

**SUPREME COURT OF ONTARIO
(DIVISIONAL COURT)**

B E T W E E N:

NSP INVESTMENTS LIMITED

Applicant

-and-

**THE JOINT BOARD (ESTABLISHED UNDER
SECTION 4 OF THE CONSOLIDATED HEARINGS
ACT, 1981, S.O. 1981, c. 20, AS AMENDED), THE
REGIONAL MUNICIPALITY OF HALTON, THE
CORPORATION OF THE TOWN OF MILTON, THE
CORPORATION OF THE CITY OF BURLINGTON,
THE WEST BURLINGTON CITIZENS' GROUP,
THE MILTON AREA CITIZENS' COALITION, THE
HALTON FEDERATION OF AGRICULTURE,
WATKIN AND DOREEN MARTIN, WALTER
TOMOSKY, THOMAS AND MARY-JEAN
MARTIN, MICHAEL AND CYNTHIA REED, AND
THE HONOURABLE JAMES BRADLEY, IN HIS
CAPACITY AS THE MINISTER OF THE
ENVIRONMENT**

Respondents

**Application under the Judicial Review
Procedure Act, R.S.O. 1980, c. 224,
Subsections 2(1), 2(3) and 2(4) and
Rule 68 of the Rules of Civil Procedure**

APPLICATION RECORD

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TABLE OF CONTENTS

<u>DOCUMENT</u>	<u>DATE</u> (Where Applicable)	<u>TAB</u>
1. Decision of the Joint Board and Addendum thereto	24 Feb. 89 and 02 Mar. 89	1
2. Evidence of Max Bacon, Transcript, Vol. 103, p. 24687	09 Mar. 88	2
3. Exhibit N-586, Tabs 1 and 2	Jan. 88	3
4. Evidence of P. Walker, Transcript, Vol. 59, pp. 13697-13711	12 Nov. 87	4
5. Evidence of Max Bacon, Transcript, Vol. 103, p. 24672	09 Mar. 88	5
6. Exhibit H-306	01 Aug. 72	6
7. Exhibit H-42, p. 19	Sept. 86	7
8. Evidence of Max Bacon, Transcript, Vol. 102, pp. 24500-503; 24553-557	08 Mar. 88	8
9. Exhibit N-587, Tabs C and H	14 Apr. 82 and 18 Dec. 86	9
10. Exhibit N-313	13 Apr. 82	10
11. Evidence of Max Bacon, Transcript, Vol. 102, pp. 24514-519	08 Mar. 88	11
12. Exhibit H-316	Oct. 87	12
13. Evidence of Watkin and Doreen Martin, Thomas and Mary-Jean Martin, Michael and Cynthia Reed, Walter Tomosky and Milton Coalition Members Transcript, Vol. 99, pp. 23668, 23706-07, 23767-68, 23739, 23728-30; Vol. 2, pp. 278-281	02 Mar. 88 and 06 May 87	13

14.	Evidence of P. Walker, Transcript, Vol. 59, pp. 13660-62	12 Nov. 87	14
15.	Evidence of P. Walker, Transcript, Vol. 59, pp. 13702-707; Vol. 60, pp. 13996-14003	12 Nov. 87 and 16 Nov. 87	15
16.	Exhibit H-11, pp. 1-4, 8-23 and 150-163	Apr. 84	16
17.	Evidence of Max Bacon, Transcript, Vol. 102, pp. 24523-24	08 Mar. 88	17
18.	Exhibit H-13, pp (i) to 1-3	June 85	18
19.	Evidence of P. Walker, Transcript, Vol. 61, pp. 14166-14203	17 Mar. 87	19
20.	Exhibit H-14, Comparative Analysis Report, pp. Ex. 5-6	Jan. 87	20
21.	Exhibit B-348, Resolution of Regional Council	04 Mar. 87	21
22.	Transcript, Vol. 1, p. 177	05 May 87	22
23.	Transcript, Vol. 177, pp. 43858-59	11 Oct. 88	23
24.	Evidence of P. Walker, Transcript, Vol. 60, pp. 14202-203 Vol. 63, p. 14814	16 Nov. 87 and 24 Nov. 87	24
25.	Submissions of Counsel for the Region, Transcript, Vol. 177, pp. 44006-07	11 Oct. 88	25
26.	Exhibit List	29 Sept. 88	26
27.	Transcript, Vol. 18, p. 4055 and Vol. 42, p. 9419; Vol. 47, pp. 10606-08	8 June 87; 14 Oct. 87; 23 Oct. 87	27
28.	Transcript, Vol. 79, pp. 18622 and 18650-51 Vol. 166, pp. 41316-319	25 Jan. 88 and 22 Aug. 88	28

29.	Transcript, Vol. 105, p. 25202	14 Mar. 88	29
30.	Transcript, Vol. 160, p. 38845	08 Aug. 88	30
31.	Transcript, Vol. 167, pp. 41662-65	23 Aug. 88	31
32.	Exhibit E-928, Witness Statement of Dr. G. Hughes, p. 2	June 88	32
33.	Evidence of S. Feenstra, Transcript, Vol. 170, pp. 42328-29	30 Aug. 88	33
34.	Evidence of A. Sobanski and J. Beechinor, Transcript, Vol. 37, pp. 8206-07; Vol. 32, p. 7005	05 Oct. 87; 23 Sept. 87	34
35.	Evidence of Drs. Charlesworth and Rowe, Exhibit M-437, pp. 1-2; Transcript, Vol. 85, p. 20338-39; Vol. 79, p. 18675; Vol. 80, p. 18865; Vol. 83, p. 19748; Vol. 86, pp. 20416-17	03 Feb. 88; 25 Jan. 88; 26 Jan. 88; 01 Feb. 88; 04 Feb. 88	35
36.	Evidence of Messrs. Petrie and Crutcher, Transcript, Vol. 121, pp. 29227-57; Exhibit B-617, p. 162	11 Apr. 88 and 08 Feb. 88	36
37.	Evidence of P. Bowen, Transcript, Vol. 160, p. 38904 and pp. 38961-63	08 Aug. 88	37
38.	Transcript, Vol. 177, pp. 44007-44008 and 44276	11 Oct. 88	38
39.	Final Written Submissions of the MOE, pp. 6, 7 and 12 to 14	14 Oct. 88	39
40.	Transcript, Vol. 180, pp. 44616-44620	18 Oct. 88	40
41.	Evidence of J. Petrie, Transcript, Vol. 135, p. 32601	05 May 88	41
42.	Exhibit B-617, pp. 159-160 and 162	08 Feb. 88	42

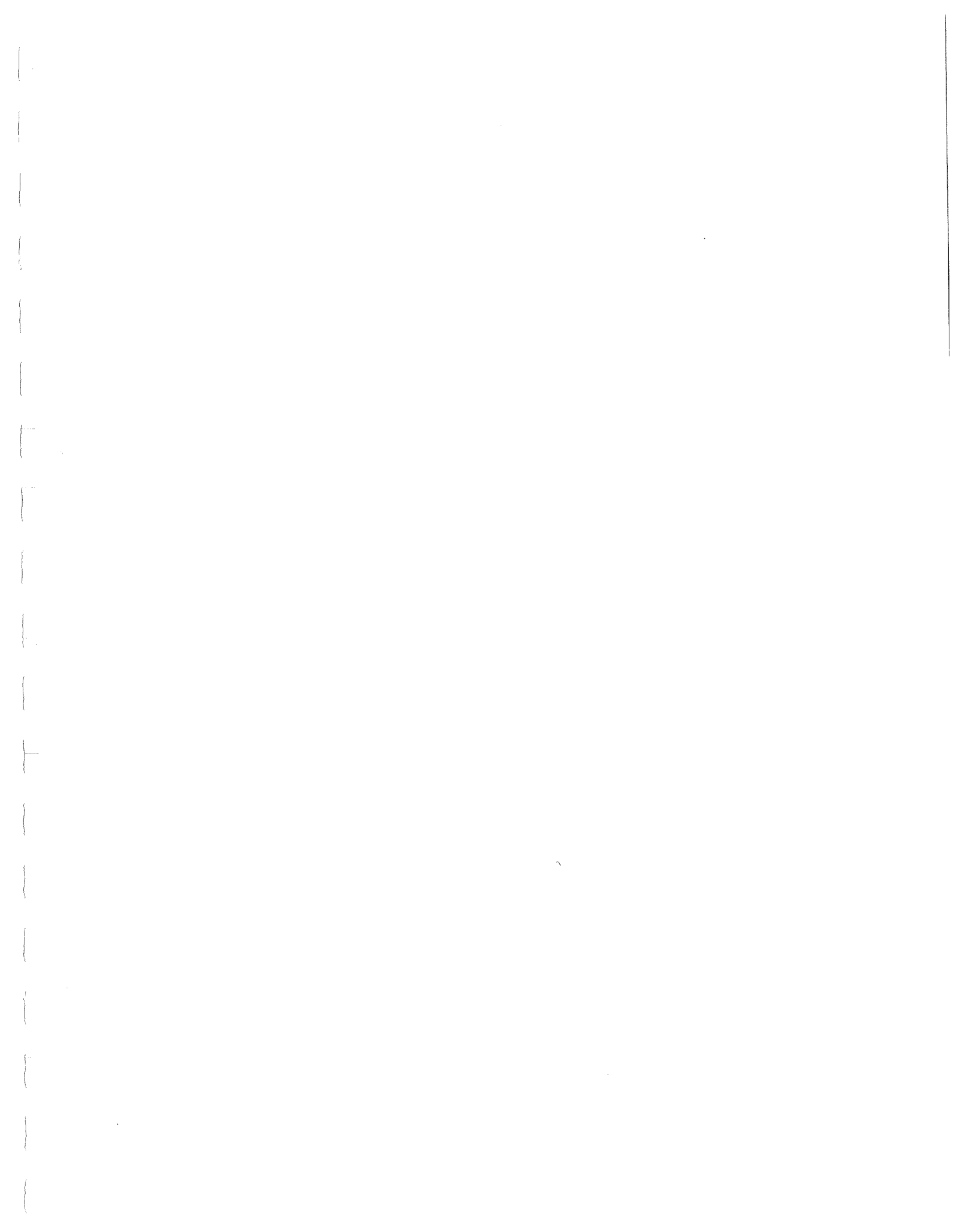
43.	Evidence of A. Crutcher, Transcript, Vol. 142, pp. 34397 to 34401	19 May 88	43
44.	Evidence of B. Gray, Transcript, Vol. 173, pp. 43116-20	13 Sept. 88	44
45.	Exhibit H-40, pp. (ii), (iii) and 137	28 Aug. 86	45
46.	Evidence of S. Feenstra, Transcript, Vol. 46, pp. 10315-16; 10323-24; Vol. 169, p. 42206, Vol. 44, pp. 10024-25	21 Oct. 87; 29 Aug. 88; 19 Oct. 87	46
47.	Evidence of P. Bowen, Transcript, Vol. 160, p. 38904; 38963	08 Aug. 88	47
48.	Evidence of Messrs. Petrie and Crutcher, Transcript, Vol. 121, pp. 29227-29; 29249-50; 29257; 29263; Vol. 131, pp. 31645-49; Vol. 28, p. 30951-52 and 30955; Vol. 132, pp. 31954-59	11 Apr. 88; 27 Apr. 88; 15 Sept. 87; 02 May 88	48
49.	Evidence of Dr. D. Charlesworth, Transcript, Vol. 85, pp. 20337-38	03 Feb. 88	49
50.	Evidence of A. Sobanski, Transcript, Vol. 32, pp. 6939-40	23 Sept. 87	50
51.	Evidence of Dr. K. Rowe, Transcript, Vol. 80, pp. 18971-72; Vol. 81, 19168-69; Vol. 83, 19732-33; and Vol. 85, 20290-92	26 Jan. 88; 27 Jan. 88; 01 Feb. 88; 03 Feb. 88	51
52.	Exhibit N-747, pp. 3, 5 and 6	Oct. 80	52
53.	Exhibit N-185, p. 2	Nov. 81	53
54.	Exhibit N-186, pp. (iii-iv)	June 80	54
55.	Exhibit N-596	17 Sept. 82	55

56.	Exhibit N-470, p. 6	15 Nov. 82	56
57.	Exhibit N-471, p. 8	23 July 85	57
58.	Evidence of J. Petrie and A. Crutcher, Exhibit 617, p. 6		58
59.	Exhibit H-936, Reply Witness Statement of S. Feenstra, p. 4, paras. 7 and 8	23 Aug. 88	59
60.	Evidence of S. Feenstra, Transcript, Vol. 169, pp. 42079-89; 42070-71; 42093-96; Vol. 172, pp. 42840-42	29 Aug. 88 and 12 Sept. 88	60
61.	Evidence of J. Petrie, Transcript, Vol. 122, p. 29562	12 Apr. 88	61
62.	Evidence of S. Feenstra, Transcript, Vol. 172, pp. 42863 and 42869	12 Sept. 88	62
63.	Transcript, Vol. 178, pp. 44240-41 (the Region) Vol. 180, pp. 44523-25 (the MOE) Vol. 181, pp. 44882-86; 44889-892; and 44894-96 (the Town of Milton); Vol. 184, pp. 45667-674 (the Milton Coalition); and Vol. 187, pp. 46447-460 (NSP)	12 Oct. 88; 18 Oct. 88; 19 Oct. 88; 24 Oct. 88; 27 Oct. 88	63
64.	Exhibit M-962, Witness Statement of Dr. N. Eyles, p. 3	22 Sept. 88	64
65.	Transcript Vol. 176, pp. 43846-43850	30 Sept. 88	65
66.	Evidence of S. Feenstra, Transcript, Vol. 169, pp. 42121-22; Vol. 172, pp. 42884-85	29 Aug. 88 and 12 Sept. 88	66
67.	Evidence of S. Feenstra, Transcript, Vol. 172, p. 42879	12 Sept. 88	67

68. Evidence of S. Feenstra,
Transcript, Vol. 175,
pp. 42914-15; Vol. 172,
pp. 42919 and 42921

16 Sept. 88 and
12 Sept. 88

68





1 DR. KINGHAM: Thank you.

2 THE WITNESS: This then indicated to me
3 that there is a limited but a good quality water
4 resource in the Aldershot area.

5 MS VIGOD: Mr. Chairman, on a technical
6 point that WB-227 was subject to proof and perhaps at
7 this point you could remove that subject to proof
8 notation.

9 Q. In terms of possible impact of
10 leachate, could you comment on that?

11 A. I feel that there won't be a
12 significant impact, there will not be a significant
13 impact in the water quality in these existing wells as
14 a result of the landfill. That is mainly because they
15 are situated a fair distance down-gradient and that I
16 believe most of the discharge of leachate will occur
17 before the groundwater flow system reaches these wells.

18 Also, given the distance between the
19 site and those wells, there is an opportunity for
20 dilution of the leachate. So, I don't think there will
21 be a significant impact in terms of the water quality
22 resource in the Aldershot area as a result of Site F.

23 Q. If we could turn to a discussion
24 of Site D starting at page 10, first of all, if you
25 have some general comments about the site suitability



1 The main reason I say that is that it is quite a
2 distance from where the leachate would enter the system
3 to where the first well is located. I believe there
4 will be enough dilution or attenuation of the leachate,
5 in that distance that one would not see any impact or
6 one would not be able to measure a significant impact
7 in the drinking water wells in the Aldershot area. I
8 base it mostly on the distance and amount of dilution
9 or attenuation I would expect to occur over that
10 distance.

11 Q. I think I understand that now and
12 I think I recall you saying that in-chief now that you
13 mention it.

14 The 10 to 20 millimetres that you have
15 estimated would exfiltrate Site F, I wanted to come to
16 that because I was trying to figure out how you got to
17 it.

18 As I understood it, you placed some
19 reliance on the basin study done for the Oakville and
20 Sixteen Mile Creeks and the second factor was the
21 absence of a discernible leachate plume at the
22 Burlington landfill. Was there anything else besides
23 those two things?

24 A. That and at least a bulk value, I
25 think the 10 to 20 millimetres a year is reasonable,



1 at all to that on page 81 of the final report of your
2 Site F report.

3 MR. PETRIE: A. That is correct.

4 Q. I suggest again to you that was
5 removed because it is not accurate because, in fact,
6 Unit 3 does have good attributes for waste disposal;
7 isn't that the case?

8 A. I do not agree that Unit 3 exists
9 as defined. Taking that, where the rock is fractured,
10 it will have attributes for attenuation capacities.
11 The question in my mind is, where is the water or
12 leachate moving through the rock. Within the
13 fractures, the attenuation is less. The higher
14 velocities in the fractures, the attenuation capacity
15 is still less. The rock moving through the matrix, I
16 beg your pardon, the leachate moving through the matrix
17 and not the fractures, yes, it has attenuation
18 capacity.

19 Q. Please answer my question.

20 I suggested to you that the second
21 paragraph in Version 2 does not appear in your final
22 report because it is inaccurate because, in fact, Unit
23 3, has "relatively good attributes for waste disposal"
24 isn't that true?

25 A. It is not entirely inaccurate.



1 When you are dealing with fractured rock, you have a
2 two-phase attenuation capacity. Within the matrix you
3 have a much better attenuation capacity than within the
4 fractures.

5 So, the unfractured portions of the site
6 will have a greater capacity to attenuate than the
7 fractured portions. However, the leachate movement is
8 more likely to be confined to the fractures rather than
9 the matrix.

10 Q. To the extent that Unit 3 is less
11 fractured than other zones at Site F, can we agree,
12 first, that that unit would have good attributes for
13 waste disposal?

14 A. Again, one would have to be able
15 to define the unit, agree that the unit exists as
16 defined and I cannot do that. Unfractured rock, or I
17 beg your pardon, the less fractured rock at the site
18 will have better capacity for attenuation than the
19 fractured rock.

20 Q. To the extent that Unit 3, as
21 interpreted by Trow, has less fracturing than other
22 areas of the rock at Site F, I suggest to you, sir, is
23 it would be an area with good attributes for waste
24 disposal, isn't that so?

25 A. If the leachate migration was



1 restricted to the matrix.

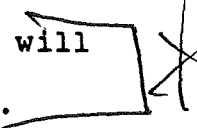
2 Q. Isn't the answer simply "yes"?

3 A. If it was restricted to the
4 matrix, the answer is yes.

5 Q. I suggest to you, sir, as well,
6 that Unit 3 as interpreted by Trow, in fact, has good
7 attenuation characteristics because its fracturing is
8 less than elsewhere; isn't that so?

9 A. That is if the leachate migration
10 is restricted to the matrix.

11 Q. Is the answer yes?

12 A. We are still in a disagreement as
13 to what it means. Unit 3 has portions which are
14 fractured and portions which are unfractured, as I
15 understand the definition of Unit 3. For leachate
16 migration within the fractures, attenuation will be
17 less. It is my opinion much of the leachate will
18 migrate via fractures rather than the matrix. 

19 For the leachate that gets into the
20 matrix, there are good attenuating capacities in the
21 shale.

22 Q. Would you agree with me, sir, that
23 nowhere at page 81 in the final version of your report,
24 do you indicate to the readers of the report that Unit
25 3 has as good attenuation characteristics in part or in



1 whole, you don't deal with it?

2 A. That is correct.

3 Q. So, what you had, in effect, at
4 page 81, I suggest is a much more subtle allusion to
5 the fact that vertical migration of leachate and hence
6 contaminants would be impeded but no reference at all
7 and no conclusion expressed regarding the attenuation
8 abilities of Unit 3.

9 A. I don't see anything subtle about
10 the statement that it is expected that the moderately
11 fractured shale will limit the migration of the
12 leachate to some extent. That is not a subtle
13 statement.

14 Q. Nowhere on page 81 do you indicate
15 to the reader of this report that in fact there are
16 good attenuation characteristics to be expected in the
17 shale in the context of this discussion. It is just
18 not there.

19 A. There is no statement on page 81
20 alluding to the attenuation capacities of fractured
21 rock or unfractured rock in Unit 3, or any other unit
22 on page 81.

23 Q. To respond to the question I asked
24 you, there is nothing on this page of your report or on
25 the preceding pages to suggest to the reader that in



1 the context of Unit 3 there are good attenuation
2 characteristics in the shale. It is not there.

3 A. There is no statement alluding to
4 the attenuation capacity of fractured Unit 3 or
5 unfractured Unit 3.

6 Q. Nor is there any indication to the
7 reader that Unit 3 would have good characteristics for
8 waste disposal. We don't see that there?

