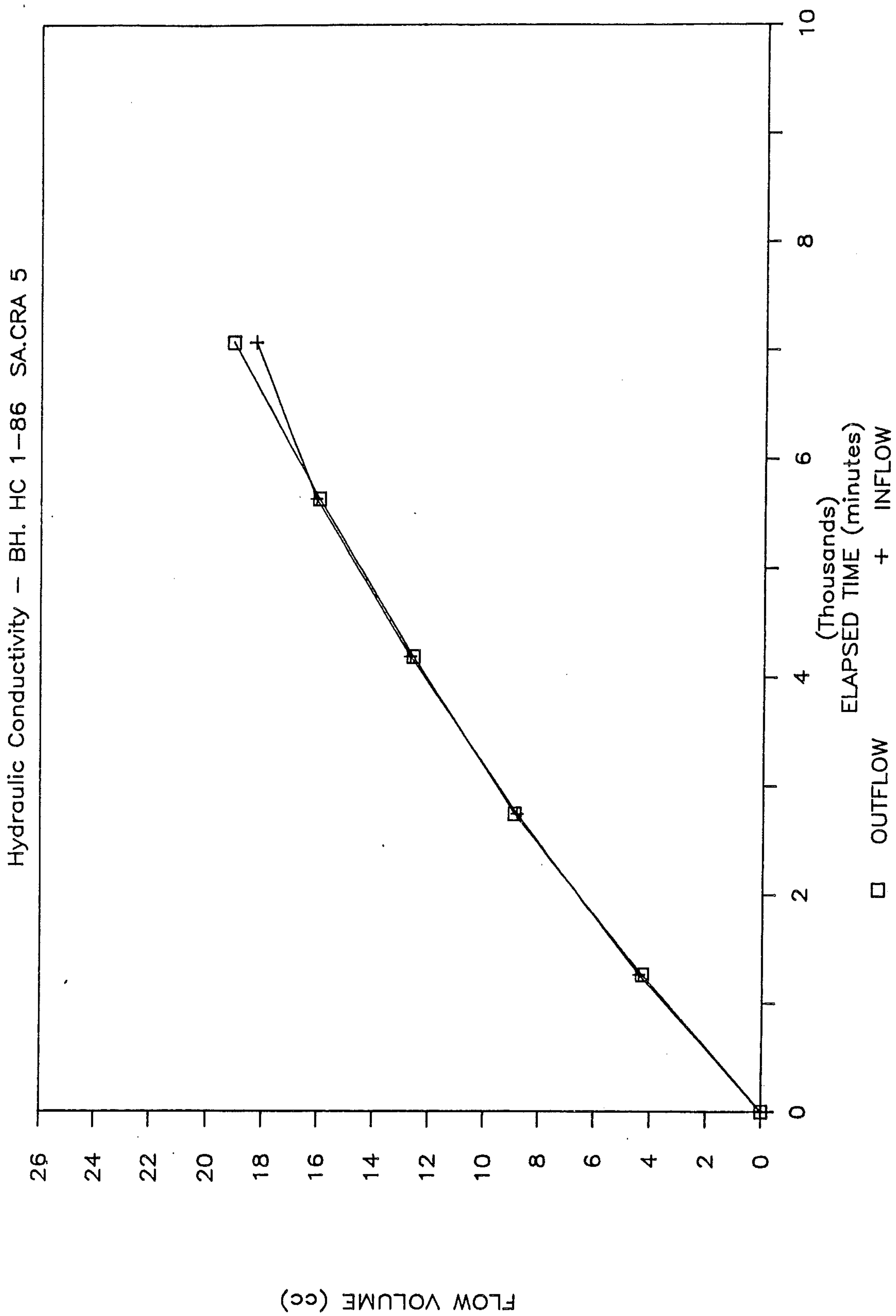
HYDRAULIC CONDUCTIVITY TEST

SHEET 2 OF 2

FIGURE 10

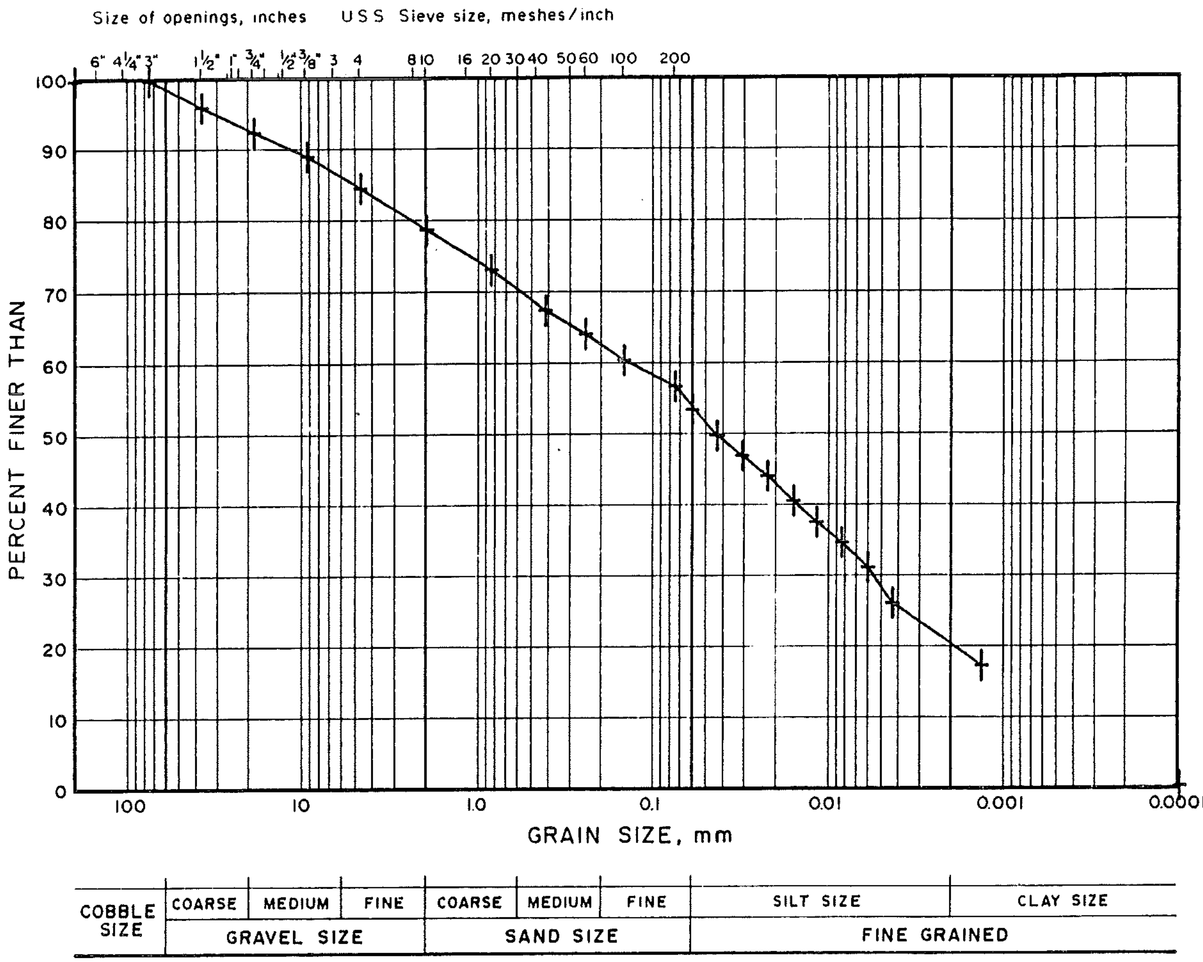