9 A. We don't see that there.

10 Q. I would like to turn, Mr. Petrie,
11 please, to the critique that you did of Trow's
12 modelling very briefly, and the modelling that your own
13 firm did.

14 I ask you to go to page 118. Do you
15 have that, sir?

16 A. Yes, I do.

17 Q. Direct your attention, as others
18 have, to the last paragraph on page 118. Just dealing
19 with the first part of the last paragraph, you indicate
20 your firm, CRA:

21 "... has reservations regarding the
22 applicability of using a porous medium
23 model to assess the hydraulics of
24 fractured rock."

25 That reservation, or expression of



1 configuration proposed by National Sewer Pipe at the
2 time?

3 A. I believe I do, yes.

4 Q. To the extent that Drs. Cherry
5 and Lush were suggesting there would be natural
6 systems on the property which would control any
7 increase in impact, those lands that would have
8 afforded that natural system are controlled now form
9 part of Site F, do they not?

10 A. I believe -- yes, but I also
11 believe that they will be removed, if that is the
12 word, by the proposed area of fill. I believe the
13 natural systems do not lie right adjacent to 403 but
14 some distance from the southern property boundary.

15 Q. Are you then, when you use the
16 term "natural systems" referring to the bulrush
17 marshes?

18 A. Yes.

19 Q. Do you acknowledge, Mr. Petrie,
20 that in fact the shale itself as it existed
21 throughout the site, has natural attenuation
22 properties inherent in the shale?

23 A. The shale will have some
24 attenuation properties.

25 Q. That includes the area north of.



1 Highway 403, south of Site F?

2 A. Yes.

3 Q. I am suggesting to you there are
4 natural systems be it the inherent characteristics of
5 the shale, the bulrushes or a combination that
6 currently exists on Site F.

7 A. Yes, but again, if I could just
8 elaborate. The difference, as I see it, reading
9 Dr. Cherry's and Dr. Lush's remarks here, was that
10 the buffer zone was quite extensive. I do not have
11 the extent.

12 I enumerated such that there was a
13 large room, so to speak, for attenuation within the
14 shales.

15 Q. Are you telling me then,
16 Mr. Petrie, you disagree with the conclusions
17 expressed as well in the last sentence?

18 A. Their conclusions were
19 referenced to the proposal at that time. I am not
20 disagreeing with their conclusions with reference to
21 that proposal.

22 Q. Are you saying then that if you
23 considered just the NSP proposal for landfilling in
24 the configuration as you understand it that you would
25 agree with Dr. Cherry and Dr. Lush that the increase



1 described and the bulrush marshes there as well,
2 notwithstanding those two factors.

3 A. That is part of it.

4 Q. I suggest as well that
5 immediately south of Highway 403 today there is a
6 large vacant parcel of land also owned by National
7 Sewer Pipe; isn't that the case?

8 A. I understand that to be the
9 case. I do not know if for a fact.

10 Q. You have not investigated the
11 land south of Highway 403 and existing Site F?

12 A. I have not investigated the
13 ownership of the land south of 403.

14 Q. Are you aware of -- in general
15 terms -- the topographic and hydrogeological features
16 of the land south of 403?

17 A. Yes.

18 Q. Would you agree with me, sir,
19 that the shale existent on those lands would bear the
20 same natural attenuation characteristics as the shale
21 immediately on the other side of 403?

22 A. Yes, I do.

23 Q. You are also aware, are you not,
24 that from time to time, on occasion, marsh areas have
25 been observed visually in that area south of 403?



1 Aldershot?

2 MR. CRUTCHER: A. It depends upon what
3 quantity.

4 Q. In the quantities identified by
5 Morrison Beatty.

6 A. They are naturally occurring and
7 you can't do anything about it and they are very
8 sporadic and only noted at one location so I do not
9 think there is any risk.

10 Q. You don't think there is any risk?

11 A. No more than what we have in the
12 environment due to natural occurrences.

13 Q. Do you think that the fact that
14 the groundwater in the shale underneath Aldershot is of
15 very poor natural quality, does that represent a risk
16 to the health and safety of the people of Aldershot in
17 your view?

18 A. You wouldn't want to drink the
19 water.

20 Q. Does the fact it's in the shale
21 underneath Aldershot represent a risk to public health
22 and safety?

23 A. Not really.

24 Q. Does the fact that -- is there a
25 risk do you think to public health and safety,



1 Mr. Crutcher, of people being allowed by the City of
2 Burlington to use the Bayview Park for a park, is there
3 a risk to those people of having leachate underneath
4 the ground, underneath their feet?

5 A. What type of risk are you
6 referring to?

7 Q. Do you consider that your client
8 is putting people at risk in terms of their public
9 health and safety, Mr. Crutcher, by allowing them to
10 use Bayview as a public park?

11 A. No.

12 Q. Do you consider, Mr. Crutcher,
13 that there are operations or any of the operations
14 going on at the Burlington landfill site which are
15 causing any adverse health or safety affects for the
16 public in Aldershot?

17 A. In what sense?

18 Q. In any sense, any sense that you
19 could think of.

20 A. For public health and safety?

21 Q. Yes.

22 A. I would have to deal with the
23 groundwater and surface water and there has been some
24 additional contamination into the groundwater and
25 surface water, but whether that causes a direct risk or



1 might have a public health and safety impact?

2 A. The perceived risk is quite high.

3 Q. So while there is no actual public
4 health and safety risk directly, there is an indirect
5 possible health impact from their psychological or
6 social impacts, is that what you are saying?

7 A. That is most certainly a risk that
8 is there and I call it perceived risk, but yes, that is
9 there and it would be there with any site. The basis
10 of being able to monitor and predict and to give
11 assurances is to reduce that risk.

12 Q. If I was a resident in Aldershot,
13 Mr. Crutcher, and if I was standing over top of five
14 feet of till and there are some trace organic
15 contaminants in the shale underneath that, you can tell
16 me with a considerable degree of assurance that I am
17 not at risk, can't you?

18 A. Directly from those contaminants
19 on that basis then, yes, I would say you will not be
20 exposed directly to those contaminants.

21 Q. I am not at risk from those trace
22 contaminants in the shale, am I?

23 A. You as an individual?

24 Q. Yes.

25 A. No, I don't believe so.



1 said there was no direct.

2 Q. There is no direct public health
3 and safety implications?

4 A. Not that I am aware of.

5 Q. All right. Therefore the concerns
6 are psychological or social impacts?

7 A. That is a major part of it, yes.

8 Q. There is no other part of it, is
9 there, Mr. Crutcher?

10 A. Again there is a cumulative effect
11 and I don't know the effects of that -- the term
12 "public health and safety" is such a broad term you
13 can't really categorize it in that fashion.

14 Q. Can you tell me, Mr. Crutcher, of
15 any public health and safety -- any adverse
16 implications for public health and safety in Aldershot
17 of having a failure at Site F and having some trace
18 diluted and attenuated leachate in the shale under me?

19 A. Not directly, no.

20 Q. So we don't have public health and
21 safety implications flowing from hydrogeological
22 problems at Site F, do we?

23 A. Not directly.

24 Q. So what we have then is some
25 concerns in the minds of people in Aldershot and those



1 that sentence?

2 A. I'm not sure what the question
3 means.

4 Q. I asked you if you had ever told
5 the City of Burlington that that was your opinion and
6 you said yes and I asked you if that is what you meant
7 with your reference to page 141. Is that how you told
8 your client?

9 A. I don't recall exactly how I told
10 them but we had discussed this matter.

11 Q. Is there a report you have done to
12 the City of Burlington that outlines that it is your
13 opinion that there is no adverse public health and
14 safety implications for Aldershot from landfilling at
15 Site F?

16 A. Not in our report, per se, but we
17 have had a number of discussions.

18 Q. Would those have been discussions
19 with City Council or City staff?

20 A. With staff and with -- not City
21 Council, per se, but committee of Council.

22 Q. Do you know if City Council have
23 ever received the information that it was your opinion
24 that there was no adverse public health or safety
25 implications from landfilling at Site F?



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Toronto, Ontario

Vol. 132

31954

Crutcher, Petrie,
cr-ex (Cronk)

1 29263
2 ~~39963~~, line 4:

3 "Q. I asked you if you had ever told
4 the City of Burlington that that was
5 your opinion and you said yes and I
6 asked you if that is what you meant with
7 your reference to page 141. Is that how
8 you told your client?

9 A. I don't recall exactly how I told
10 them but we had discussed this matter.

11 Q. Is there a report you have done to
12 the City of Burlington that outlines that it is your
13 opinion that there is no adverse public health and
14 safety implications for Aldershot from landfilling at
15 Site F?

16 A. Not at our report, per se, but
17 we have had a number of discussions.

18 Q. Would those have been discussions
19 with City Council or City staff?

20 A. With staff and with -- not City
21 Council, per se, but committee of
22 Council."

23 A. Could you go back to a bit earlier,
24 because I want to check. I don't recall the wording
25 that way.

Q. May I finish the passage?



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31955

Crutcher, Petrie,
cr-ex (Cronk)

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"Q. Do you know if City Council have ever received the information that it was your opinion that there was no adverse public health or safety implications from landfilling at Site F?

A. I don't know. I know I dealt with the committee not the Council generally.

Q. Which committee was that?

A. The Environmental Management Committee.

Q. How many councillors sit on that committee, Mr. Crutcher?

A. I don't really know, maybe six to eight or something like that.

Q. Out of how many in the whole City?

A. I don't know.

Q. When was the first time you would have given that opinion to that committee?

A. Very early on in the process.

Q. What do you mean by that, in 1984?

A. That is essentially when we were commencing and, yes, we indicated to our client that the groundwater quality was poor and essentially this statement



1 would apply."

2 And the preceding discussions at all the pages tabbed
3 is where you indicated to Mr. Garrod that there would
4 be in your opinion no direct risk to public health and
5 safety in the event of landfilling at Site F and do you
6 recall that?

7 A. I recall that, but that is not what
8 my query was about, but the way you worded it, because
9 I did not recall me using those words.

10 Q. After you had communicated in 1984
11 that opinion to the City of Burlington, what
12 instructions did you receive from the City?

13 A. To evaluate the proposal as it came
14 forth and pass our comments.

15 Q. Insofar as you are aware, Mr.
16 Crutcher, did the City of Burlington officials
17 communicate your opinion in that regard to the
18 residents of Aldershot by way of any public report or
19 any communication made at any public meeting after you
20 had informed them of your opinion?

21 A. I can't really speak for the City.

22 Q. So far as you are aware?

23 A. I really didn't deal with that
24 matter, so I am not aware of it one way or the other.

25 Q. Do you know one way or the other



1 whether the City of Burlington or its officials
2 communicated that opinion to National Sewer Pipe after
3 you had given it?

4 A. Again, I did not deal with those
5 matters, so I really don't know.

6 Q. Did you sir, personally, at any of
7 the public meetings you attended or in any written
8 document delivered to the city and released to the
9 public, communicate that opinion in writing or orally
10 at a public meeting to the residents of Aldershot?

11 A. I attended one public meeting and I
12 believe -- I believe it was only one public meeting at
13 the end of 2C, I think to provide comments on the 2C
14 documentation.

15 Q. Yes?

16 A. I don't recall if I passed that
17 opinion at that time or not.

18 Q. Did you ever do so in writing, sir?

19 A. There is a document we entered
20 earlier on, I think, which passes that opinion on, that
21 the water quality is poor.

22 Q. I am speaking of the opinion that
23 there would be no direct risk to public health and
24 safety on the residents of Aldershot in the event of
25 landfilling at Site F?



1 A. We have never been able to be
2 definitive about that, so I doubt if we have, in that
3 blunt a terminology.

4 Q. I suggest there is no written
5 document authored by CRA or by yourself in which that
6 opinion is expressed. Does that accord with your
7 recollection of all the documents your firm has
8 produced in this matter?

9 A. Our recent report, the section you
10 referred to this morning documents that.

11 Q. I am sorry, I am suggesting, and
12 let's be clear, that in none of the reports authored by
13 CRA throughout your entire involvement in this case,
14 has it ever been said by your firm in writing that
15 there was no direct risk to public health and safety
16 from landfilling at Site F. Isn't that right?

17 A. May I just refer to that section?

18 Q. Yes, by all means.

19 A. Dealing with suitability for
20 landfilling on page 141, and in fact I think I went
21 through this with Mr. Garrod, and on the last
22 paragraph, the one you read out this morning:

23 "From a strictly technical perspective,
24 an argument can be made that the
25 contaminant release from Site F to the



1 natural environment would not cause any
2 adverse impact as it would be
3 diluted/dispersed/attenuated/masked
4 within the naturally poor quality
5 groundwater."

6 Q. Did you intend that statement, Mr.
7 Crutcher, to communicate to the reader CRA's opinion
8 that there was no direct risk to public health and
9 safety by landfilling at Site F?

10 A. Not that you could determine, yes.

11 Q. That was the intent of the
12 statement?

13 A. Essentially, yes.

14 Q. Can we go this far; that is not
15 necessarily entirely clear from the words which appear
16 at page 141?

17 A. It was to me.

18 Q. You certainly don't use the
19 language public health and safety anywhere in that
20 paragraph, do you?

21 A. I don't.

22 Q. Prior to the preparation of this
23 report which was produced at this hearing, Mr.
24 Crutcher, am I correct that in no document prepared by
25 CRA at any point in your involvement in this case, was

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1 expressed to this Board that from a public health and
2 safety point of view, Site F was to be preferred over
3 Site D. From that perspective and with that focus, do
4 you agree or disagree with that opinion?

5 A. Yes, from a hydrogeological aspect
6 I would agree. Well, sorry, could you say that again?

7 Q. Overall, Trow expressed the
8 opinion that from a public health and safety viewpoint,
9 Site F was preferable to Site D for regional
10 landfilling. Do you agree with that or disagree?

11 A. I think the case, the case at D,
12 as I have said, is not proven, as there are no ground
13 water users at Site F that would be likely to be
14 impacted, yes I would agree.

15 Q. I am going to suggest some other
16 potential areas of agreement between you as well, Dr.
17 Charlesworth, and if I am incorrect, please tell me.

18 Mr. Feenstra indicated in his evidence
19 before the Board that based on the contaminant
20 migration work which he had performed, Site F possessed
21 natural attenuation characteristics which he regarded
22 as being superior to those at Site D. Do you share
23 that view?

24 A. Based on what I understand from
25 Mr. Feenstra's testimony and Dr. Rowe's work, yes, I



would agree.

Q. Mr. Feenstra also expressed the opinion to the Board that in the case of Site F, we need not be concerned about adverse impacts from any possible contamination south of the site. Given the nature of your evidence, I take clearly that that is also your opinion?

A. I am sorry, could you repeat that, please?

Q. Mr. Feenstra indicated that it was his opinion that in the case of Site F, the Board need not be concerned about the possibility of adverse impact from contaminants south of the landfill site?

A. Yes, from everything that I have seen, I think, it is my opinion that the Board need not be concerned.

Q. Mr. Sobanski in his evidence, indicated and expressed the view that Site F was an unusual site in Ontario in many ways and agreed that in his view the advantages it affords should be utilized. Do you regard Site F as unusual in hydrogeological terms?

A. Yes. Yes, I would agree with that.

Q. In what respect?



1 depth and ultimately it will come up in Lake Ontario?

2 A. That is right, yes. Yes, that is
3 a possibility. I shouldn't say it's a possibility, but
4 as a scenario it's a scenario other than the one we have
5 put forward, the case we put forward.

6 Q. Under the assumptions I have put
7 to you that is one of two results, isn't it?

8 A. Yes, it is.

9 Q. Under that scenario, I suggest to
10 you, that it will take a very great number of years for
11 it to reach Lake Ontario. Isn't that so?

12 A. Based on what we are seeing at
13 Bayview and Burlington, yes, I would agree with that.

14 Q. We are talking dozens of years?

15 A. At least.

16 Q. At least?

17 A. Yes.

18 Q. ~~How long do you think in fact it~~
19 would take, would it be hundreds of years?

20 A. Well, we have got 700 metres and
21 maybe it has moved that far in nearly 40 years, so
22 probably well over 100 years anyway.

23 Q. ~~Throughout that entire period of~~
24 time it will be attenuated by the soils through which
25 it is moving. Isn't that so?



1 A. I expect it would be even though
2 that wasn't assumed in the model but, yes, indeed, I
3 believe the shale will attenuate this leachate.

4 Q. Perhaps you can see where I am
5 going. I am really suggesting that under that scenario,
6 by the time it reaches the lake there will be no con-
7 taminants that are distinguishable from background
8 water quality given the length of time it will have to
9 take before it gets there and the attenuation mechanisms
10 that will be at work en route, and isn't that in fact
11 the result of that scenario?

12 A. I would expect that to be the case
13 and it certainly would appear to be borne out by the
14 results of monitoring at the two existing sites.

15 Q. Just on that scenario and the
16 length of time that in fact it might take, you said it
17 would certainly be over 100 years, I would like to show
18 you what I promise will be my last extract from
19 Dr. Cherry's book on "Groundwater." I don't profess
20 to speak for any others, but this is my last.

21 MR. ESTRIN: Why not photocopy the whole
22 book?

23 MS CRONK: You can photocopy the whole
24 book. I would prefer to do it by extracts.

25 Q. This is an extract from page 158

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2 of 25 years and if we are dealing with very large
3 distances, as you will see in my subsequent evidence,
4 we are dealing with times of hundreds to thousands of
5 years for the contaminant to move past the 403 and the
6 CNR tracks.

7 My fifth conclusion is that matrix
8 diffusion results in a substantial attenuation of
9 contaminants. I believe that it is an important
10 mechanism at Site F. I am certain it is not the only
11 mechanism, for example, with reactive contaminants.
12 There are other mechanisms giving attenuation but this
13 is an important mechanism.

14 Q. Now, Dr. Rowe, in your witness
15 statement, your joint witness statement, Exhibit M-444
16 at paragraph 5, you have also set out general
17 conclusions arising from your October, 1987 report
18 concerning Site F. You have told us that your report,
19 your 1987 October report deals with scenario A.

20 A. That is correct.

21 Q. If we could look at paragraph 5 of
22 your witness statement on page 2, perhaps the first
23 several of these are an elaboration of the points on
24 the overhead but I think I would like you to go over
25 them because I believe they expand to some extent and
then f and g perhaps go further than your overhead.



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A. That is correct.

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Q. So we are at paragraph 5 of the
witness statement. I would like you to read those and
then tell us if there is anything further at this
point.

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A. My first point, point a:

"Assuming there was no matrix diffusion
or dispersion, then contaminants moving
along the fractures might be expected to
move at the same velocity as the
groundwater; however, this is not a
realistic assumption for the shale at
Site F."

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The shale at Site F, Mr. Chairman, has a fairly high
matrix porosity and for realistic diffusion
coefficients there should be and there will be
substantial attenuation. It is not realistic to assume
that contaminant will travel at the speed of
groundwater.

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Point b:

"If matrix diffusion is considered at
Site F, the speed of contaminant
movement is much slower than the average
linearized groundwater velocity."

As we will see, matrix diffusion substantially reduces



1 "The simulations performed at Site F
2 suggest that given the
3 hydrostratigraphic conceptualization of
4 the flow system, the potential for
5 absorbtion of these volatile organic
6 chemicals under relatively long flowpath
7 length to the discharge zone, there will
8 be a fairly significant degree of
9 attenuation irrespective of matrix
10 diffusion."

11 And it goes on to say:

12 "Now, what the observations at the
13 Bayview and Burlington sites suggest to
14 us is that due to the effect of matrix
15 diffusion, our simulations as we
16 performed at Site F in 1986 are probably
17 excessively conservative...."

18 What is your opinion with respect to
19 that?

20 A. I agree with what he is saying in
21 essence. As I understand it, he is indicating that
22 organic chemicals can be attenuated due to processes
23 such as sorption and that will cause attenuation as it
24 moves downgradient. In addition to that he is
25 indicating the potential importance of matrix diffusion



1 and I have spent several hours addressing why it is
2 important.

3 Q. What then is your general
4 conclusion with regard to Site F?

5 A. Well, Mr. Chairman, based on the
6 information which I have reviewed and the results of
7 the analyses which I have performed with respect to the
8 potential for contaminant migration at this site, it is
9 my professional opinion that Site F is suitable for the
10 development of a municipal landfill such as proposed by
11 the Region.

12 Q. Thank you very much, Dr. Rowe.

13 DR. KINGHAM: Just before you sit down,
14 sir, at the risk of analogies and over-
15 simplifications, I know there are serious risks in
16 that, it would seem that what you have been telling us
17 for the last couple of days is that if this Board was
18 to consider the soils beneath Site F to be like a
19 saturated sponge, through which water and contaminants
20 might diffuse, then what Trow Hydrology Consultant Ltd.
21 were telling us was that as water was poured on that
22 spongy surface, a certain percentage will flow off the
23 top and be collected and some percentage will flow
24 through that sponge and be released elsewhere.

25 It would seem that what you have been



1 collection systems at Site F, I am referring to the
2 purple system which is the deeper system and to the
3 general leachate collection tiles which I referred to
4 as mauve.

5 Dilution due to contaminant, I
6 indicated my evidence with respect to Trow's better-fit
7 model, H-221, that their Flonet model indicated that
8 there was approximately one cubic metre per annum
9 coming in beneath Site F and another cubic metre coming
10 in from north of the site. So, based on that number
11 one has approximately a 50 per cent dilution factor at
12 Site F. It is a very simplistic calculation but
13 nevertheless it indicates that there is dilution, apart
14 from anything else, to give you attenuation. At Site D
15 there doesn't appear to be any significant potential
16 for dilution of the contaminant due to flow in the
17 upper granular unit coming from all sides.

18 Potential for attenuation due to matrix
19 diffusion. Now, in both sites, Mr. Chairman, I have
20 focused my attention on what I consider to be the
21 primary mechanism for contaminant transport off-site.
22 At Site F it is movement down into the shale and then
23 laterally off-site beneath Highway 403. I have
24 discussed in some detail the concept, the matrix
25 diffusion as it flows through the fractures, it can



1 diffuse into the matrix of the shale. At Site D I am
2 referring here again to the primary transport path
3 which is down through the upper till, possibly along
4 the thin bed of silt, and as I indicated, the concept
5 of matrix diffusion I think applies to that thin bed of
6 silt and that is why in my calculations I didn't get a
7 big impact. If you go further on down through the
8 upper till to the upper granular unit then there is no
9 significant potential for matrix diffusion as it flows
10 along the upper granular unit. I think at least
11 passing reference was made to that in earlier
12 testimony.

13 The potential attenuation zone, that is
14 how far has contaminant got to travel and attenuate
15 before you need to be too worried about it. Based on
16 Trow's calculations in Exhibit H-86, for example, they
17 did calculations for 650-metres travel distance and a
18 1,400-metre travel distance; whereas, in Site D, we are
19 concerned about the impact 100 metres down, 100 metres
20 from the landfill. That is at the site boundary. This
21 is an attempt to compare the two sites based on Trow's
22 own picture of what the sites are like. My conclusion
23 based on that information alone would be that Site F
24 appears to be a much better site than Site D.

25 Q. Now, I believe that in your



1 characteristics of the site, would you regard as being
2 the likely consequences of that in terms of impact on
3 ground water?

4 DR. ROWE: A. Mr. Chairman, based on
5 the results that I have obtained and which are
6 presented in my report, I have concluded that the
7 impact on the ground water quality south of the 403
8 would be minimal. If that ground water was coming up
9 through a till material, for example, there would be
10 further attenuation which would reduce already minimal
11 concentrations to even less minimal.

12 Q. I want to be sure that I
13 understand that, Dr. Rowe.

14 A. The impact would be negligible.

15 Q. Are you saying as well that
16 because of the distance that the contaminants would
17 have to travel, that they would be significantly
18 attenuated, based on the work that you have done?

19 A. Based on the work that I have done
20 and the results I reported in evidence, the
21 contaminants are significantly attenuated by the time
22 they have moved, the range of distances I looked at was
23 300 metres to 800 metres. So that is well south of the
24 403, well south of the 403. Based on those results,
25 the impact was minimal and I am adding that what I



1 didn't consider was coming up through till. If I did
2 consider that, that would further attenuate the
3 results.

4 Q. Where is your 300 metre distance,
5 Dr. Rowe?

6 A. I am referring, at the moment, to
7 Exhibit M-437-D1, and 300 metres south of the site, for
8 purposes of my consideration, I was treating the centre
9 of the site as being a representative position. So if
10 you went 300 metres south of there, you would be just
11 on the southern highway of Highway 403.

12 Q. That is measured from the centre
13 of the southern portion of the site?

14 A. That is correct.

15 Q. Where is your 800 metre
16 measurement, a line that you referred to in your model?

17 A. Approximately from the same
18 reference point, it is on the CN tracks.

19 DR. KINGHAM: When you say the centre of
20 the southern portion, do you mean the centre of the
21 southern boundary?

22 DR. ROWE: Essentially I am taking a
23 point, Dr. Kingham, a point in around here.

24 MS. CRONK: Q. Where is here?

25 DR. ROWE: A. Roughly in the centre of



1 400 metre wide zone I was modelling. Approximately
2 200 metres in from the western edge of the site.

3 If I wanted to take it from the
4 southern-most point of course, that moves the distances
5 down in the case of the most southern point to about
6 100 metres south of the 403 and about 50 metres south
7 of the CN tracks. That is the most southerly of the
8 points.

9 Q. Then if we were to look at the
10 figures which you have provided the Board by way of
11 overhead in terms of the contaminant concentrations at
12 800 metres south from the line you have indicated at
13 the site, that would put us in the vicinity of the CN
14 tracks?

15 A. That is correct, yes.

16 Q. The exchange that I just put to
17 Dr. Charlesworth that took place between Ms Vigod and
18 Mr. Feenstra involved the suggestion of a discharge
19 zone south of the CN tracks between the CN tracks and
20 the lake. That would be further south yet from your
21 800 metre line?

22 A. You would get additional
23 attenuation beyond what I considered in the model.

24 Q. Now, with respect to the
25 suggestion made by Trow, Dr. Rowe, that there is a

ORIGINAL

EX N 747

**HYDROLOGICAL SUITABILITY OF
THE NSPL LANDFILL SITE,
BURLINGTON, ONTARIO**

**Prepared For: The Regional Municipality
of Halton, Oakville, Ontario**

**By: John A. Cherry, Ph.D., P.Eng.
Consulting Hydrogeologist
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October 1980

INTRODUCTION

The purpose of this report is to assess, from a hydrogeological and hydrological viewpoint, the suitability of the proposed National Sewer Pipe Limited (NSPL) site, Burlington, Ontario, for use as a sanitary landfill. The specific site-related information that served as a basis for this assessment was obtained from the following hydrogeological reports:

Morrison Beatty Associates Limited, Hydrogeologic Impact Study, Site A Landfills, Burlington, January, 1979 (referred to herein as Phase I report).

Morrison Beatty Associates Limited, Phase II, Hydrogeologic Investigation, National Sewer Pipe Limited, Landfill Site, Burlington, June 1980.

Proctor and Redfern Limited, Functional Report, Commercial Landfill Site, For National Sewer Pipe Limited, August 1979.

Gartner Lee Associates Limited, Hydrogeological Study, Final Report, Proposed Burlington Landfill Expansion. For M.M. Dillon Limited, September 1979.

The first two reports listed above (by Morrison Beatty Associates) describe the results of two phases of a hydrogeological study of the Bayview landfill. The Bayview landfill, which is inactive, is situated immediately northwest of the proposed NSPL site. The fourth report listed above (by Gartner Lee Associates) describes the results of a hydrogeologic investigation of the area that includes the site at which landfilling is currently ongoing (the Burlington landfill) and

the area immediately northwest of the active landfill where an expansion is to occur in the next few years. The proposed NSPL site is situated immediately northeast of the active landfill and the expansion area. The proposed NSPL site is directly between the abandoned Bayview landfill and active Burlington landfill. [Because of the closeness of these two existing landfills to the proposed site, assessment of the hydrogeological aspects of the proposed site will be made using hydrogeological information obtained almost exclusively from the two existing landfill areas and from the adjacent areas down the escarpment from the Bayview landfill.] The Morrison Beatty Phase I and II reports include only a limited amount of data from the actual area of the proposed site. However, the more detailed information on the Burlington and Bayview landfills and the areas downslope of these landfills has been sufficient for us to draw conclusions on the NSPL site.

ORGANIZATION OF THE REPORT

The purpose of the appraisal of the existing hydrogeological information relevant to the NSPL site was to arrive at a conclusion with regard to the hydrogeological suitability of the site for a landfill. The conclusion is presented in the following section of this report. The details of the nature of our appraisal and our involvement as technical advisors representing The Region of Halton in the design of the Phase II investigation by Morrison Beatty Associates Limited are described in Appendix A.

Although we arrived at a conclusion with regard to the general suitability of the site for a landfill, we have not prepared recommendations with regard to choice of design options for a landfill. The choice of a particular option should be made after various hydrogeologic, engineering and economic factors and provincial guidelines and policies are evaluated in more detail than has been the case to date. To provide some assistance in this endeavor, various types of information are presented in the appendices to this report. Appendix B describes the hydrogeological features of the NSPL site in the context of groundwater resources. Appendix C briefly describes the hydrogeological and hydrological nature of the landfill-related guidelines and policies that have been issued by the Ontario Ministry of the Environment during the past decade. The current guidelines and policies of the Ministry of the Environment are not specific with regard to the hydrogeological aspects of the problem and therefore recommendation made by consultants on landfill suitability and design are unavoidably problematic.

Appendix D describes the potential for contaminant migration and attenuation at the site. It indicates that the data presented in the Morrison Beatty Phase II

report can be used to obtain conclusions that are different from some of the conclusions stated by Morrison Beatty Associates Limited. In Appendix E, comments of clarification are presented that relate to the practical design concept for the NSPL landfill described by Proctor and Redfern Limited for NSPL.

In Appendix F, the general ecological status and the water quality conditions in the main stream that drains the area of the Bayview landfill and the area of the NSPL site prepared by Dr. Donald Lush of Beak Consultants Limited is presented. This stream, referred to as the Rambo-Hager Diversion, receives leachate-derived contaminants from the Bayview landfill and it is expected that if a landfill is constructed on the NSPL site, it will receive an additional contaminant input.

An unavoidable consequence of a new landfill on the NSPL property will be an eventual increase of the input of landfill-derived contaminants into Hamilton Bay, either by way of a sewage treatment plant or by way of streamflow. A brief review of the manner in which these types of contaminants would enter Hamilton Bay is presented ~~in Appendix G.~~

CONCLUSION OF SITE SUITABILITY

In our opinion, the site proposed by National Sewer Pipe Limited is suitable for a sanitary landfill for municipal refuse. This conclusion is based primarily on the following features of the site:

1. Groundwater in the shale beneath the landfill site and in the area between the landfill and Hamilton Bay has a poor natural quality and is generally not suitable in its present state for human consumption. No water supply wells are known to exist in this area. Even if a means of economically desalting water of the type that occurs in the shale is developed in future decades, it is unlikely that the shale would be viewed as a significant reservoir of groundwater resources because the permeability is not high enough for large-scale pumping.
2. The landfill will occupy only part of the land area owned by NSPL; a large area of NSPL property exists downslope from the area in which landfilling is to occur and this area would receive the most direct seepage of leachate-affected water from the landfill.
3. The general vicinity of the proposed NSPL site has received refuse for many years. The area of the proposed site, which is situated between two landfills, is not expected to cause any unique impacts on the groundwater system or the associated surface water system. The impact, at worst, would be an increase in the scale of the existing types of impacts. This increase could, to a large degree, be controllable by natural and engineered systems to whatever degree is desired.

It should be noted that the conclusion we have drawn does not mean we believe that the specific landfill design plan proposed by National Sewer Pipe Limited is the most suitable for the site. There are various possible options for leachate-management at a landfill on the NSPL site. These options are discussed in general terms in the next section of this report. Specific comments on the leachate-management scheme proposed by Proctor and Radfern in the Functional Report are presented in Appendix E.

APPENDIX A

SCOPE AND INVOLVEMENT

Our involvement in a hydrogeological assessment of the suitability of the NSPL site was initiated by telephone conversation between Mr. Dennis Y. Perlin, Regional Solicitor, and Dr. John Cherry, followed by a letter from Mr. Perlin, dated August 31, 1979, to Dr. Cherry. The letter indicated that Regional Council would be approached to seek authorization to retain Dr. Cherry as an independent hydrologist to review the hydrogeological investigations and reports of the hydrogeological consultants to National Sewer Pipe Limited (i.e., Morrison Beatty Associates Limited) and then to advise the Region as to whether the particular site is "hydrogeologically safe and sound or can on a reasonable basis be made hydrogeologically safe and sound". At this time, the National Sewer Pipe Limited Functional Report, which included a Phase I Hydrogeologic Study by Morrison Beatty Associates Limited, was provided to Dr. Cherry.

On October 23, 1979, in the company of Mr. Brian Beatty of Morrison Beatty Associates Limited, Dr. Cherry walked over the Bayview landfill and the proposed NSPL site. At this time, the general plans for a Phase II hydrogeological study of the Bayview landfill to be conducted by Morrison Beatty Associates Limited were discussed. Morrison Beatty conducted most of the field aspects of the Phase II study in December, 1979, and January, 1980. Dr. Cherry provided specific advice on methods and procedures for collection and treatment for the sampling of groundwater from the network of piezometers installed at the Bayview site during the Phase II field program.

On March 24, 1980, Dr. Cherry attended a meeting at the Ministry of the Environment in Toronto. At this meeting, Mr. Beatty presented the results of a preliminary interpretation of the data collected during the Phase II field investigation. Technical questions were asked by Ministry personnel and comments were provided with regard to aspects of the study that would warrant more detailed consideration in the final interpretative phase of report preparation.

Dr. Cherry received a Draft Report on the Phase II investigation in late June, 1980. A copy of the final Phase II report was received in early July. On July 31, 1980 Dr. Cherry received a letter from Mr. Beatty that provided some information on the flow conditions in the small streams that drain the escarpment in the vicinity of the Bayview landfill and comments on the peripheral leachate collector drains that were recently installed at the active landfill next to the NSPL site.

In early September 1980, Dr. Cherry requested that Dr. Don L. Lush of Beak Consultants Limited provide assistance in site assessment. On September 9, Drs. Cherry and Lush walked around the existing landfill, across the proposed NSPL site, and inspected springs and stream channels in the vicinity of the Bayview landfill and the main stream channel at several locations in the City of Burlington. Further discussions between Drs. Cherry and Lush (in the company of Mr. Dennis Perlin) in matters related to the ecology and water quality of streamflow downslope from the Bayview landfill were conducted on September 21. This report was prepared in September and October, 1980 by Drs. Cherry and Lush.

In this report, we summarize the hydrogeological and surface water features of the escarpment area in which the Bayview and the existing Burlington landfill and the proposed NSPL site exist, with emphasis on those features that pertain

most significantly to the question of suitability of the NSPL site. For detailed information in the form of tables and diagrams, the reader is referred to the reports by Morrison Beatty Associates Limited and the report by Gartner Lee Associates. Critical evaluation of the specific hydrogeologic data and conclusions in these reports are presented here only in the case of some of the points that bear directly on the conclusions and recommendations, presented herein. In other words, this report does not contain an item by item assessment of previous hydrogeologic and surface water investigations of the two landfills adjoining the NSPL site.

APPENDIX C

COMMENTS ON GUIDELINES AND POLICIES

The decision with regard to whether or not a site is hydrogeologically suitable is, to a significant degree, a matter of personal judgement. Personal judgement is an important factor largely because the Ontario Ministry of the Environment has almost no regulations, policies, or guidelines that are specific in a hydrogeological context. This situation is at present the most problematic aspect that one encounters when attempting to evaluate a proposed landfill site. Because of the nature of this situation and its importance, this appendix provides some comments on the existing regulations, policies, and guidelines as we perceive them at the present time.

In the area of surface water management the policy regulation guidelines are more specific and the general intent in most instances is quite clear. Personal judgement, however, also enters into this area in that provision is made for exceptions where conditions are warranted.

In August 1973, Regulation 824 (Regulation Made Under The Waste Management Act) was issued by the Ontario government. This document has a few sentences of hydrogeological significance. For example:

Page 5:

"Wastes shall be placed sufficiently above or isolated from the maximum water table at the site in such a manner that impairment of groundwater in aquifers is prevented..."



Ex. N-185

PHASE III
HYDROGEOLOGIC INVESTIGATION
NATIONAL SEWER PIPE LTD.
LANDFILL SITE
BURLINGTON

MORRISON BEATTY LIMITED
290 The West Mall
Etobicoke, Ontario
(416) 622-9374

NOVEMBER, 1981
PROJECT NO. 130-792

BRIAN. W. BEATTY, P.Eng.

1.0 SUMMARY AND CONCLUSIONS

The Phase III piezometer nests confirm the presence of the two main groundwater flow systems that were identified in the Phase II report: a deep regional flow system with recharge (downward) hydraulic gradients, and a shallow flow system with both recharge and discharge (upward) hydraulic gradients. The shallow flow system is generally limited to the upper 15 m of the groundwater regime. There is no evidence of discharge gradients in the regional flow system south of Hwy. 403.

The water quality data indicates the leachate plume from the Bayview landfill is smaller than originally predicted. The absence of tritium in the deep piezometers means that no leachate-derived constituents could have migrated to the 20 m depth in the shale. The leachate plume is confined to the shallow flow system and has not migrated more than a few tens of metres from the landfill.

Comprehensive analysis of the water quality in the piezometer nests shows that natural organic matter deep in the shale contributes ammonium, nitrate, BOD, COD, DOC, phenols and increased heavy metals to groundwater in the regional flow system.

The study of the Indian Creek watershed south of Hwy. 403 indicates that there is no possibility that leachate, which enters the shallow flow systems at either of the existing landfills or the proposed NSP landfill, could discharge into the tributaries of Indian Creek, south of Hwy. 403.

The findings of our Phase III investigation support our conclusion in the Phase II report that the hydrogeologic conditions at the NSP site are ideal for landfilling operations. To ensure long-term environmental protection, however, it will be necessary to incorporate the design criteria and operating standards outlined on pages 45 to 53 of our Phase II report, into the landfill proposal.

2.0 INTRODUCTION

2.1 Background

This report describes the results of the Phase III hydrogeologic study of the proposed National Sewer Pipe Ltd (N.S.P.) landfill in the City of Burlington. The study provides supporting information for our Phase II report, dated June, 1980. There are numerous cross references to the Phase II report and we request the reader to refer to that report.

The Phase III studies were carried out in response to questions raised by Dr. John Cherry in his report titled "Hydrogeologic Suitability of the N.S.P. Landfill Site, Burlington, Ontario", dated Oct. 1980. On page 30 of that report, Dr. Cherry comments that "neither the Phase I nor the Phase II reports provide an adequate technical basis for concluding Queenston shale is capable of 'assimilating leachate.....within a relatively small leachate mixing zone'", and further, that "the data do not provide a definitive indication of how the front of the subsurface zone of leachate contamination has moved".

Ex. N-186

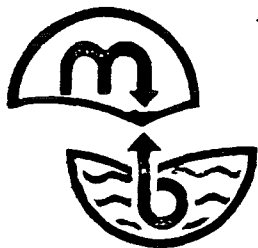
PHASE II
HYDROGEOLOGIC INVESTIGATION
NATIONAL SEWER PIPE LTD
LANDFILL SITE
BURLINGTON

MORRISON BEATTY LIMITED

290 The West Mall
Etobicoke Ontario
(416) 622-9374

June, 1980
Project No. 130-792

Brian W. Beatty, P.Eng.



morrison beatty limited

consulting engineers and hydrogeologists

4500 dixie road, unit 12a, mississauga, ontario L4W 1V7 (416-624-9308)

November 14, 1980

Proctor and Redfern
110 James Street
St. Catharines, Ontario
L2R 7E8

Attention: Mr. Robt. Tait, P.Eng.

re: Phase II Hydrogeologic Investigation
National Sewer Pipe Landfill Site
Burlington
Our File No. 130-792

Dear Sir:

This report describes the results of both our Phase I and Phase II hydrogeologic studies of the proposed National Sewer Pipe landfill. The Phase II studies have expanded on our Phase I investigation of the impact of the Bayview Park landfill. It also examines the potential impacts of the National Sewer Pipe landfill.

Based on the results, we have developed design criteria for the National Sewer Pipe landfill that are required to control the long-term impacts. Emphasis is placed on reducing infiltration into the landfill controlling leachate migration beneath the site, and monitoring the various water regimes on the National Sewer Pipe property.

Yours very truly --

MORRISON BEATTY LIMITED

Brian W. Beatty, P.Eng.