GRAIN SIZE DISTRIBUTION

FIGURES 11 to 16

GRAIN SIZE DISTRIBUTION

FIGURE 11



LEGEND

SYMBOL	LOCATION	SAMPLE	DEPTH (m)
+	HC5-85	CRA 1	5.18

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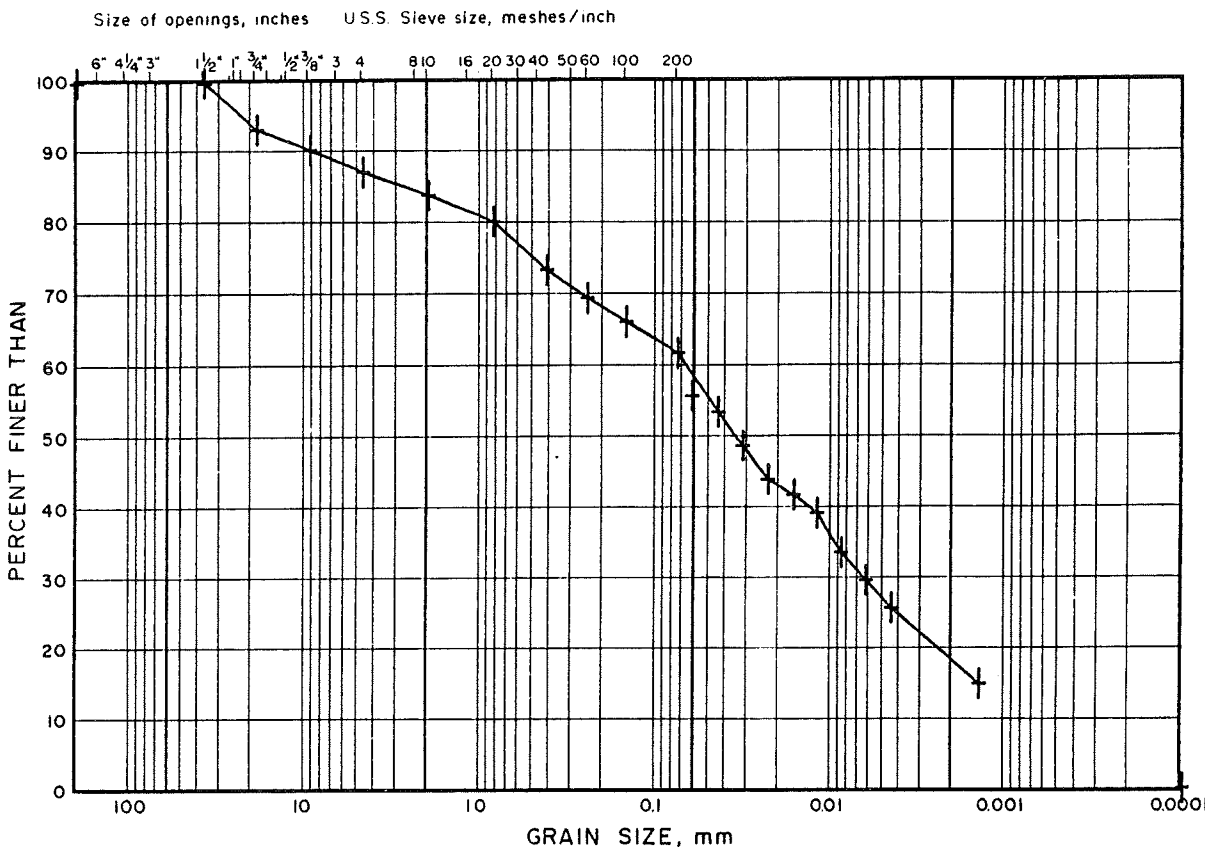
GRAIN SIZE DISTRIBUTION