BWB/dp

TABLE OF CONTENTS

1.0	SUMMARY AND CONCLUSIONS - i to iv	
2.0	INTRODUCTION	1
2.1	BACKGROUND	1
2.2	PURPOSE AND SCOPE OF PHASE II STUDY	2
2.3	BAYVIEW LANDFILL DETAILS	4
2.4	PREVIOUS STUDIES	5
3.0	STUDY METHODS	7
4.0	RESULTS AND DISCUSSION	9
4.1	GENERAL	9
4.2	PHYSIOGRAPHY	11
4.3	WATERSHEDS AND DRAINAGE	11
4.4	HYDROLOGIC BUDGET	13
4.4.1	Watersheds	13
4.4.2	Bayview Landfill	18
4.5	BEDROCK GEOLOGY	20
4.6	GROUNDWATER	23
4.6.1	Occurrence and Movement	23
4.6.2	Groundwater Quality	27
4.6.3	Groundwater Uses	29
4.7	IMPACT OF BAYVIEW LANDFILL	30
4.7.1	Leachate Generation	30
4.7.2	Leachate Quality	31
4.7.3	Leachate Migration and Assimilation	36
5.0	N.S.P. LANDFILL SITE	44
5.1	HYDROGEOLOGIC SETTING	44
5.2	ENVIRONMENTAL PROTECTION	45
5.2.1	Infiltration Control	45
5.2.2	Surface Drainage Control	47
5.2.3	Leachate Control	48
5.2.4	Gas Control	49
5.2.5	Leachate Treatment	50
5.3	MONITORING GUIDELINES	52

The entire urban and industrial area south of the site is serviced with water and sewers. There are no existing or potential future uses of groundwater between the site and Lake Ontario.

The key observations of our impact study at the Bayview site are:

- i) a portion of the leachate generated at the site migrates downward into the deep shale formation and, ii) the remainder of the leachate discharges directly to several streams on the N.S.P. property. Our study focussed on identification of the leachate assimilation zone in the groundwater regime; a parallel study by the Ministry of the Environment focussed on leachate assimilation in the Indian Creek tributaries. The significant findings of both studies is that leachate from the Bayview site is assimilated in the natural hydrogeologic environment within the limits of the N.S.P. property. The lower reaches of Indian Creek do contain concentrations of some heavy metals, pesticides and bacteria that are marginally above the Ministry of the Environment water quality criteria; however, the landfill does not appear to be the sole contributor of these constituents.

Based on the Bayview site studies, we conclude that the hydrogeologic conditions at the N.S.P. site are ideal for a landfill operation. Some of the hydrogeologic factors that make the site ideal are:

- i) large buffer zone which extends over 1000 m southward (the direction of lateral leachate migration)
- ii) absence of aquifers and private water supplies south of the site
- iii) natural poor quality groundwater
- iv) low permeability of shale
- v) presence of a shale resource which can be extracted simultaneously with the landfill operation
- vi) presence of landfills on both sides of the site that have not caused significant impacts on water resources beyond the N.S.P. property
- vii) presence of on-site marshes that can be utilized for natural leachate treatment, if required
- viii) the presence of an extensive buffer zone, a shale formation and marshes which can be used for natural on-site treatment of leachate

To minimize the long-term environmental impacts of the landfill, the key element in the site design involves controlling the amount of water that infiltrates into the refuse. This will be achieved by contouring the fill and placement of a layered soil cover on the completed site.

Ideally, the infiltration will be controlled to rates that can be accommodated in the groundwater regime beneath the site; however, contingency plans have been developed to collect excess leachate that mounds in the landfill. The contingency plans also include alternative methods of achieving total on-site treatment of the excess leachate. This will be accomplished by natural systems such as marshes, or a combination of mechanical and natural treatment.

The performance of the leachate control and treatment systems will be closely monitored. A network of multi-depth piezometers and stream monitoring stations will be required to assure the Ministry of the Environment that water resources downgradient of the site are protected.

In summary, we conclude that the N.S.P. property is hydrogeologically suitable for the proposed landfill. There will be no adverse impacts on water resources in the vicinity of the site providing the methods of infiltration control and leachate control and treatment outlined in this report are carried out.



Respectfully Submitted,
MORRISON BEATTY LIMITED

A handwritten signature in cursive script, appearing to read "Brian Beatty".

Brian W. Beatty, P.Eng.

Ex. 596.

The Corporation of the
City of Burlington
8th Floor, City Hall
426 Brant Street
Burlington, Ontario
L7R 3Z6

Attention: Mr. G. Vance
Assistant to the
Chief Administrative Officer

Dear Sir:

Solid Waste Management Strategy Study
Final Report

We are pleased to submit our final report concerning the Region of Halton solid waste management strategy and our comments on the National Sewer Pipe (NSP) proposal to operate a private landfill.

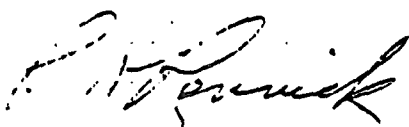
Our findings indicate that the production of saleable steam from an Energy-From-Waste (EFW) recovery plant, combined with materials separation at source and landfill, is the best waste management option.

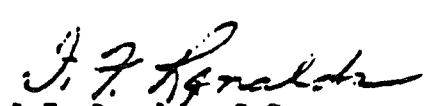
We consider that the NSP site is suitable for a landfill operation. However, due to conflicting interpretations concerning the hydrogeology, we are not able to support the proposed design for leachate collection. We are confident that the research being conducted by the University of Waterloo will clarify this matter and that the NSP proposal can be modified to the satisfaction of all parties.

It is our view, that leachate from all three sites, i.e. Bayview, Burlington and the proposed NSP can be collected and treated at the Burlington Pollution Control Plant, without placing a stress on that system. In fact, a co-operative effort may result in a substantial cost saving and will reduce concern for surface and groundwater quality.

Lastly, we very much appreciate the cooperation received from yourself, City and Regional staff and the Solid Waste Management Committee during this interesting and challenging study.

Sincerely yours,


P.H. Rennick
Study Director


I.F. Ronalds, P.Eng.
Vice-President and Manager,
Industrial Division

no longer with
Acres

Keros Cartwright
Hydrogeologist
310 West John Street
Champaign, Illinois 61820

Ex. N 470

EVALUATION OF THE NATIONAL SEWER PIPE LTD.
BURLINGTON LANDFILL SITE
November 15, 1982

Background

I have reviewed all the hydrogeologic data, three reports by Morrison Beatty Ltd., and two reports by J. A. Cherry, the engineering drawings of the site by Proctor and Redfern Ltd., as well as other documents. I also made field surveys of the site and surrounding area on May 18, 1981, and September 15 and 16, 1981.

Following my first review I posed several questions, which I felt needed clarification, to Brian Beatty concerning his report. I also suggested that three more piezometer nests be drilled, and that the existing piezometer network be re-sampled. The work resulting from these suggestions is included in the Morrison Beatty Ltd. "Phase III Hydrologic Investigations."

Based on the hydrogeology of the site, which is summarized below, it is my opinion that the proposed landfill site is suitable for municipal waste.

Hydrogeology

The landfill site is underlain by the Queenston Shale, and burial is to take place in this shale unit. Southeast of the landfill site, but still on NSP property, a thin veneer of lake and glacial sediments overlies the shale. The overlap takes place near the abrupt change in topography from eroded uplands to the nearly flat land of the lake plain, and the thickness of sediments over the shale increases southward toward Lake Ontario.

The intermediate groundwater flow path is the most probable pathway for any leachate that may migrate from the proposed landfill. Some of the groundwater in this system originates in the proposed disposal area and migrates toward the lake. With the reduced hydraulic conductivities with depth, the movement of water in this zone is relatively slow. Water in this zone is also brackish; although some leachate from the existing Bayview Landfill may have become mixed into this water, it cannot be distinguished from the background water quality.

The local groundwater flows in the site area are, in general, perpendicular to the surface streams on the property, flowing from the topographic highs to the streams. This pattern is well documented in the Morrison Beatty Report and is evidenced by the discharge areas along the streams. Much of this system will be eliminated during landfill construction in the landfill area. To the south, where topography changes to the gentle slope toward the lake, the local groundwater flows probably are southward toward the lake. The water quality in this zone is better in the two deeper flow paths; however, even this water is not high quality drinking water.

Some groundwater discharges between the CN Railroad tracks and the site.
Water levels in the piezometers in this region (OW 13-79, 16-81, 17-81 and 18-81) indicate both recharge and discharge in this region. Field reconnaissance suggests groundwater is discharging in several areas. It is likely that the recharge/discharge relationships change with the seasons and climatic factors. { The abrupt change in slope from the hilly topography to the flat lake plain probably is the principal control of this system. Between the CN tracks and the lake, urban development has altered the relationship of groundwater and surface water by controlling the drainage. Almost no groundwater, if any, discharges in this area.

Design Considerations

There are two aspects of the landfill design that need careful attention if the site is to utilize natural attenuation and assimilation. These are the design of the berm-rock interface, and the final cover.

Quarrying operations are planned, which will remove the upper several meters of the weathered shale. This zone is the most permeable, and the removal of this zone will reduce the amount of leachate that can be transmitted to the groundwater system. The maximum area of shale, especially in the southeastern part of the fill, should be available to accept leachate. The perimeter berm must be keyed deep enough into the rock to prevent leachate springs from developing at the toe of the landfill and still not prevent lateral migration of the leachate. A modified design similar to that suggested by Morrison Beatty on August 10, 1981, should be included in the final design.

Since the most permeable zone of the bedrock will be removed, the leachate that can leave the site through the groundwater system will be greatly reduced (probably to less than one inch of infiltration). Thus, the design and maintenance of the final cover are critical to maintaining the water balance. The cover will have to be designed to maximize surface runoff without excessive erosion and to inhibit infiltration. A heavy clay or layered type of cover will most likely be necessary. At present, most landfill covers do not seem to restrict infiltration to the degree required here. However, surveys are underway to assess existing covers, and considerable research is taking place on cover design. I am sure a cover can be designed for the site which will fulfill the need.

An internal leachate collection system should be installed in the landfill. During the operation of the landfill, it may not be possible to limit infiltration to the same extent as after closure. Thus, it is likely that the leachate collection system will have to be used during much of the operating life of the landfill.

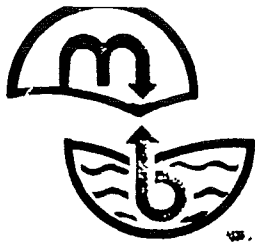
would also be in place should monitoring indicate it necessary at some future time.

Conclusion

In conclusion, the site appears to be well suited for the disposal of municipal waste. The existence of two sanitary landfills on adjacent land provides a unique opportunity to assess the effects of a landfill in this environment. The old Bayview Landfill is especially instructive, since it has been in existence for a considerable period of time.

Leachate from the Bayview Landfill is traceable only a few 10's of meters from the waste. Some leachate may have become mixed with the deeper brackish groundwaters; however, they are indistinguishable from the poor quality water already present in the aquifer. There is no indication of extensive migration of leachate from the old Bayview Landfill.

Considering the carefully engineered plans for the proposed landfill, the new landfill should have little or no impact on the groundwater in the area around the landfill. I believe the proposed landfill is well sited and well engineered for the site



morrison beatty limited

consulting engineers and hydrogeologists

4500 dixie road, unit 12a, mississauga, ontario L4W 1V7 (416-624-9300)

July 23, 1985

Ex N.471

Proctor and Redfern Limited,
20 Hughson Street South,
Suite 1001,
Hamilton, Ontario.
L8N 2A1

Attn: Mr. R. Tait, P.Eng.

Dear Sir:

Re: Review of Technical Reports
on the Hydrogeologic Suitability of
Site F for the Proposed
Region of Halton Landfill
Our File 130-791

This letter contains our review of the following two technical reports which pertain to the hydrogeological suitability of Site F for the proposed Region of Halton Landfill:

Report 1: Response to Halton Landfill Environmental Assessment, Draft Phase 2 Stage 2C Reports, Draft Technical Report No. 7(1) - Hydrogeologic - Hydrologic Assessment - Hydrology Consultants, prepared by Ecoplan Limited and Conestoga-Rovers and Associates Limited for the Corporation of the City of Burlington, March, 1985.

Report 2: Hydrogeological Suitability of Candidate Sites, Proposed Halton Regional Landfill Site, prepared by Golder Associates for the Town of Oakville, May, 1985.

We have addressed the most salient concerns of Conestoga-Rovers (CRA) which they believe reduce the suitability of Site F for a proposed landfill. We have also included a brief discussion of the risk ranking carried out by Golder Associates.

1.0 REVIEW OF REPORT 1

1.1 Fracture Flow

A major concern reported by CRA relates to the complexity of groundwater flow systems in fractured rock. They suggest that this complexity leads to uncertain predictability of groundwater movement and contaminant migration. CRA maintains that these are major constraints upon the safe operation of a landfill on fractured shale.

On a micro scale, say of tens of cubic meters of fractured Queenston shale, groundwater movement may be considered complex. It is very difficult to identify actual groundwater flow paths and accurately estimate groundwater velocity along these paths. On a regional scale however, between the Niagara Escarpment and Lake Ontario, groundwater movement through the Queenston shale appears to exhibit a general trend that is not complex. As a red, silty mudstone, the Queenston Formation is remarkably uniform over its entire thickness.

The regional groundwater flow system in the fractured shales in the vicinity of Site F has been effectively defined using conventional methods of groundwater monitoring. It is this flow system that will affect the overall movement of contaminants and so should be considered in an evaluation of hydrogeologic impact of a proposed landfill.

From available stratigraphic information, candidate sites D and E appear to have more complex regional groundwater flow systems than that in the shale. Although the overburden at these sites is predominantly till, it is known that the till contains intermittent and continuous deposits of water-bearing sand. The permeability contrasts between these coarser sediments and the till matrix cause perturbations in regional flow systems.

1.2 Groundwater Resources

Another area of concern reported by CRA relates to the impact of a proposed landfill on groundwater resources. They acknowledge that the shale is not an aquifer and that there are no downgradient well users. They suggest that the suitability of Site F over the other sites on this basis is not justified because bedrock water quality from the other sites has not been defined. Based on a review of limited data, they advocate that no significant difference exists in the quality of the deep bedrock waters at all six candidate sites.

This is the case, however a comparison of bedrock quality between the sites is not a valid one. To evaluate a potential impact on groundwater resources a comparison must examine the groundwater resource most likely to be effected by a proposed landfill. In the vicinity of Sites D and E, local aquifers found in the till are potential sources of water supply. Unlike the area downgradient of Site F, none of the properties around Sites D and E are serviced with municipal water supplies.

The development of a landfill at Sites D and E therefore creates a potential risk to the existing and future groundwater supplies. There is no such risk associated with a proposed landfill at Site F. An additional risk associated with Sites D and E is that the use of groundwater from aquifer zones cannot be controlled in abutting properties. A high capacity well on a neighbouring property, for example, could create unforeseen contaminant impacts.

1.3 Surface Water Resources

A further concern of CRA relates to an impact on surface water resources in the vicinity of Site F. They suggest that mounding of the water table in the refuse will increase the horizontal groundwater flux through the shallow weathered bedrock. Any discharge of this contaminated groundwater off-site will impact surface streams and wetlands.

The top few meters of the shale is extremely weathered and does comprise a zone of distinctly higher permeability. Any potential channeling of flow through this zone has been taken into account in the Proctor and Redfern landfill design, however. The design specifies that the weathered shale in the upland areas will be removed by excavation and that the weathered shale in the intervening valleys south of the landfill will be removed and replaced by compacted clay material. If leachate seepage around the periphery of the landfill is found to cause unacceptable impacts on surface streams, the underdrain system incorporated in the landfill design will be activated.

Any leachate not captured by the underdrain system installed at the refuse/bedrock contact will be transported along deeper groundwater flow paths in the shale that eventually discharge to Burlington Bay. Contaminants contained in this groundwater do not pose a threat to surface water because the flow paths are deep and have not been found to intersect the surface between the NSP property and the lake. The large dilution capacity of Burlington Bay will prevent any perceptible impact on surface water quality at this ultimate discharge point.

2.0 REVIEW OF REPORT 2

The ranking of candidate sites by Golder Associates was based on potential risk to human health and safety and to the natural environment. An overall ranking of sites with minimal engineering found Site D to be of lowest risk followed by Sites E and F. We feel a re-evaluation of two criteria which contributed to this ranking would lead to a more favourable relative ranking of Site F.

2.1 Off-Site Degradation of Groundwater

The risk of off-site degradation of groundwater is assigned by Golder Associates as low-medium for Sites D and E and medium for Site F. We feel that the risk of off-site degradation of groundwater is largely dependent on the hydraulic conductivity of the subsurface soil or rock. Values of hydraulic conductivity from research on groundwater movement in the Queenston Formation vary over the same range as those reported for the tills at Sites D and E. On this basis, one could not justify unequal ranking of the sites.

In their risk assessment Golder Associates indicate that aquifers may exist at Sites D and E but they do not acknowledge that this is a constraint to landfilling unless the base of the fill is in contact with the aquifer. We have confirmed that aquifers do exist at both Sites D and E. In our opinion, the existence of aquifers, regardless of their stratigraphic position, should be considered a constraint for Sites D and E compared to Site F where no aquifer exists.

2.2 Reaction Time to Off-Site Migration of Contaminants

Golder Associates also evaluated the candidate sites in terms of available reaction time to off-site migration of contaminants. We feel this criterion is inappropriate because the "use" of the surrounding groundwater resource is not considered. According to the Ministry of the Environment, off-site impacts only occur if "existing or future uses" of a water resource are threatened. At Site F, we have established that there are no existing or future uses. However at Sites D and E, future uses may be effected because of existing aquifer zones.

We feel this criterion is also inappropriate because Golder Associates suggest that detection of contaminants in shale cannot be done effectively. They suggest stratigraphic and hydrogeologic complexity effect the reaction time available to mitigate a contaminant release. We maintain that a comprehensive monitoring network could be designed at Site F to identify a contaminant release. As part of the monitoring network, a contingency system could be activated immediately if such a release were identified.

3.0 LINER CONSIDERATIONS

Based on our knowledge of the groundwater and surface water conditions at Site F, we remain convinced there is no valid technical reason to install a liner. This is because:

- (i) the Queenston shale contains poor natural groundwater quality
- (ii) there are no existing or future groundwater uses between the site and Lake Ontario.

If a liner is needed to obtain political support, it is our opinion that shale quarried on-site could be used for this purpose. To be ideal for use as a liner, the shale would have to be weathered to reduce the large shale fragments. Laboratory tests by Golder Associates on weathered shale samples taken in the vicinity of the Bayview Park landfill (Aug. 1979) suggest that it may be possible to achieve a permeability in the order of 5×10^{-8} cm/sec.

The liner thickness of 1.2 m suggested by Golder is the criteria for Metro Toronto's landfill at Maple which is situated above two major aquifer zones. Obviously, such a stringent design is not necessary for Site F, where there are no groundwater uses downgradient of the site. We therefore expect that the required liner thickness at this location would be considerably less.

4.0 SUMMARY

On the basis of the preceeding discussion it is apparent that the concerns of CRA regarding a proposed landfill at Site F are not valid. Based on our knowledge of the three sites, we have been able to easily diffuse their concerns about the complexity of fracture flow and the potential impacts on groundwater and surface water resources.

Our review of the Golder Associates ranking approach reveals that they did not award sufficient emphasis to groundwater non-use between Site F and Lake Ontario. A re-evaluation of criteria with this in mind would lead to a lower overall risk for Site F than for Sites D and E. 

Based on our review of the various consultants reports, no new information has been put forward that changes our hydrogeologic assessment of Site F. We are satisfied that there would be no risk to human health and safety as a result of landfilling at this site. There are few landfill sites in Ontario where one can be so confident.

If you would like to discuss anything in greater detail, we would be pleased to meet with you.

Yours very truly,
MORRISON BEATTY LIMITED



Janet P. Hewetson, M.Sc.
Hydrogeologist



B.W. Beatty, P.Eng.

JPH/sg

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.

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**WITNESS STATEMENT FOR REPLY EVIDENCE
OF STANLEY FEENSTRA**

In the Matter of the Consolidated Hearing for the Environmental Assessment of the Proposed Halton Landfill.

INTRODUCTION

I am a hydrogeochemist and President of Applied Groundwater Research Ltd. of Mississauga, Ontario. My involvement in the hydrogeological assessment of the candidate sites for the proposed Region of Halton Landfill began in the spring of 1986. My initial work was performed as a sub-consultant to Trow Hydrology Consultants Limited and resulted in the preparation of a report entitled "Evaluation of Groundwater Contaminant Migration at the Candidate Sites for the Proposed Region of Halton Landfill" dated July 2, 1986. This report is filed as Exhibit H-86. Prior to my testimony before the Hearing, I prepared a Witness Statement dated October 4, 1987 and filed as Exhibit H-86A. My testimony before the Hearing took place on October 14, October 15, October 19, October 20 and October 21, 1987 and is reported in Volumes 42, 43, 44, 45 and 46 of the transcripts. On behalf of the Region of Halton, I have been present at the Hearing for, or reviewed the transcripts of all of the testimony related to hydrogeology and most of testimony related to landfill design for Sites D and F.

This Witness Statement summarizes the topics related to the hydrogeological assessment of the candidate sites, Site D and Site F, which I will address in reply evidence. Included with this Witness Statement are four attachments to which I refer in the following paragraphs.

SITE D

1. The possibility of fractures extending downward through the unweathered Upper Till was discussed at length by Mr. Estrin and Mr. Petrie during cross-examination of Mr. Petrie (Transcripts v. 122, p. 29,504 to 29,606). Mr. Estrin and Mr. Petrie discussed fracturing in the Maryhill Till in Waterloo and the unweathered basal Vandalia Till in Illinois. The Vandalia Till is of Illinoian Age (>225,000 years) and has experienced a considerably different history than the late Wisconsin tills such as the Maryhill and the Halton Till (<15,000 years) in southern Ontario, and these tills are not likely comparable in terms of the nature and origin of fracturing. However, both examples do illustrate that evidence of fracturing cannot be determined from laboratory hydraulic conductivity tests and from Hvorslev (slug) tests in vertical boreholes. Mr. Petrie described that angled boreholes and

test pits are appropriate methods for investigating the presence of fractures and neither of these methods was used at Site D.

In June of 1988 I was asked by Dr. John Cherry of the University of Waterloo (UW) to review a draft of a paper which he and Wilf Ruland had prepared entitled "The Depth of Fractures and Active Groundwater Flow in a Weathered Clayey Till in Lambton County, Ontario". This paper described the results of their research which found physical evidence of chemically weathered fractures to a depth of 5.6 m and has found evidence of tritium penetration and seasonal water level fluctuations to depths of 10 to 12 m at some sites, well below the depth at which the till shows visual evidence of weathering. This paper was derived from a Masters project by Mr. Ruland (see Attachment 1). These results differ from the first studies conducted by UW at Sarnia and several other sites in Eastern North America starting in 1979 which indicated tritium only as deep as the weathered zone and it was assumed that this simply meant that open fractures did not extend deeper than the weathered zone. This finding appeared consistent from site to site but only a relatively small number of tritium profiles were developed. For the research by Ruland, more detailed tritium profiles have been developed at more sites spanning a wider range of settings. These studies have found much deeper penetration of tritium and evidence for fractures extending below the zone of weathering. These results together with the discussion of fracturing by Mr. Petrie and Mr. Estrin led me to consider the possibility and implications of fracturing in the unweathered upper till at Site D.

2. In the work done at Site D, it was assumed that the depth of fracturing and the depth of weathering coincided. The weathered zone and therefore the fractured zone extended only to a depth of approximately 4 m below ground surface. The unweathered Upper Till from a depth of 4 m to 7 or 8 m was assumed to be unfractured. If, however, the unweathered Upper Till underlying the landfill is fractured, the assessment of potential contaminant migration out of the landfill must be very different than that performed by THCL and Dr. Rowe. Though matrix diffusion may result in some degree of attenuation, the very short travel path (3 to 4 m) would result in a rapid impact on the groundwater quality in the Upper Granular Unit (UGU) in the event of failure of the hydraulic trap.
3. The presence of fractures through the unweathered Upper Till has not been confirmed or even suggested by field data at Site D (though test pits and angled boreholes were not used) and would appear to contradict the lack of tritium in the THCL tritium nest and the lack of tritium in the UGU and Lower Granular Unit (LGU) pumping test discharge water. However, the lack of tritium in the UGU and LGU could be explained by the fact that some of

the water supplying these zones at Site D may be older water derived from the upward gradients from the bedrock. The lack of tritium at a single nest of piezometers may be due to the fact that the vertical fractures extending through the unweathered Upper Till are widely spaced (metres or so) and were not intersected at that location. It may also be that the upper 4 m or so of the weathered till afforded a significant degree of attenuation (due to closer fracture spacing) and reduced the tritium at deeper levels.

4. The presence of vertical fractures in the unweathered Upper Till could not likely be detected by Hvorslev tests in vertical boreholes due to smearing of the surface of the borehole and/or if the fractures were not intersected because of their wide spacing, and could not be identified by laboratory hydraulic conductivity tests. There was no evidence of significant vertical leakage (ie. flattening of the log-log drawdown plots shown in the THCL Report Exhibit H-39A, Appendix 10) during pumping test PW-2 but the effects of boundary conditions may have masked any effects of minor vertical leakage.
5. Based on the hydraulic conductivity of the fractured clay till in the weathered zone at Sarnia and the possible fracture frequency at greater depths, the bulk hydraulic conductivity of sparsely fractured unweathered till at Site D might be in the range of 10^{-6} to 10^{-7} cm/s. This range is not unlike that suggested by Dr. Rowe (Rowe Report Exhibit M-442, p. 21) but he gave no indication that he expected fracturing to impart these values which exceeded those measured by TCHL by Hvorslev tests in vertical boreholes. Indeed if one considers that this hydraulic conductivity is imparted by fracturing, the travel velocities for contaminants would be much higher than suggested by Dr. Rowe and THCL because of a much lower transport porosity. Because the hydraulic conductivity of weakly fractured till is not likely to be significantly higher than the range previously suggested for this unit, the flux (flow rate) of contaminants from the landfill, and consequently the boundary concentrations, for the fractured case might not be significantly different from many of the estimates made previously. However, the travel times will be much shorter.
6. The assessment of the existence and characteristics of fractures in the unweathered Upper Till is a difficult one. Deep trenching and physical examination of the till might enable one to identify the presence or absence of fractures but cannot indicate whether the fractures are open unless groundwater flow is actually observed (possible but not very likely). In any case, the hydraulic conductivity cannot be quantified in this way. In addition, the excavation and careful examination of trenches 7 to 8 m in depth is not a trivial undertaking. Angled borings may be able to intersect fractures if the fracture spacing is not more than several metres. The presence of fractures may be evident in core samples. The hydraulic

conductivity of the fractures identified in angled borings could be determined using Hvorslev (slug) tests if piezometers were installed precisely where the fractures were located and in such a way as to remove or minimize the zone of smearing from the surface of the borehole.

7. The presence of fractures extending through the unweathered upper till has a significant effect on the nature of contaminant transport through this unit. In the event of failure of the hydraulic trap, contamination of the UGU may occur rapidly (less than a year). Though there are no site-specific data indicating the presence of fractures at Site D, at this time, it is my opinion that it is a reasonable possibility that they exist.
8. In the event that fractures extend through the upper unweathered till, a groundwater monitoring plan such as typically implemented at municipal landfills in Ontario will not be sufficient to protect the nearby groundwater users. Groundwater monitoring programs at municipal landfills in Ontario typically involve the sampling of monitoring wells on an annual or bi-annual basis. The process of sample collection, analysis in the laboratory, evaluation of the data, re-sampling and re-analysis of anomalous results, and preparation of a monitoring report can frequently take 1 to 2 months. At Site D, in the event that failure of the hydraulic trap is detected either by monitoring within the landfill itself or monitoring in the groundwater adjacent to the landfill, implementation of the primary contingency of purge wells likely would require 4 to 6 months for design, installation and testing. In the case where the unweathered upper till is unfractured and travel times are measured in years, these time requirements are not problematic. However, for the case where the unweathered upper till is fractured and travel times may be less than a year, the time required for detection of groundwater contaminants and construction of the purge wells, contaminants from the landfill may result in impacts on the nearby groundwater users.
9. Much of the time delay in the implementation of the contingency could be eliminated by design, installation and testing of the purge well system before the start of landfilling. In this way, if groundwater contaminants or a failure of the hydraulic trap are detected, capture along the site boundary can commence immediately. In addition, in selected key areas such as along the First Line, monitoring should be sufficiently frequent with respect to estimated contaminant travel times for early detection of contamination. During the installation and testing of the purge well system, information can be gathered with regard to the continuity of the granular units westward toward the First Line and beneath the site. In addition, detailed pumping tests of the type discussed by Mr. Estrin and Mr. Petrie (Transcripts v. 122, p. 29,504 to 29,560) could be conducted to assess the presence of fractures in the unweathered upper till.

This information can be used effectively to design the final groundwater monitoring program.

10. The potential impact on the nearby groundwater users could also be eliminated by connection of these residences to a piped municipal water supply. This action would not eliminate the possible impact of off-site contaminant migration on surface water surrounding the site. Such impacts must also be controlled but the time frame is longer because these receptors are generally located at greater distances from the landfill and human health and safety will not be directly effected. The effect of fractures extending through the unweathered upper till can also be eliminated by construction of a liner of re-compacted native clay silt till on the base of the landfill.
11. The THCL and CRA landfill designs for Site D call for a head difference of 0.4 m between the maximum leachate mound height and the hydraulic head in the underlying geological units (primarily the Upper Granular Unit or UGU). The head in the UGU must be greater than the head of leachate in the landfill to prevent flow of leachate downward out of the landfill into the underlying geological units. The head difference of 0.4 m can be considered a margin of safety in maintenance of the hydraulic trap. Factors which act to increase the leachate head or decrease the head in the UGU will serve to create a failure of the hydraulic trap.
12. Of concern with respect to the maintenance of the hydraulic trap are factors which could result in widespread declines in the head in the UGU. The THCL design is based on only a short period of groundwater level monitoring, for most wells less than one year from Sept. 85 to Apr. 86 (THCL Report H-39A, Appendix 8). The design does not take into account possible year to year fluctuations due to dry years (drought). The effect of drought will be twofold. Firstly, there may be less infiltration of water into the groundwater system, and secondly, drought will also result in greater groundwater usage and this increased pumping may also reduce groundwater levels. For the UGU, THCL calculated (THCL Report H-39, p. 133) that 2 purge wells pumping at a rate of 12.6 L/min. (2.8 Igpm) would create a sufficiently large zone of influence to control groundwater flow across the entire site. If private wells began pumping at significantly increased rates for lawn watering, irrigation or livestock, groundwater levels beneath the site could be affected similarly (Charlesworth Report Exhibit M-438, p. 6-6). Groundwater fluctuations of 0.4 m (the margin of safety for the hydraulic trap) are not large in the context of year to year changes in recharge and groundwater usage. Intermittent short-term (seasonal) failure of the hydraulic trap is not critical if the travel times through the unweathered upper till are measured in years (ie. no fractures)

- (Testimony by Mr. Sobanski, Transcripts v. 23, p. 5,385) . However, if the unweathered upper till is fractured, even seasonal failure of the hydraulic trap could allow contaminants to enter the UGU.
13. Another factor which could act to reduce the groundwater level in the Upper Granular Unit is the reduction in the area of recharge to the UGU due to the creation of a large landfill above. Unless the UGU is continuous off-site to a significant degree, ~~a large proportion of the water~~ which enters the UGU likely originates as infiltration directly on Site D. When the landfill is built and hydraulic trap in operation, this recharge will be cut off .
 14. A simplified calculation based on the area of the proposed landfill (53.2 ha, THCL Report H-41, p. 50) and an infiltration rate of 9.5 mm/a (THCL Report H-39, p. 66) suggests that approximately 10 L/min (2.2 Igpm) could enter the UGU from above under natural pre-landfill conditions. A reduction of the infiltration to the UGU of this order is comparable to the amount of groundwater withdrawal suggested by THCL for a purge well system in the UGU. The purge well system is expected to result in a significant reduction in water levels in the UGU and consequently it is reasonable to expect that a reduction in the recharge to the UGU from above could also reduce the groundwater levels in the UGU. The degree to which this reduced recharge will effect the groundwater levels beneath the site will depend on the relative proportion of the reduction in recharge, how readily the reduced recharge can be replaced by inducing groundwater flow from other sources, and the proportion of the flow in the UGU which is utilized by wells drawing from this unit.
 15. During testimony by Dr. Charlesworth (Exhibit M-438, p. 5-4), it was indicated that there are upward gradients from the bedrock into the LGU and UGU in some areas on Site D. If this is the case, then much of the groundwater in the UGU may originate from below rather than above, and the effect that the landfill might have on the water levels in the UGU will be less. The effect of the landfill itself on the groundwater levels beneath the site is difficult to quantify without a computer model and a good understanding of the areal extent of the units, the existing recharge and discharge areas, and the groundwater flow patterns. A more detailed understanding of the groundwater flow system would be required before a rigorous evaluation of the effect of the landfill on groundwater levels beneath the landfill can be made. Groundwater level monitoring will necessarily be a part of the groundwater monitoring program at Site D, but specific emphasis should be placed on identifying and characterizing short-term and long-term groundwater level fluctuations in the units underlying the landfill because of their key role in maintenance of the hydraulic trap.

16. In the event that drought or reduced recharge due to the landfill result in significant reductions in the groundwater level in the UGU, rather than purging contaminated groundwater from the UGU, it may be possible to maintain the hydraulic trap by recharging the UGU using a series of injection wells. Water could be obtained from piped municipal supply or from bedrock or basal overburden zones to surcharge the UGU to maintain a hydraulic head above that of the leachate in the landfill. There are various potential difficulties in the operation of such a system which must first be addressed such as clogging or chemical precipitation in the injection wells, long-term changes in water quality in the UGU and a reliable source of injection water.
17. In summary, in my opinion there is a reasonable possibility that fractures extend through the unweathered upper till and these fractures may provide a rapid pathway for the movement of contaminants from the landfill into the UGU in the event of the failure of the hydraulic trap. It is also my opinion that reductions in the groundwater level in the UGU due to drought or the effect of reduced recharge due to the landfill may result in seasonal or long-term failure of the hydraulic trap. The conditions described in these opinions can be overcome by modifications to the proposed contingencies, monitoring or landfill design and Site D can be made to be suitable for landfilling but these modifications will be more involved and will likely be more costly than the original designs.

SITE F

18. The following discussion of Site F is presented in response to the opinion of Mr. Petrie that the hydrogeological conditions at Site F are unsuitable for siting a landfill because they are too complex to be understood sufficiently. Based on the available data and the performance of the Burlington and Bayview landfills, it is my opinion that there is sufficient information available to develop an understanding of the hydrogeological conditions to allow a satisfactory assessment of the suitability of Site F for landfilling.
19. Examination of rock core from the shale beneath Site F indicates the presence of many horizontal and dipping discontinuities such as fractures, bedding plane openings, sealed fractures and clay mud seams. Occasional vertical discontinuities were also observed in the core. Open fractures and bedding planes provide the pathways for groundwater flow horizontally and vertically through the shale. Examination of the rock core and correlation between boreholes indicate a zone of fractured and weathered shale in the upper several metres of the bedrock. Mr. Petrie labelled this zone as the "weathered mantle" (CRA Report Exhibit B-617, p. 151). Underlying this, is a zone which contains fewer fractures and more

sections of intact unfractured shale between the fractures. Some of these sections of intact core are up to 1.5 m in length. Underlying this zone is a zone of more frequent fracturing though many fractures are still separated by lengths of intact shale core.

20. These zones correspond to the Hydrostratigraphic Units defined by THCL: Unit 2 - the Moderately Fractured and Weathered Shale, Unit 3 - the Weakly Fractured Shale and Unit 4 - the Highly Fractured Shale. These units are not units which can be strictly characterized in terms of areal and vertical extent and hydraulic properties. For example, within the moderately fractured and weathered shale unit there will be low hydraulic conductivity zones through which there are no fractures. Similarly, within the weakly fractured shale unit there will be zones which contain fractures. The simplification of the site conditions into the hydrostratigraphic units is necessary to allow estimation of parameters such as infiltration rates and contaminant migration pathways.
21. The key contaminant migration pathways identified by THCL were lateral migration through the Moderately Fractured and Weathered Shale, and downward through the Weakly Fractured Shale and then laterally through the Highly Fractured Shale. It was assumed that lateral flow through the Moderately Fractured and Weathered Shale would either discharge on-site or be otherwise captured in a perimeter drain system. Downward flow was considered to occur through the Weakly Fractured Shale unit having a hydraulic conductivity of 1×10^{-7} cm/s. Lateral flow through the Highly Fractured Shale was considered to occur rapidly through a zone of much higher hydraulic conductivity (1×10^{-4} cm/s or greater). Simulations of contaminant migration performed for this scenario and reported in the THCL Report Exhibit H-40 were considered to be conservative but generally consistent (given the range of uncertainty in the model input parameters) with the observations of contaminant migration made by the University of Waterloo (UW) then thought to be the case for the Bayview Landfill. That is, there were measurable levels of organic contaminants in the shallow and deep groundwater at distances of up to 800 m from the landfill which developed during the 30 years since landfilling commenced (Hewetson Thesis Exhibit E-214). At that time, there had been no attempt to assess the occurrence of high chloride concentrations in the groundwater or to reconcile the distribution of organic contaminants with the chloride concentrations in the groundwater.
22. Results of the 1986 groundwater monitoring program at the Burlington Landfill indicated that there was little if any migration of organic contaminants south of the landfill in the 15 years since landfilling commenced at the site. These, data plus some data collected by THCL south of the Bayview site were not consistent with the extent of migration of organic

contaminants observed by UW at Bayview. This inconsistency caused me to re-evaluate (Feenstra Witness Statement Exhibit H-86A) the results of the groundwater monitoring at both Bayview and Burlington. My conclusion from this re-evaluation is that the organic chemical concentrations observed south of Bayview are, most or perhaps all, the result of extraneous contamination from the piezometer installations and do not reflect actual groundwater concentrations.

23. The 1987 groundwater monitoring results from Burlington indicate that low concentrations of organic contaminants have migrated as far as 25 m south of the Burlington site in the upper several metres of the shale bedrock. The concentrations of volatile organic contaminants at this location are considerably lower than those measured in the leachate from the Burlington leachate collection system indicating a significant degree of attenuation during migration through the shale.
24. At the Bayview site, it is not possible to determine the extent of migration of organic contaminants based on the UW study because of the effect of extraneous contamination from the piezometer installations. However, the highest concentrations of chlorobenzene and 1,4-dichlorobenzene occur in the shallow shale (MB-1-2) immediately south of the landfill. Though the true concentrations in the groundwater are likely to be lower than these values due to the contribution of extraneous contaminants from the monitoring wells, these results probably indicate contaminant migration through the upper shale at this location.
25. In May 1988, Conestoga-Rovers (CRA) pumped and sampled THCL pumping well PW-3 screened in the upper 3 to 10 m of the shale and located approximately 200 m south of the Bayview site. Low concentrations (2 to 6 µg/L) of chlorobenzene and 1,1,1-trichloroethane were detected and these compounds likely represent landfill derived contaminants. Xylene and benzene were also detected at low concentrations (1 to 2 µg/L) but these compounds may occur naturally in the shale. The pumping well was constructed of steel casing which was not specifically cleaned before installation. However, because the wells was pumped at a significant rate (several litres per minute) for several hours before sampling, the effects of any extraneous contamination are expected to be minimal compared to the sampling of a monitoring well or piezometer which is only purged of its standing water several times. The results from PW-3 suggest there may be some degree of lateral migration of organic contaminants through the upper portion of the shale south of the landfill.
26. In May 1988, CRA also pumped and sampled THCL pumping well PW-1 which is screened at a depth of approximately 4 to 22 m below bedrock surface and located at a distance of 600 m

south of the landfill. Only a trace of toluene ($3.7 \mu\text{g/L}$) was detected in PW-1 and toluene can occur naturally in the shale. PW-1 is screened considerably deeper than PW-3 and these results give no indication that organic contaminants are found deeper in the shale at this location.