FIGURE 12



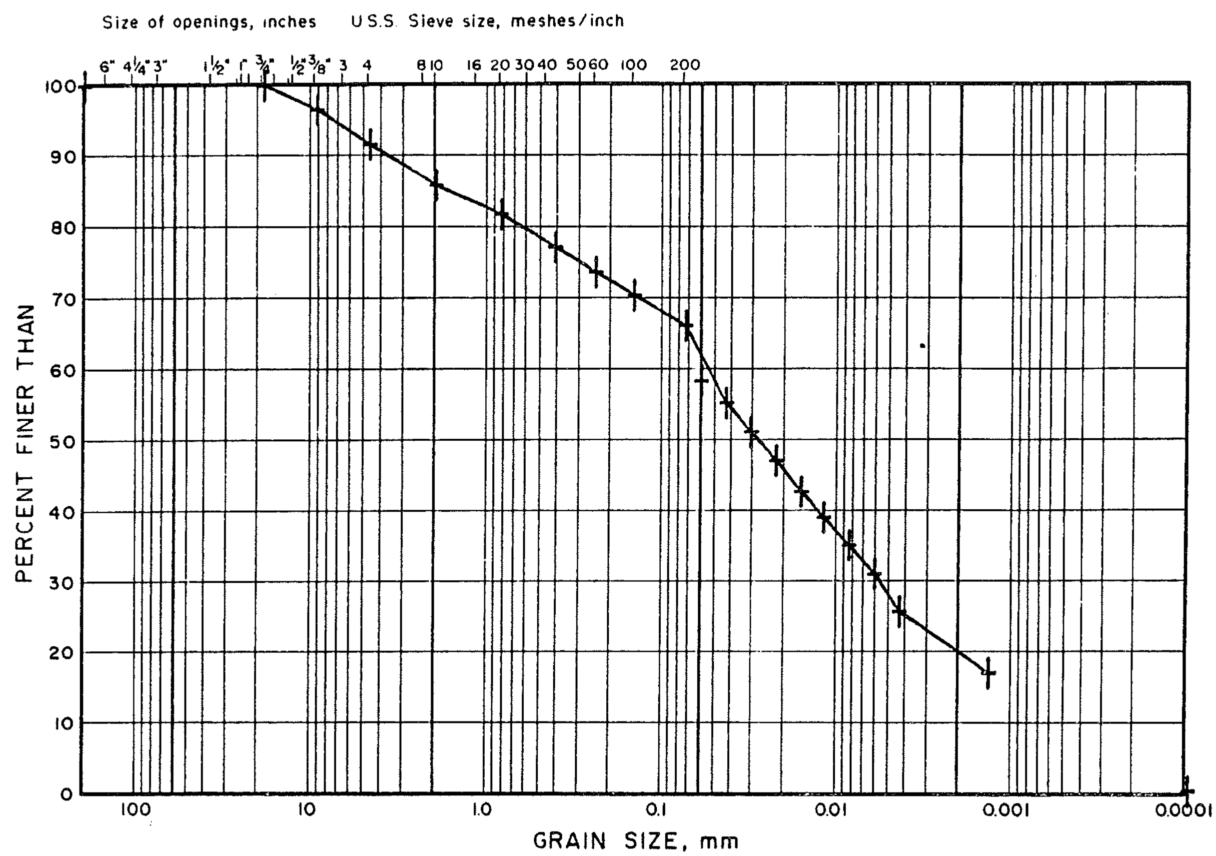
COBBLE SIZE	COARSE	MEDIUM	FINE	COARSE	MEDIUM	FINE	SILT SIZE	CLAY SIZE
	GRAVEL SIZE			SAND SIZE			FINE GRAINED	