27. The apparent extents of contaminant migration at the Bayview and Burlington landfills are generally comparable. The migration of organic contaminants has occurred laterally through the upper portions of the shale. The rate of migration has been much less than would be expected based on the hydraulic conductivity measured in the weathered shale ($\sim 10^{-4}$ cm/s), the hydraulic gradient and the estimated transport porosity. Travel velocities of 100 m/year would be estimated. Computer simulations performed by Dr. Rowe for his reply evidence indicate that matrix diffusion and sorption processes in the weathered shale cannot account for the degree of attenuation observed. The most likely explanation for observed extent of migration is that the weathered upper shale is not a continuous zone having a horizontal hydraulic conductivity of $\sim 10^{-4}$ cm/s and some areas of the weathered upper shale have hydraulic conductivities significantly lower. This interpretation is consistent with the observed limited extent of influence during pumping tests PW-2, PW-3 and PW-4.
28. The potential vertical migration of contaminants is less readily evaluated because there is no reliable way to identify directly the degree of vertical fracturing and the vertical hydraulic conductivity of the shale strata. Occasional vertical fractures have been identified in the rock core but it is not possible to determine their frequency or measure their hydraulic conductivity with packer tests as can be done for horizontal fractures. The presence of significant sections of intact (unfractured) shale in the rock core indicates that there are likely zones of very low hydraulic conductivity in the shale. The hydraulic conductivity of intact shale from Site F has not been determined but is likely to be as low as 10^{-9} to 10^{-10} cm/s (Testimony by Mr. Petrie, Transcripts v. 117, p. 28,221). Horizontal hydraulic conductivities in the range of 10^{-7} to less than 10^{-8} cm/s have been measured in the shale so that vertical hydraulic conductivities could be in the range of 10^{-8} cm/s or lower provided there are no significant vertical fractures. The strong vertical downward hydraulic gradients present on-site can only be explained by zones of low vertical hydraulic conductivity within the shale strata. The limited extent of influence vertically due to the pumping tests at PW-1, PW-2 and PW-3 also supports the interpretation that zones of low hydraulic conductivity exist in the shale, even in the upper weathered portion of the shale.
29. Insight into the vertical hydraulic conductivity of the shale strata can also be gained by consideration of the chloride and tritium concentrations in the groundwater. Groundwater

containing high chloride concentrations (5,000 to 50,000 mg/L) likely represents groundwater which originated in the shale or has resided in the intergranular pore space in the shale for a very long period of time (tens of thousands of years or more). Chloride cannot be derived from the dissolution of minerals in the shale (Chloride content of shale Exhibit H-660) The high chloride groundwater generally occurs deep in the shale strata. Groundwater flow through zones of high chloride concentrations either through the intergranular pore space or through any fractures which may be present is very slow. The vertical hydraulic conductivity of the shale in these areas must be very low to prevent the movement of low chloride groundwater from above into these deeper zones.

30. Groundwater containing low chloride concentrations (<1,500 mg/L) likely represents groundwater which has originated from infiltration of meteoric water from the ground surface. Low chloride groundwaters generally occur in the upper 5 to 10 m of the shale. Groundwater flow through the upper shale will occur through fractures. High chloride groundwater originally present in the fractures will be rapidly flushed out and low chloride infiltration will enter the fractures. As the infiltrating water moves through the fractures, chloride from the high chloride porewater in the porous matrix of the shale will diffuse into the water in the fractures. In this way, the infiltrating water acquires chloride concentrations. Where groundwater flow through the fractures is high, the chloride concentrations in the fractures will be relatively low but the high flow rates will rapidly remove chloride from the matrix of the shale. Where groundwater flow through the fractures is lower, chloride concentrations in the groundwater in the fracture will be higher and the removal of chloride from the shale matrix will be slower. Low chloride concentrations indicate regions of relatively active groundwater flow.
31. Groundwaters containing moderate chloride concentrations (1,500 to 5,000 mg/L) represent a transition between the zone of active groundwater flow the zone of inactive groundwater flow. This transition does not result from physical mixing of waters but rather reflects a zone in which the fracture characteristics (spacing, aperture and interconnection) allow more flow than in the inactive flow zone but less flow than in the active flow zone.
32. The relationship between tritium concentrations and chloride concentrations in groundwater at the Bayview Site and Site F was shown in Exhibit H-664. Tritium levels corresponding to post-1950 water are found in groundwaters containing less than 1,500 mg/L chloride and pre-1950 tritium levels are found in groundwaters having higher chloride concentrations. There are only 3 exceptions to this relationship (MB-16-3, MB-12-3 and HC-5-1) for the 24 samples compared. Given the possibility for the introduction of tritiated water

36. The ~~geochemical character of the groundwaters in the~~ Queenston shale beneath Site F ~~indicates a vertical zonation with relatively shallow zone of active groundwater flow in which~~ groundwater resides in the subsurface for tens of years or less, and a deeper zone of ~~very~~ inactive flow in which ~~groundwater resides in the subsurface for thousands of years~~. Separating these zones is a transition zone in which it is not possible estimate whether residence times may be many tens, hundreds or a few thousand years. The geochemical character of the groundwater in the shale indicates a relatively good hvdraulic connection (ie. higher vertical hydraulic conductivity) in the upper portions of the shale. This hydraulic connection is likely due to more intensive vertical fracturing in this zone.
37. The depth of this zone of more active groundwater flow varies from 0 m below bedrock surface at HC-8, HC-15 and GL-26 to approximately 20 m at HC-4. It is my opinion that the thickness of the active zone should be largely controlled by the degree of vertical fracture connection. Mr. Petrie suggested to Dr. Kingham (Transcripts v. 133, p. 32,131) that the thickness of the active zone (zone of low chlorides) may be greater in areas where there is no till cover. If one considers a scatter plot of thickness of the active flow zone to overburden thickness for all the boreholes having chloride data, no such relationship is evident (see Attachment 2).
38. The thickness of the active zone varies without an identifiable areal pattern across the Burlington, Bayview and Site F sites. For example, in each of the three areas south of the Burlington site and the Bayview site and on Site F, there are boreholes which indicate an active zone which is very thin from 0 to 5 m and boreholes which indicate a thicker active zone ranging from 10 to 15 m (see Attachments 3a, b, c and d, Attachment 4). Of particular significance with regard to Site F is the relatively thick active zone underlying the middle portions (HC-4 and HC-5) of the site. This suggests that leachate which exfiltrates the landfill may penetrate deeper (10 to 20 m) into the shale in this area than in areas such as beneath the existing Burlington and Bayview landfills. Within this active zone leachate may move laterally off-site. However, across the southern portion (HC-8) of the site the active flow zone is non-existent. This suggests that for leachate from northern and central portions of Site F to flow off-site, the leachate might be diverted to the west and / or to the east around the area of HC-8. The thickness of the active flow zone ~~to the west~~ (GL-27) and to the east (MB-17) of HC-8 ranges from 5 to 10 m. With this possible scenario in mind I would recommend that groundwater monitoring sites for Site F ~~be located~~ along the southwest and southeast boundaries of the site as well as the southern boundary.

additional benefit to the addition of a liner, consequently, it is my opinion that a liner is not required at Site F.

CONCLUSIONS

50. It is my opinion that Site F is suitable for landfilling. There should be no significant impact on the groundwater or surface water environments due to landfilling at Site F. In the event that subsurface conditions differ from my interpretation of the site and these conditions allow the migration of groundwater contaminants off-site, no water supply wells would be threatened and there would be ample time for implementation of contingencies if they were required.
51. It is my opinion that Site D can be made suitable for landfilling. For conditions when the hydraulic trap is functioning, there will be no leakage of leachate from the landfill. In the event of failure of the hydraulic trap, leachate will escape the landfill and could result in contamination of the private wells believed to draw water from the granular units underlying the landfill. If the unweathered upper till is unfractured, travel times for contaminants to reach the private wells will likely be many years. Either failure of the hydraulic trap or migration of contaminants would be detected by monitoring before the occurrence of contamination at the private wells. Within this timeframe, contingencies such as the pumping of leachate from the landfill to re-establish the hydraulic trap or the purging of contaminated groundwater from the granular units could be readily implemented.
52. If the unweathered upper till is fractured, travel times for contaminants from the landfill to the ~~private~~ wells may be less than a year. In this event, it is unlikely that a typical landfill monitoring program could identify the failure of the hydraulic trap and permit timely implementation of appropriate contingencies before the private wells might be contaminated. It is my opinion that it is a reasonable possibility that fractures exist in the unweathered upper till. Given the threat to the private wells, it is my opinion that this possible eventuality should be avoided by alternatives such as design, installation and testing of the purge well system prior to landfilling, the connection of the residences to piped municipal water supply, or construction of a liner of re-compacted native clay silt till on the base on the landfill.
53. The existence of fractures in the unweathered upper till and possible rapid contamination of the UGU also magnifies the importance of even short-term (seasonal) failures of the

hydraulic trap. Because of this, a specific emphasis on the monitoring of the leachate levels in the landfill and the groundwater levels beneath the landfill should be part of the groundwater monitoring program for Site D.

54. In summary, Site D can be made to be suitable for landfilling. Because of the possibility for fracturing in the unweathered upper till, modifications to the proposed contingencies, monitoring plans or landfill design are necessary to protect the nearby private wells. These modifications will be more involved and will likely be more costly than the original design.
55. On the basis of the preceding discussion, it is my opinion as a hydrogeologist and hydrogeochemist that Site F is preferable to Site D for the proposed Region of Halton Landfill.

ATTACHMENT 1

The Depth of Fractures and Active Groundwater Flow
in a Weathered Clayey Till in Lambton County, Ontario

by

Wilfrid W. Ruland

FRACTURE DEPTHS AND ACTIVE GROUNDWATER FLOW
IN A WEATHERED CLAYEY TILL IN LAMBTON COUNTY, ONTARIO

by

Wilfrid W. Ruland

A project
presented to the University of Waterloo
in fulfillment of the
project requirement for the degree of
Master of Science
in
Earth Science

Waterloo, Ontario, 1988

(c) Wilfrid W. Ruland

ABSTRACT

The St. Clair Plain in Lambton County, Ontario is underlain by extensive clayey till deposits of about 40 m depth. The till is vertically fractured in a thick zone near the ground surface. This study investigates the depth of active groundwater flow through the fractures. Observations in test pits show that most weathering features reach a depth of only 2.5 m to 4 m, though isolated major fractures extend past the pit bottom of 5.6 m at some sites. Water level response tests show bulk hydraulic conductivity of the fractured till ranges from $< 10^{-6}$ to 10^{-7} cm/s. Hydraulic head profiles show that fractures influence groundwater flow to depths of 5 m to more than 10 m. The water table is usually within 2 m of the surface, but piezometers went dry to depths of 2 m to 4.7 m in a dry period in 1987. Tritium levels > 0.7 T.U., indicating the presence of modern water, are found to maximum depths between 7.5 m and 12 m at all study sites. Tritium is transported by groundwater flow through deep, open fractures and also by molecular diffusion. Increasing $\delta^{18}O$ depletion with depth at most sites indicates that the deeper waters are older, but two of the sites show almost no change in $\delta^{18}O$ with depth. Evidence of active groundwater flow in widely spaced deeper fractures may go undetected in vertical piezometers. The maximum depth of fracture flow is variable, ranging from 5 m to more than 10 m at the 13 sites studied in Lambton County.

ACKNOWLEDGEMENTS

I thank Tricil Limited as well as the Lambton Industrial Society and its member companies for the funding, cooperation, land access and assistance provided over the course of this project. Canadian taxpayers provided additional funding through a Strategic Research grant from the National Sciences and Engineering Research Council, for which I am also thankful.

I am grateful to my supervisor, Dr. John Cherry, who provided many helpful suggestions and yet allowed me the freedom to develop my own ideas and research interests.

Thanks also to all students, staff, and professors in the Department of Earth Sciences and the Institute for Groundwater Research for providing a warm, supportive, and stimulating atmosphere for learning and conducting research.

Special thanks to Andre D'Astous, Jim Smith, Rob Hillier, Don McPhee, Martin Adomait, Sam Vales, Larry McKay, David Thomson, Andy Pentney and Jeff Bridges for their cheerful and energetic assistance with the (often muddy) field research, and to Shirley Schellenberg for her valuable assistance in editing this paper.

TABLE OF CONTENTS

TABLE OF CONTENTS	vii
LIST OF FIGURES	viii
INTRODUCTION	1
METHODS OF INVESTIGATION	4
RESULTS	
Observations from Test Pits	7
Water-level Response Tests and Hydraulic Head Profiles	11
^{18}O and ^2H Results	12
Distribution of Tritium with Depth	13
DISCUSSION	
Visual Evidence of Fractures	14
Hydraulic Evidence of Active Groundwater Flow in Fractures	16
Isotopic Evidence of Active Groundwater Flow in Fractures	18
Implications	23
CONCLUSIONS	25
REFERENCES	27
TABLES	30
FIGURES	31
APPENDIX	48

LIST OF FIGURES

Figure 1:	Location of study sites	31
Figure 2:	Typical test pit cross-section	32
Figure 3:	Fracture spacing vs depth in test pits at four Lambton County study sites . .	33
Figure 4a:	Water level variations - Roycroft and Union Carbide (Novacor) sites . .	34
Figure 4b:	Water level variations - Esso and Allen sites	35
Figure 4c:	Water level variations - Polysar Corunna and Rural Polysar sites . . .	36
Figure 4d:	Water level variations - Dow and CIL sites .	37
Figure 4e:	Water level variations - Tiernay and Dupont sites	38
Figure 5:	^{18}O vs ^2H results	39
Figure 6:	^{18}O vs. depth profiles for Lambton County .	40
Figures 7a:	Field and model tritium vs. depth profiles .	41
Figures 7b:	Field and model tritium vs. depth profiles .	42
Figure 8:	Maximum depth of fractures from drill cores or excavations in Lambton County . .	43
Figure 9:	Fracture spacing vs probability of encountering fractures with various diameter cores .	44
Figure 10:	Probability of encountering fractures at various depths with drill cores of different diameters	45
Figure 11:	Comparison of ^{18}O vs depth profiles	46
Figure 12:	Profile of tritium vs depth with the best fit theoretical profile .	47

INTRODUCTION

Many parts of southwestern Ontario are covered with clay-rich glacial tills, including the physiographic region known as the St. Clair clay plain (Chapman and Putnam, 1984). Lambton County and the city of Sarnia are located within this large, flat-lying region. In Lambton County clayey tills of Quaternary age extend from within a meter of ground surface to depths of 25 m to 50 m, with an average thickness of about 40 m (Desaulniers, 1986). The tills are dark grey, clay-rich, somewhat pebbly sediments which contain sporadic beds or lenses of sandy or silty material (Fitzgerald et al, 1979).

The surficial zone of the tills has undergone weathering by physical, geochemical, and biological processes (D'Astous et al, 1988). Rodvang (1987) observed fractures in drill cores as deep as 9.3 m, and Adams (1969) reported fractures at depths of more than 10 m. The deepest root is that observed by Hanna (1966) at 9 m depth. The fractures and root holes are ubiquitous near the surface, but the frequency of these features diminishes sharply below a few meters depth.

Chemical weathering has caused a colour change in the tills from grey to brown due to oxidation of chlorite in the clay (Ogunbadejo and Quigley, 1973). This process is most active within 2.5 m of the surface and along fractures. The fractures and root holes in the tills are easily

distinguished due to colour changes associated with precipitates or chemical alteration haloes.

Based on piezometer test data, Harding (1986) believed that fractures in the clay tills of Lambton County are usually closed and are rarely significant pathways for groundwater flow. D'Astous et al (1988) showed that borehole smearing caused by augering prevented piezometers from responding with hydraulic conductivities governed by open fractures. When the smeared clay was removed from boreholes, hydraulic conductivities of 10^{-8} to 10^{-6} cm/s were commonly obtained for the fractured tills. These values are one to three orders of magnitude higher than those measured in the underlying and unfractured tills. D'Astous et al (1988) concluded that the fractures and fossil root holes are pathways for 'active' groundwater flow.

The goal of this study is to determine the depth to which fractures cause active groundwater flow in the clayey tills. Information was obtained from 13 sites across Lambton county (Figure 1). One part of the study involves the aquisition of visual evidence about fractures from test pits. In the other part of the study the depth of fracture flow is investigated using isotopes of hydrogen and oxygen to determine groundwater age, and using hydraulic evidence from water level response tests and from monitoring of water level fluctuations over time in piezometers.

Information pertaining to the depth of active groundwater flow is relevant to many types of land use in the clay plains of Lambton County and other parts of southwestern Ontario. Such information is important to rural residents for installation of agricultural drainage or development of water supplies. Knowledge about fractures and fracture flow is also required when trying to determine or predict the extent of groundwater contamination from sources such as landfills or spills of industrial chemicals or petroleum products. Finally, the depth of active groundwater flow through fractures must be accounted for in the design and monitoring of waste disposal facilities such as landfills and lagoons.

METHODS OF INVESTIGATION

Six test pits were excavated by backhoe at four sites, three at Tricil in 1986 and one each at the Dow, Union Carbide and Esso sites in 1987. D'Astous et al (1988) used two pits at the Tricil site for a tracer test and used the third pit, located about 20 m away, for more detailed investigation of the tills. The test pits at all sites were located near previously installed piezometer nests and were about 2 m wide, 4 m long, and 5 m to 6 m deep.

A backhoe provides a quick and safe method of pit excavation and is required for installation of the hydraulic safety supports in the open pits. Smearing of clay on the test pit walls during backhoe excavation is unavoidable. Trowels and paint scrapers were used for prying the smeared clay from the pit walls to expose fractures and other features. Fracture spacings (the number of fractures intersecting the pit wall per horizontal meter) were recorded at half-meter depth intervals. Fracture strike, dip and length were recorded for the 3 pits at the Tricil site. Coatings of the fractures, till colour and consistency, and the maximum depth of fracturing and root penetration were also recorded.

Nests of the Shelby-hole type of standpipe piezometers were installed at 10 of the 13 study sites in 1985. The ten piezometers in each nest ranged in depth from 0.9 to 16 m.

The piezometer tips and standpipes had a diameter of 5 cm. To install a Shelby-hole piezometer a hole is augered to about 0.5 m above the target depth, and a 70 mm diameter Shelby tube is pushed through the base of the augered hole to the target depth. The piezometer tip is installed in the hole created by the Shelby tube, thus avoiding the clay smearing caused by the augering process (D'Astous et al, 1988).

Water levels have been measured monthly in all Shelby-hole piezometers since installation. The piezometers were pumped dry immediately after installation, and water levels recovered for 10 months. The piezometers were then sampled for analyses of major ions, ^{18}O , deuterium and tritium. The water-level recoveries of the piezometers after installation and sampling were analyzed for hydraulic conductivity using the method of Hvorslev (1951).

Auger-hole piezometers at the Lambton and Sarnia sites used by Desaulniers (1986), and Shelby-hole piezometers at the Tricil site used by D'Astous et al (1988) were also sampled for tritium. All tritium analyses from were done at the University of Waterloo Isotope Laboratory using the enrichment method.

Tritium, a radioactive isotope of hydrogen, is often used as an indicator of groundwater age (Payne, 1972). Background atmospheric levels of tritium in Ontario were low, about 3 to 5 tritium units until the early 1950's (Robertson

and Cherry, 1988). Subsequent aboveground nuclear tests caused atmospheric levels of many radioactive isotopes to increase dramatically. Measured tritium concentrations in precipitation reached several thousand tritium units (T.U.'s) by 1963, when most above-ground testing ended. Tritium has a half-life of 12.3-years. Groundwater recharged by precipitation prior to 1952 has tritium levels < 0.7 T.U. today. If water samples have higher tritium levels then mixing with at least some 'modern' precipitation has taken place.

Deuterium and ^{18}O are isotopes of hydrogen and oxygen which are used for determining groundwater origin directly, and groundwater age indirectly. Their relationship is described by the 'meteoric water line', the line of the equation which best fits the relative concentrations of these isotopes in precipitation. This line varies around the globe but is quite stable for any one region. Groundwater samples falling on or near the local meteoric water line have recharged directly from precipitation, with little or no evaporation having taken place. The concentrations of both ^{18}O and deuterium in precipitation decrease with decreasing air temperature. Desaulniers (1986) used plots of ^{18}O vs depth to determine the relative age of groundwaters in Sarnia-area clays. The older waters at depth, recharged in the colder climate prevalent after the last glaciation, were more depleted in ^{18}O than modern near-surface groundwaters.