LEGEND

SYMBOL	LOCATION	SAMPLE	DEPTH (m)
+	HC5-85	CRA 2	8.53

GRAIN SIZE DISTRIBUTION

FIGURE 13



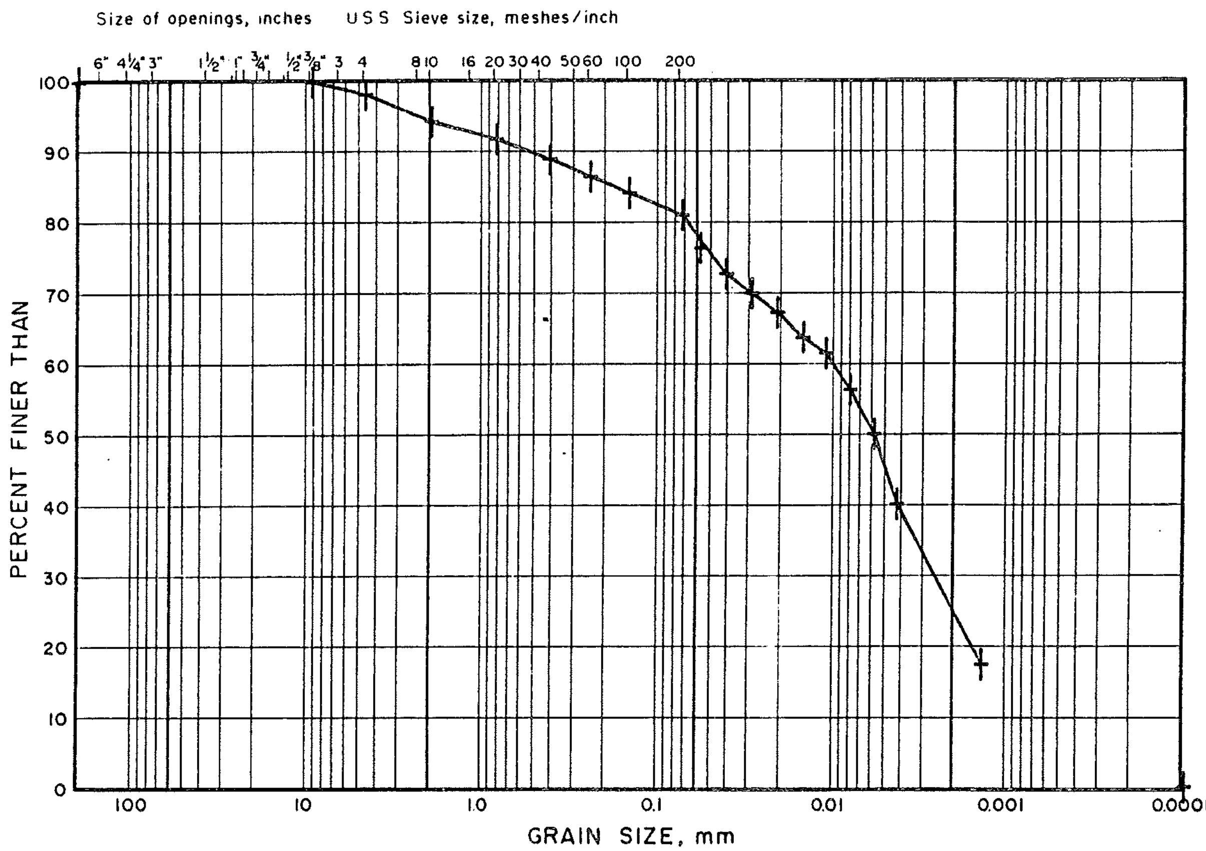
COBBLE SIZE	COARSE	MEDIUM	FINE	COARSE	MEDIUM	FINE	SILT SIZE	CLAY SIZE
	GRAVEL SIZE			SAND SIZE			FINE GRAINED	