RESULTS

Observations From Test Pits:

The following features were observed in each of the six test pits (Figure 2):

- 1) A soil zone extends from the surface to depths of up to 1 m. The soil is composed of a reddish-brown, aggregated, highly oxidized and organic-rich clay. The base of the soil zone is marked by a colour change from reddish-brown above to brown below.
- 2) Underlying the soil zone is a zone of oxidized, brown or mottled-brown clay which reaches depths of 2.2 m to 2.5 m. The boundary to the soil zone above is also marked by the appearance of carbonate minerals leached from the soil zone, which are present as secondary coatings or areas of alteration around fractures.
- 3) A gradual colour change occurs over the next 0.3 m to 1.3 m. Below depths of 2.5 m to 3.5 m the clay then has the grey colour characteristic of the unweathered tills. Quigley and Ogunbadejo (1976) attributed this colour change from grey below to brown above to oxidation of illite and chlorite to form swelling clays near the surface of the Lambton County clay tills.
- 4) Fractures extend from the soil zone through the brown

clay and into the underlying, unweathered grey clay zone. Fractures reach depths of at least 4.5 m at all sites.

5) The fractures have red, black, or grey-white coatings or reddish-brown oxidation zones, giving them a different colour from the surrounding matrix of grey or brown clay. Red coatings are likely iron hydroxides (Quigley and Ogunbadejo, 1973) and the black fracture coatings have the appearance of manganese. The grey-white coatings reacted strongly with acid and are apparently calcareous. Chemically weathered fractures extend past the bottom of the 5.6 m deep test pits at the Esso and Tricil sites, but were not observed below 5 m depth at the Dow and Novacor sites.

6) Below the oxidized brown clay zone some fractures are the same colour as the surrounding grey clay matrix. These fractures were only discovered by chance when the clay, which is otherwise very stiff, parted more easily along the relatively smooth planar fracture surfaces.

7) Most fracture dips are vertical or near-vertical. There are no apparent preferred directions of strike (D'Astous et al, 1988).

8) Fracture spacing steadily increases, from one fracture every 1 cm near the surface to one fracture every 50 cm to 2 m at 4.5 m depth (Figure 3). Fractures are closely spaced and obviously interconnected near the surface. Just below

the oxidized zone there are often criss-crossing systems of sub-parallel and closely spaced fractures (one fracture every 2 cm to 6 cm), separated by blocks of unweathered clay. These fracture systems decrease in number with depth and the blocks of unweathered clay become larger. The systems eventually reduce to single isolated fractures, which at depths of about 4.5 m to 5.5 m often become indistinguishable from the surrounding grey clay till matrix. The fractures without visible weathering features detected below the oxidized zone were not counted for fracture spacing determinations.

9) The vertical length of the fractures varies widely. There are many small fractures (2 cm to 20 cm long) generally found near the ground surface. Longer fractures up to 1 m in length are usually found between depths of 2 m and 4 m. Very long fractures, which can extend from near the ground surface to 5 m depth or more, are infrequent but were observed at all sites.

10) Roots or fossil roots were observed to depths of 3.9 m. The roots develop preferentially along fracture surfaces, though isolated root channels with visible weathering features such as oxidation haloes were observed in otherwise unweathered clay from drill cores at depths of 2.5 m to 4 m.

11) The clay becomes increasingly moist and plastic as the depth below ground surface increases.

The following observations were made in test pits at one or more, but not all of the sites:

- 1) Water was observed flowing from fractures after rainfall events at the Tricil and Novacor sites. Test pits were excavated at the Tricil site during a very wet summer (1986), and flow rates of up to 90 L/hour into the open pits were observed (D'Astous et al, 1988). The test pit at the Novacor site was excavated 12 hours after brief showers had occurred, and fracture surfaces were moist near the surface and dripping water at the trench bottom. Trenches at the other sites were excavated during a long drought (in 1987), and fractures ranged from dry near the surface to moist at the trench bottom.
- 2) Fossil root channels acting as macropores for vertical groundwater flow were observed dripping water at the Tricil site. Further evidence of roots acting as macropores are the alteration or oxidation zones in the clay matrix around root channels.
- 3) Gypsum crystals were observed in fractures, and also in the clay matrix unassociated with fractures, near the surface of the Novacor site. Smaller amounts of gypsum occur around fractures at the Esso site, Dow site and in one but not the other two test pits at the Tricil site.

Water Level Response Tests and Hydraulic Head Profiles:

Hydraulic conductivities based on water level response tests show significant variation (Table 1). Piezometers in the upper 3 m of the tills commonly have hydraulic conductivities greater than 10^{-6} cm/s. Below 3 m, values usually range from between 10^{-6} cm/s to 10^{-7} cm/s. Though there are exceptions, values tend to decrease with increasing depth below the ground surface.

Many of the deeper piezometers took until the spring of 1987 (even longer in a few cases) to recover to equilibrium levels following installation in 1985 and sampling in 1986. The piezometers had 'fully recovered' once water levels, which climbed steadily after installation and sampling, levelled-off or fell.

In the spring of 1987 there was an almost uniform downward hydraulic gradient throughout the profiles (Figures 4a to 4e). Soil frost prevented groundwater-surface interactions during the previous winter and a downward hydraulic gradient developed. The water table was close to the surface because of the heavy precipitation of the preceding year.

The summer profiles (recorded during a period of below-normal precipitation) show the downward hydraulic gradients observed in spring being replaced by an upward gradient near

the ground surface. This was caused by evapotranspiration and may have been influenced by lateral gradients caused by small-scale local topographic irregularities. Several of the near-surface piezometers were completely dry.

By the fall of 1987 (the dry conditions persisted through this period) a strong upward gradient developed. Piezometers were dry to depths of up to 4.7 m at some sites.

^{18}O and ^2H Results:

A plot of $\delta^2\text{H}$ vs $\delta^{18}\text{O}$ was prepared for all data from the 10 sites (Figure 5). The meteoric water line for Simcoe, Ontario (Fritz et al, 1987), which is the closest location for which this information is available, is included for comparison. The data points fall on or slightly below the Simcoe meteoric water line, indicating that there has been little or no change in the isotopic composition of these waters since they fell as precipitation.

Profiles of $\delta^{18}\text{O}$ vs depth are presented in Figure 6, and fall into two distinct groups. Near the ground surface, $\delta^{18}\text{O}$ values of -8 to -10 ‰ are common. As depth below surface increases, the groundwater at six of the sites becomes increasingly depleted of ^{18}O . Samples from 15 m depth at these sites have values around -13 ‰. The other four sites show much less of a depletion of ^{18}O with depth, with values at 15 m depth of about -10 ‰.

Distribution of Tritium with Depth:

Tritium vs depth profiles (Figures 7a, 7b) generally show maximum tritium concentrations of 30 to 80 T.U. at depths of less than 3 m. There is then an abrupt drop to about 10 T.U. over the depth interval of 3 m to 5 m. There are anomalously long 'tails' on the tritium profiles, with levels gradually dropping to below detection limits of the enrichment method (of 0.7 T.U.) at depths of about 7.5 m to 12 m. The occasional increases in tritium levels below 3 m are not commonly seen on such profiles.

DISCUSSION

Visual Evidence of Fractures:

An air photograph of the Tricil site (Richards et al, 1984) shows wet and dry areas indicative of a well defined sub-surface lateral flow system influenced by very small local topographic irregularities. Similar flow systems have been observed in other clay plains by several researchers (Keller et al, 1986 and Gartner Lee Limited, 1987), and are believed to be caused by groundwater flow through fractures.

The depth of visible fractures varies across Lambton County. Most (>90 %) of the fractures with visible weathering features such as coatings or oxidation haloes do not extend below 5 m depth (Figure 3). Significant numbers of these fractures do, however, extend well beyond 5 m depth.

There is evidence in the literature that fractures have been observed in drill cores beyond 10 m depth in places in Lambton County (Figure 8). Most researchers determined the maximum depth of fractures from observations of drill cores, except Harding (1986) and Vorauer et al (1986) who also used shallow test pits like those used in this study.

Though the number of fractures decreases steadily with depth, there is no easy way to determine whether or where there is an absolute cut-off depth below which there are no

fractures. Figure 9 is a theoretical graph of the probability of encountering equally spaced vertical fractures of specified spacing in vertical drill holes of different diameters. Combining the average fracture spacings vs depth recorded in the 6 test pits (Figure 3) with Figure 9, yields a plot showing the probability with depth of encountering vertical fractures with drill holes of different diameters (Figure 10).

Below 5 m depth there is less than a 10 % chance of encountering fractures with the vertical holes used in conventional drilling programs, though there are still significant numbers of fractures present (eg. an average of 5 fractures every 10 m at a depth of 5.5 m). Vertical drill holes will miss vertical fractures which lie directly beside but do not intersect those holes. If fractures are not encountered with vertically drilled holes beyond a given depth, this does not necessarily mean that there are no fractures present beyond that depth.

Fractures without weathering features, discernible only because the clay parted easily along well-defined and smooth planar surfaces, were encountered near the bottom of all test pits. It is not clear whether groundwater flow is occurring through these fractures.

Groundwater flow is definitely occurring in at least some of the visible fractures. This was proven by the

observations in test pits at the Tricil site, where water flowed through fractures into test pits at rates of up to 90 L/hour.

Hydraulic Evidence of Active Groundwater Flow in Fractures:

The water-level response tests show that piezometers near the ground surface, where the probability of intersecting fractures is greatest, have hydraulic conductivities significantly higher than deeper piezometers (Table 1). The presence of a surficial fractured zone of higher hydraulic conductivity means that only a minimal amount of (downward) flow through the unfractured, unweathered clay below this zone is to be expected (Richards et al, 1984 and Desaulniers, 1986).

The hydraulic conductivities obtained from Shelby-hole piezometers in this study represent an increase of one to three orders of magnitude over the values obtained by Desaulniers (1986) and Harding (1986), who used piezometers installed in augered holes. The Shelby-hole piezometers give measured hydraulic conductivity values more representative of fracture flow in the clayey tills than those obtained from conventional auger-hole piezometers. Other types of installations may, however, be required if truly representative measurements of the hydraulic conductivity of the fractured tills are to be achieved.

A comparison of water level fluctuations over time can assist in determining the depth to which fracture flow is occurring in clayey deposits. Significant water level fluctuations occur to depths of 5 m to 10 m across Lambton County, and provide strong evidence of an active zone of groundwater flow through fractures.

Water level fluctuations exceeding half a meter over the 6 months from spring to fall 1987 must be caused by fracture flow. Such fluctuations take place to depths of between 5 m and 10 m at most sites, and are observed throughout the profile at the Allen site (Figures 4a to 4e). At most sites water levels are virtually constant below a depth of 5 m to 10 m, indicating that below these depths the fractures are not significantly contributing to groundwater flow or are so widely spaced that their influence is not felt by piezometers.

In a related, detailed study at the Tricil Ltd. site of water level fluctuations using piezometers and tensiometers equipped with pressure transducers, Adomait (1988) reported a 5 m deep zone of rapid piezometric response to rainfall events overlying a deeper unresponsive zone.

The drying out of shallow piezometers in the fall of 1987 provides another indication of groundwater flow through fractures. In unfractured clays, strong negative hydraulic heads can develop without an appreciable amount of water

being drawn from the clay. The pore spaces in the clay are so small that capillary effects hold water in the pores against significant negative hydraulic head. Fractures in clays drain more quickly in dry periods than the unfractured blocks of clay matrix because the water in the fractures is more readily available. When piezometers go dry to depths of more than 4 m as in the fall of 1987, this implies that water is being removed through fractures at that depth.

Isotopic Evidence of Active Groundwater Flow:

The depth profiles of ^{18}O in this study are similar to the upper part of Desaulniers' 35 m to 45 m profiles (Figure 11). Desaulniers (1986) found that porewaters from the unfractured zone of the Sarnia tills became increasingly depleted in ^{18}O with depth. He attributed depleted ^{18}O values in the deeper waters to their being composed of precipitation or meltwater from local ice sheets of the much colder late Pleistocene or early Holocene time periods. Groundwater closer to the surface has higher ^{18}O levels because of mixing with less depleted modern waters.

Six of ten ^{18}O profiles from this study are similar to the typical ^{18}O profiles of Desaulniers (1986), for which he hypothesized a downward flow velocity of 0 below the active zone. Four other site profiles (Allen, Dupont, Tiernay, & CIL) are similar to Desaulnier's profile from the Lambton II

site, which had a large hydraulic gradient (0.4) and an estimated downward flow velocity of 0.25 cm/year. The high ^{18}O levels at Lambton II and at 3 of the study sites are likely due to high rates of recharge of modern water. Water level fluctuations show that fractures are deepest at the Allen and Dupont study sites, while the Tiernay and Dupont sites have the largest hydraulic gradients (0.3) observed in the study. The CIL profile starts with very enriched ^{18}O levels but then shows a more typical depletion of ^{18}O with depth. Since the site is located in a bog, isotopic fractionation during evaporation may have caused the recharging groundwater to become enriched in ^{18}O .

Further evidence of fracture flow was provided by groundwater tritium levels, which exceeded detection limits to maximum depths of 7.5 m to more than 12 m.

A one-dimensional analytical model was used to generate theoretical profiles of tritium vs. depth, which were then compared to measured tritium profiles from the study sites. The model features an analytical solution to the one-dimensional advection-dispersion equation given by Cleary (1978). An effective diffusion coefficient value of $6 \times 10^{-6} \text{ cm}^2/\text{s}$, similar to values obtained from laboratory tests by Desaulniers (1986), was used to represent Lambton county clays. Longitudinal dispersivity and average flow velocity were varied to obtain a theoretical profile with the best

possible fit to the field profiles.

The Ottawa, Ontario tritium vs time relation was used in the model to represent precipitation input conditions (Robertson and Cherry, 1988). Levels recorded for Ottawa are the world's only continuous record dating back to 1952 of tritium in precipitation. Tritium values before 1952 are assumed to be 3 T.U.

The best fit of a theoretical profile of tritium vs depth was obtained using an average linear velocity of 2 cm/year and a longitudinal dispersivity of 3 m (Figure 12). The general shape of the simulated profile, with highest tritium levels near the surface and a steady decline to below detection limits as depth increases, is observed in most profiles (Figure 12). There are however anomalous increases in tritium concentrations at various depths in 8 of the profiles, and long 'tails' on the tritium profiles before they drop below detection limits of 0.7 T.U.

The 'tails' of tritium could be indicative of a significant downward flow velocity in the Lambton County tills. Previous modelling by Desaulniers (1986) indicates, however, that field profiles of ^{36}Cl and Cl^- over the entire till sequence can best be fitted by simulated curves with a zero downward flow velocity below the fractured zone. The 'best fit' average flow velocity from the model used in this study is also insignificant over the tritium timescale of 35

years. Another explanation must be found for the significant tritium levels at depths of 8 m or more.

The likelihood of sample contamination is remote, as is the possibility of contamination of the piezometers. Tritium values eventually do drop to below detection limits at the bottom of the profiles. It is unlikely that only samples from near-surface piezometers are contaminated, with deeper samples being unaffected.

One explanation for the observed profiles is that the zone of fracture flow does not have an abrupt lower boundary, and instead that the density of fractures and the degree of their interconnectedness decreases slowly with depth. Flow through isolated, exceptionally deep and open fractures could be the cause of the anomalous features in the tritium profiles. This is consistent with the modelling results, in which the high downward flow velocity and longitudinal dispersivity can be interpreted as representing groundwater flow through fractures.

Most of the fracture flow in the Lambton County tills should be lateral however, with only a minor downward component in the areas of topographic highs. In the summer, significant rates of upward flow could even be expected. In such a flow system, molecular diffusion to the matrix as described by Day (1977) should be reducing concentrations of tritium in fractures to very low levels even if fracture flow

occurred in fractures to depths of 5 m to more than 10 m, with subsequent molecular diffusion carrying tritium about 2 meters into the underlying unweathered clay.

The maximum depth of the fractured zone in Lambton County clay tills ranges from 5 m to more than 10 m, and groundwater flow occurs in at least some fractures throughout that zone at all study sites. Future studies must address the question of what depth the fractures without visible weathering features extend to, and whether the lack of weathering features necessarily implies that those fractures do not contribute to groundwater flow.

The increase in fracture spacing with depth results in considerable uncertainty in determinations of the maximum depth of fracture flow using hydraulic, isotopic or other evidence from piezometers. The results of this study should be viewed as a conservative estimate of the actual maximum depth of active groundwater flow in fractures in Lambton County.

TABLE 1: Hydraulic Conductivity ($\times 10^{-7}$ cm/s) vs Depth
for 10 Lambton County Study Sites

Approx. Depth	Lambton County Study Sites									
	Roy	Dow	Ess	Dup	PC	UC	RP	CIL	T	Allen
1.0 m	>10	>10	>10	>10	>10	>10	>10	>10	>10	>10
2.0 m	3	>10	>10	>10	>10	>10	3	>10	>10	>10
3.0 m	4	2	>10	>10	>10	>10	3	2	3	>10
4.0 m	2	5	3	4	2	1	2	2	2	>10
5.0 m	3	4	1	2	3	3	2	1	3	3
6.5 m	2	3	2	2	2	2	2	2	2	2
8.0 m	2	2	2	1	3	2	1	1	1	6
9.5 m	3	2	1	1	3	2	2	2	0.9	3
12.6 m	2	3	1	1	1	2	6	1	0.9	4
15.7 m	1	3	1	1	1	2	1	2	1	4

TABLE 2: Indicators of Maximum Depth of Fracturing
in Lambton County

Indicator	Lambton County Study Sites									
	Roy	Dow	Ess	Dup	PC	UC	RP	CIL	T	Allen
tritium	6.1	8.1	12.9	8.0	13.0	8.1	8.1	9.6	7.7	7.8
w.levels	4.8	6.5	9.6	9.6	9.8	5.0	6.6	5.0	3.9	15.6
test pits		4.5	>5.6			4.5				
cores			5.0			9.3	9.2	2.1		

The maximum depth of fracturing should be seen as a conservative estimate based on the line of evidence indicated