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH (m)
+	HC2-86	CRA3	5.33

GRAIN SIZE DISTRIBUTION

FIGURE 14



COBBLE SIZE	COARSE	MEDIUM	FINE	COARSE	MEDIUM	FINE	SILT SIZE	CLAY SIZE
	GRAVEL SIZE			SAND SIZE			FINE GRAINED	

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH (m)
+	HC2-86	CRA4	8.38

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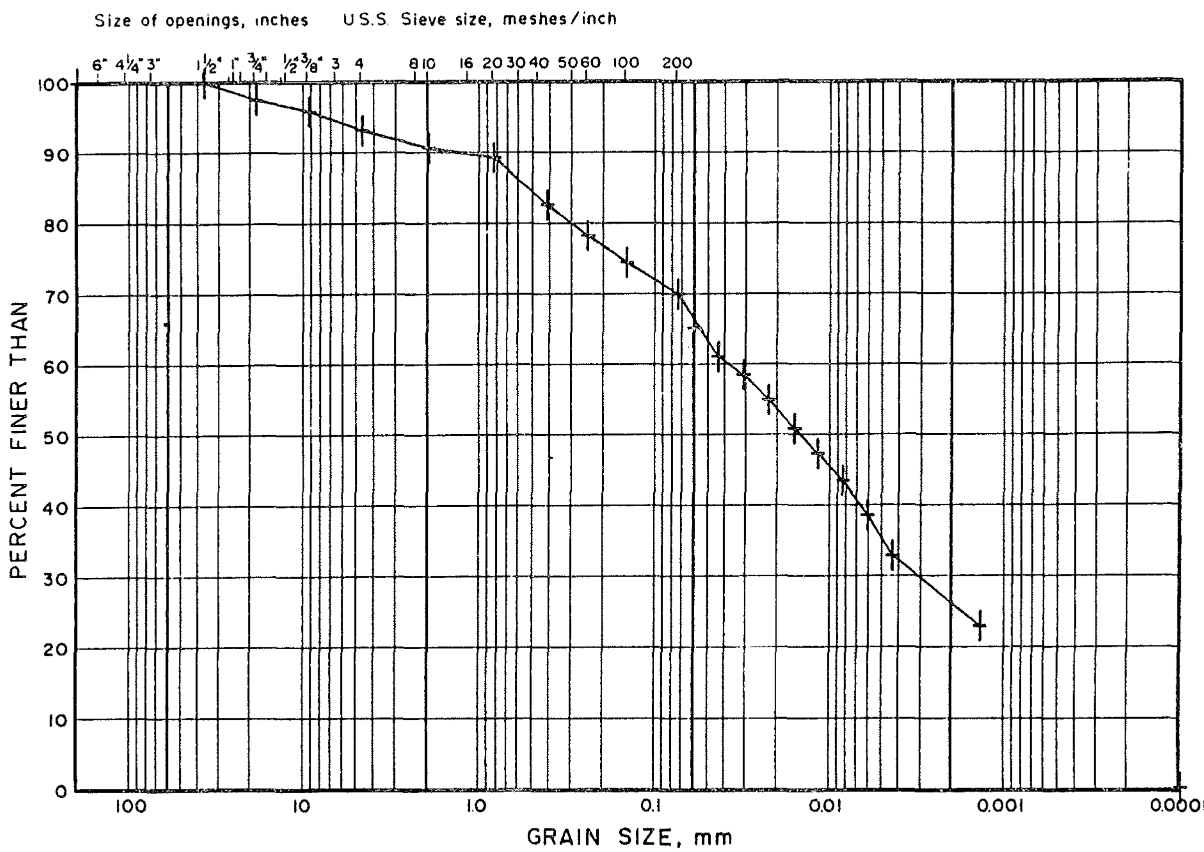
GRAIN SIZE DISTRIBUTION

FIGURE 15



COBBLE SIZE	COARSE	MEDIUM	FINE	COARSE	MEDIUM	FINE	SILT SIZE	CLAY SIZE
	GRAVEL SIZE			SAND SIZE			FINE GRAINED	

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH (m)
+	HC1-86	CRA-5	3.05

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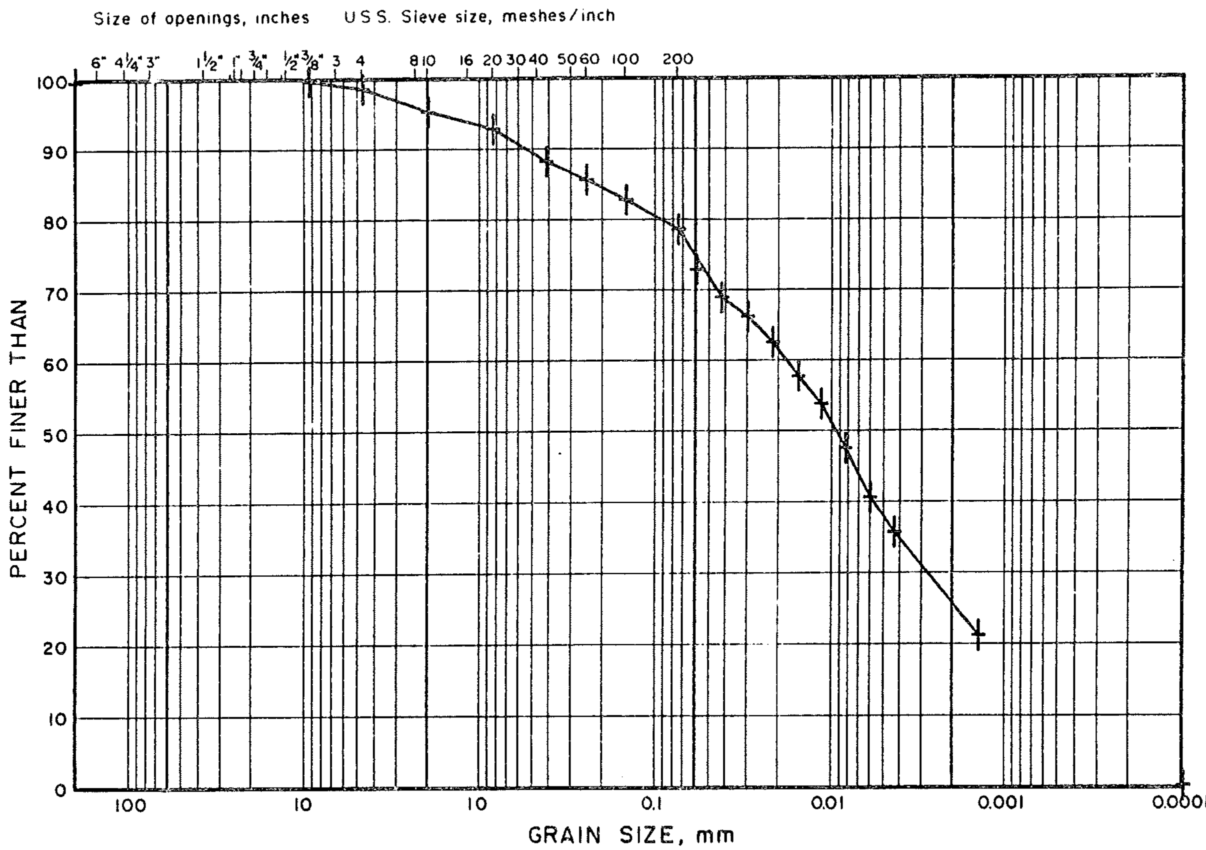
GRAIN SIZE DISTRIBUTION

FIGURE 16



COBBLE SIZE	COARSE	MEDIUM	FINE	COARSE	MEDIUM	FINE	SILT SIZE	CLAY SIZE
	GRAVEL SIZE			SAND SIZE			FINE GRAINED	

LEGEND

SYMBOL	LOCATION	SAMPLE	DEPTH (m)
+	HC2-86	CRA 6	7.62

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APPENDIX

CONSTANT HEAD HYDRAULIC CONDUCTIVITY TEST PROCEDURE

Ref: The Triaxial Test, Bishop & Henkel

CONSTANT HEAD HYDRAULIC CONDUCTIVITY TEST PROCEDURE

The constant head hydraulic conductivity tests were carried out using the pore water pressure mercury/water triaxial apparatus.

The test samples were trimmed from core samples at 90 deg. to the horizontal plane. After placing on the cell pedestal, with 80 Kv bauxite filter stones on each end, the samples were encased with high vacuum grease, membrane sheath, high vacuum grease and a second membrane sheath. The triaxial cell was then assembled and filled with water.

Saturation by Back Pressure

The test samples were saturated by back pressures at incremental stages of 70 kPa until a pore pressure B value of 0.96 was obtained.

For a saturation incremental stage, a cell pressure of 70 kPa and a back pressure of 62 kPa is introduced to the sample and allowed to absorb air for about 8 hours prior to increasing to the next increment until saturation has been completed.

Isotropic Consolidation

Upon achieving saturation, the cell pressure was increased above the saturation back pressure to a value that would equal the required effective consolidation pressure.

The sample was then allowed to consolidate for a minimum period of 24 hours, at which time the consolidated sample size was calculated. Using the consolidated length value, a hydraulic gradient of approximately 20 was calculated and the required head pressure was applied to one end of the sample while the saturation back pressure was applied to the opposite end. In order to maintain the original consolidation pressure, the cell pressure was adjusted so that the differences between the head pressure and cell pressure were equal to the required isotropic consolidation.