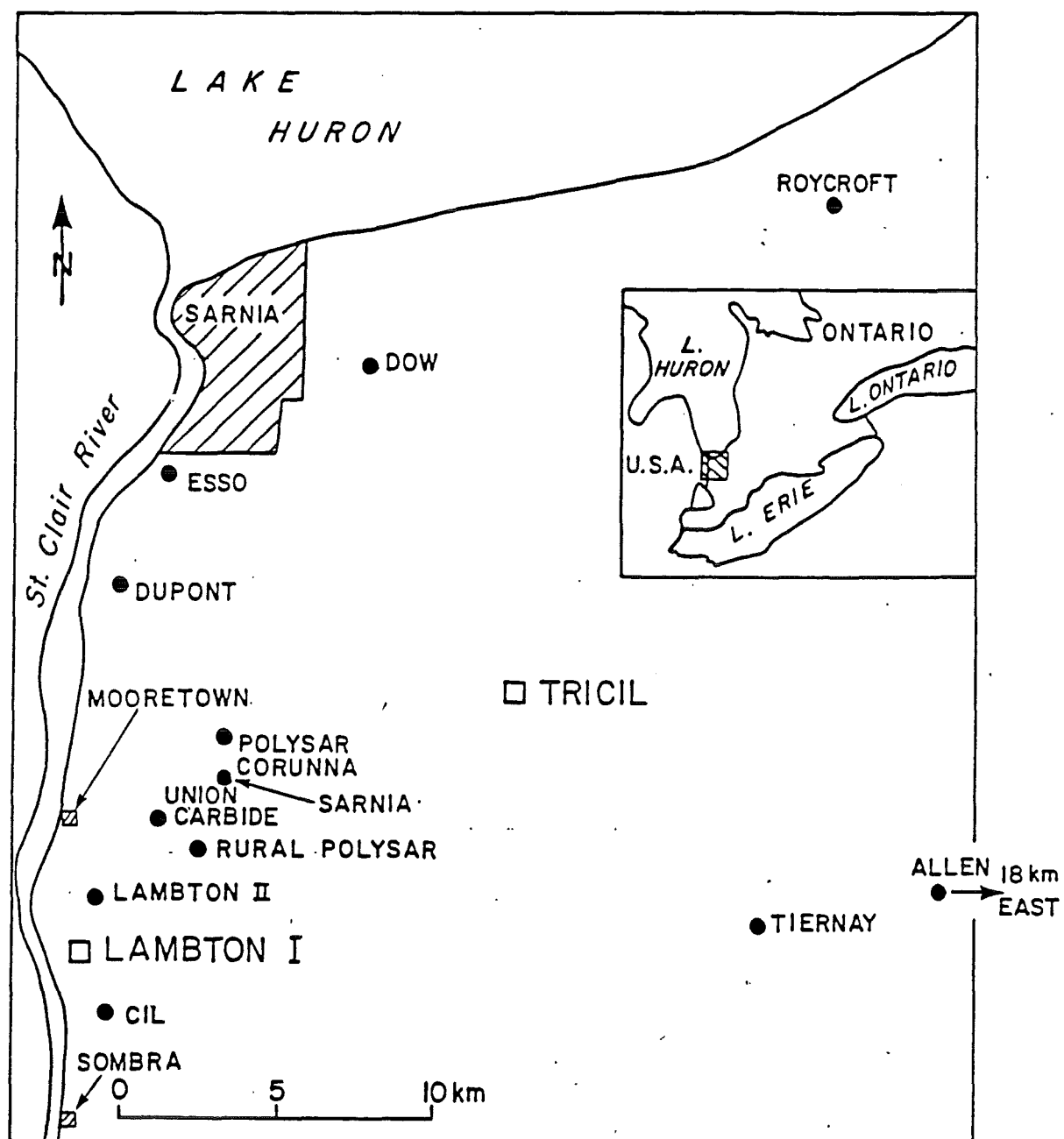


Figure 1: Location of study sites

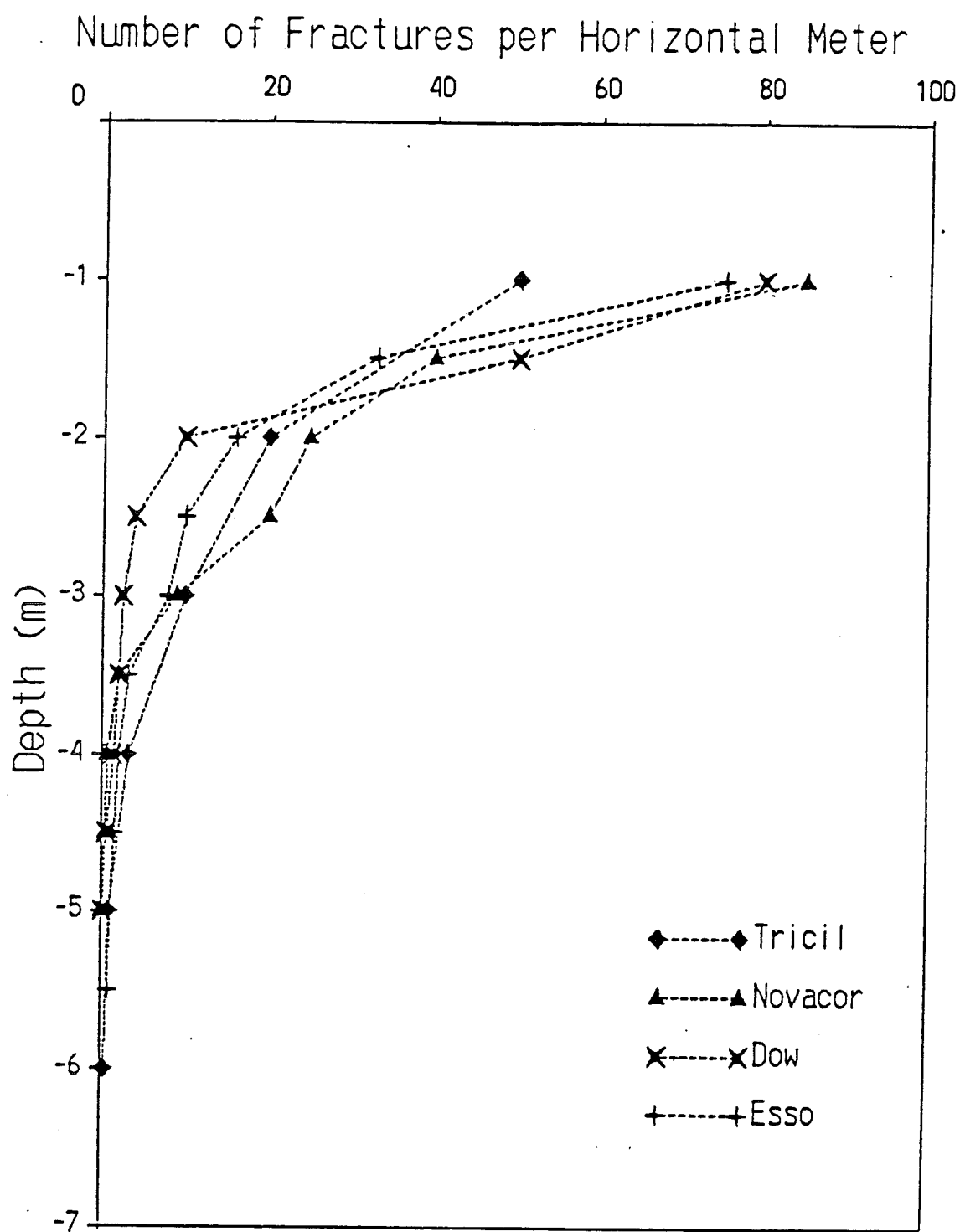


Figure 3: Fracture spacing vs depth in test pits at four Lambton County study sites

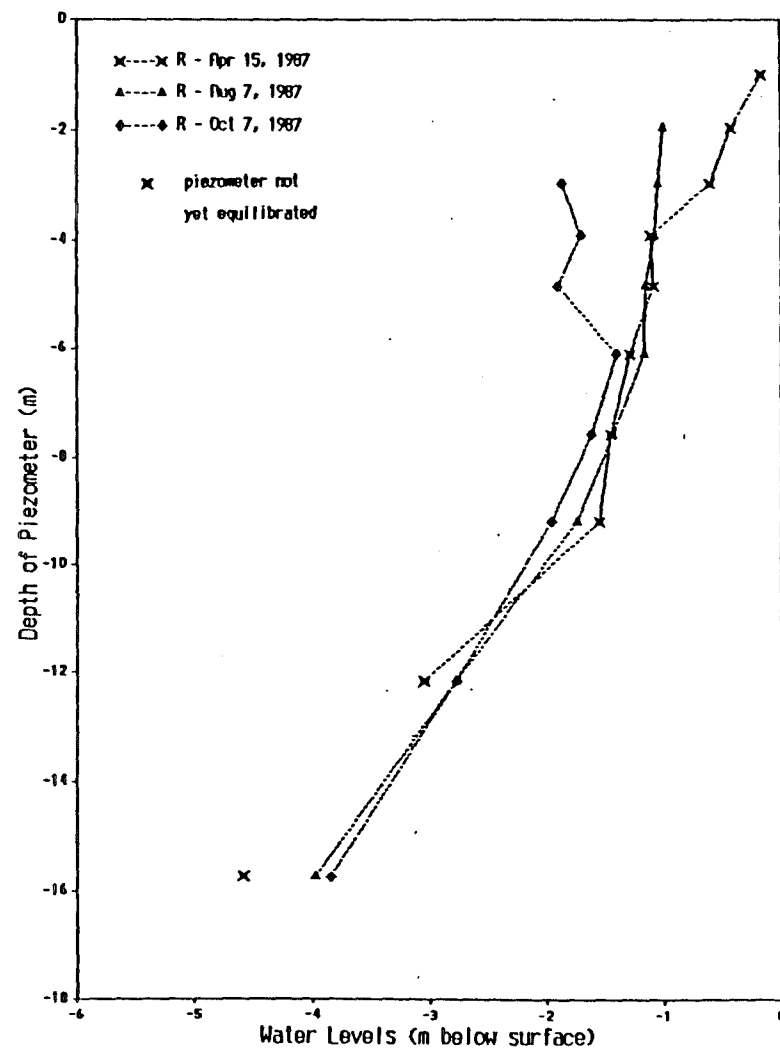
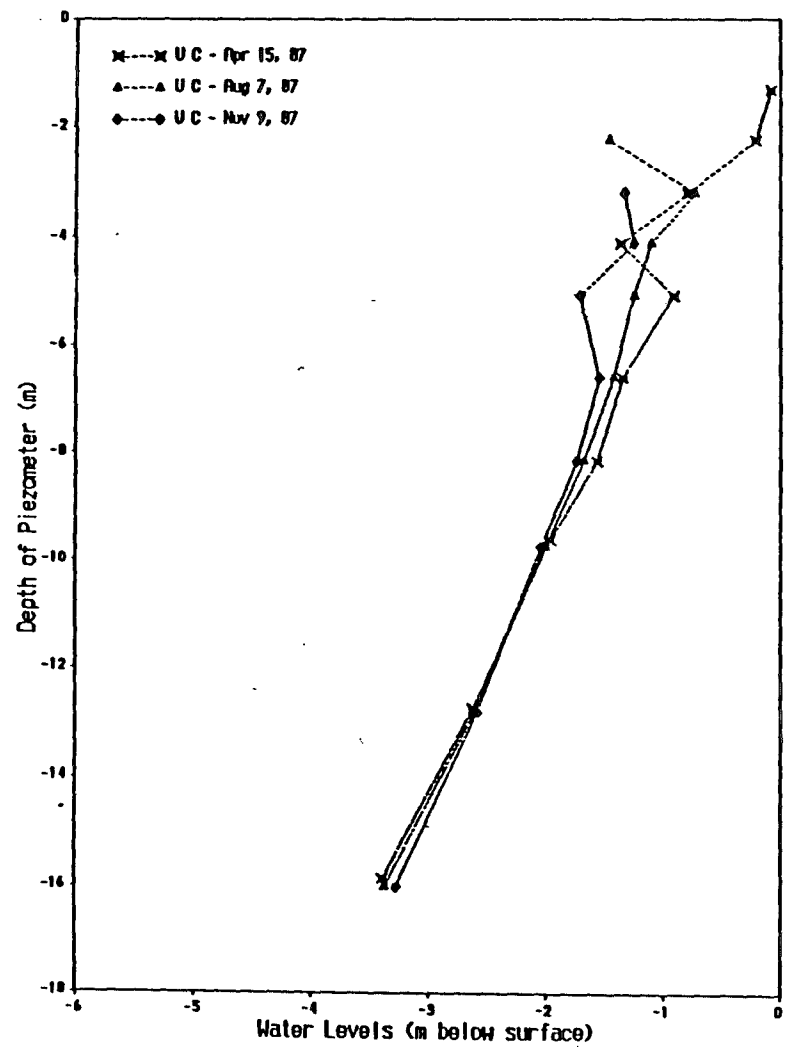


Figure 4a: Water level variations - Union Carbide (Novacor)
and Roycroft sites

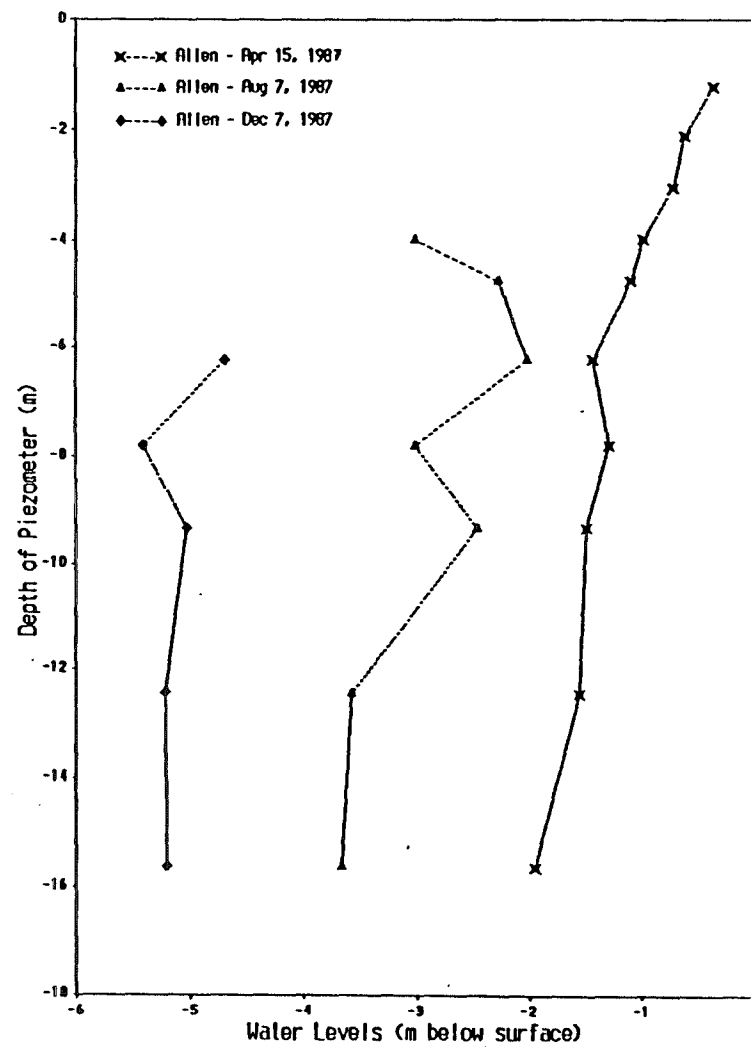
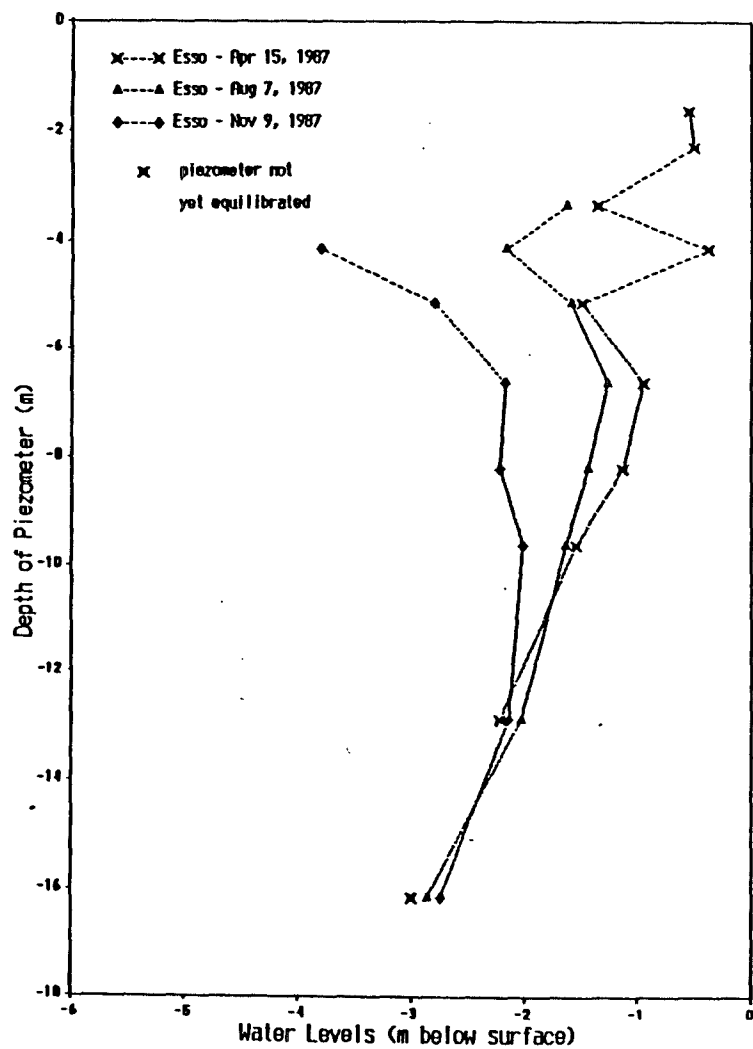


Figure 4b: Water level variations - Esso and Allen sites

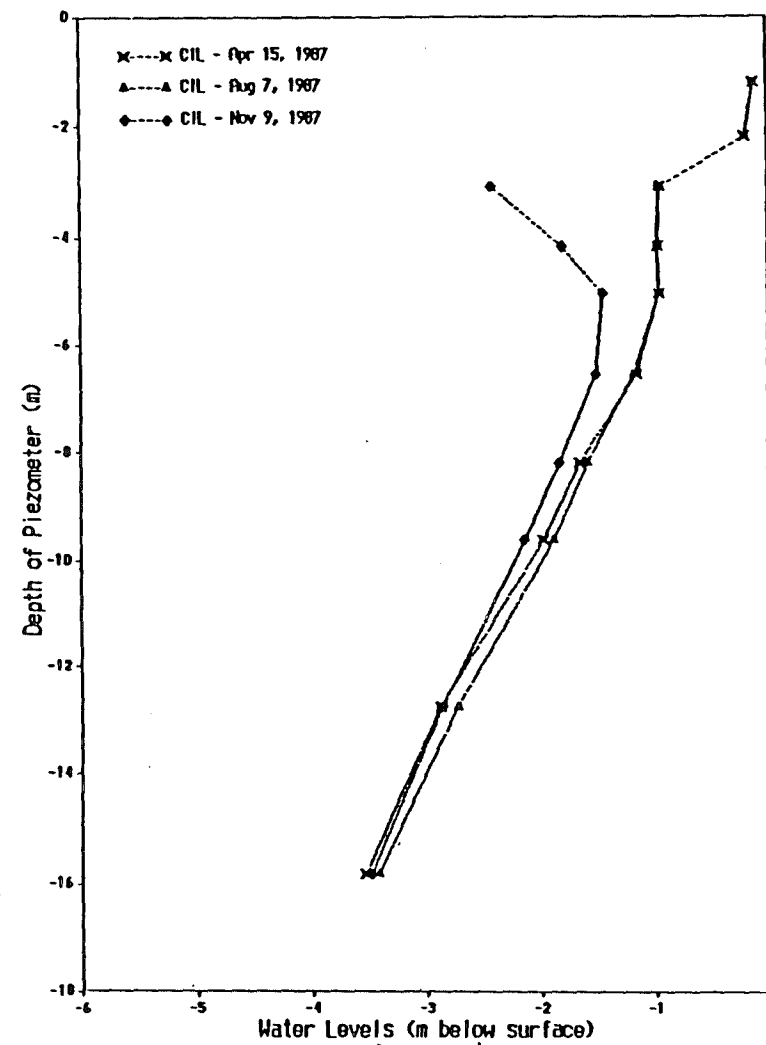
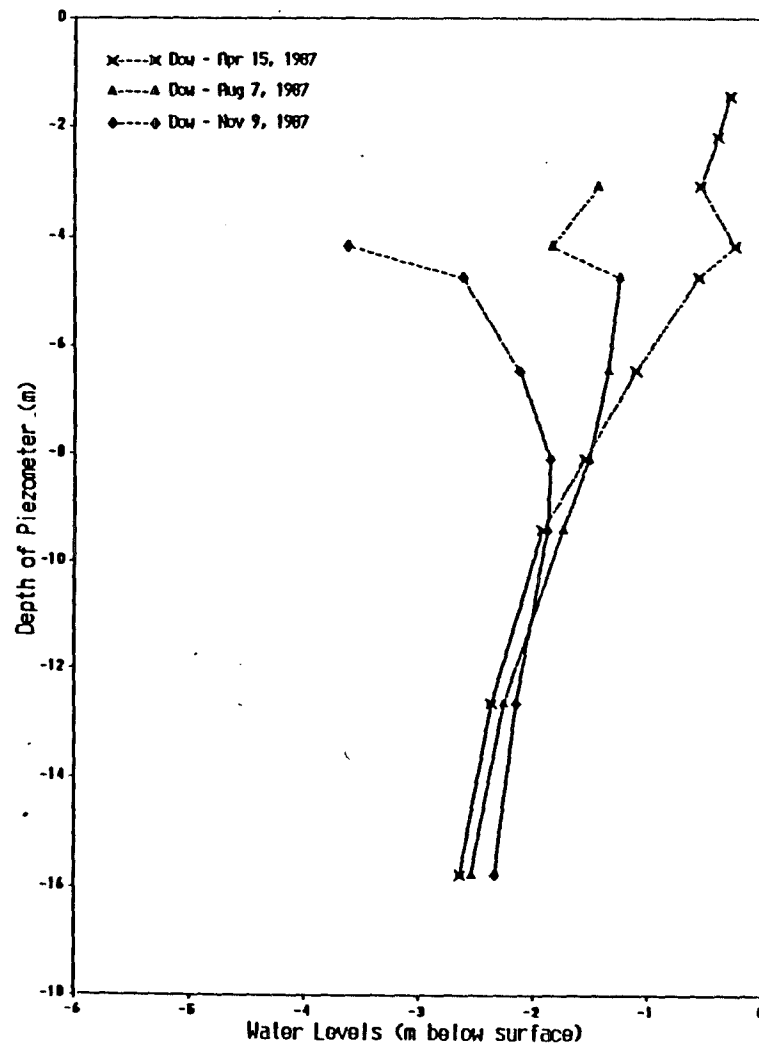


Figure 4d: Water level variations - Dow and CIL sites

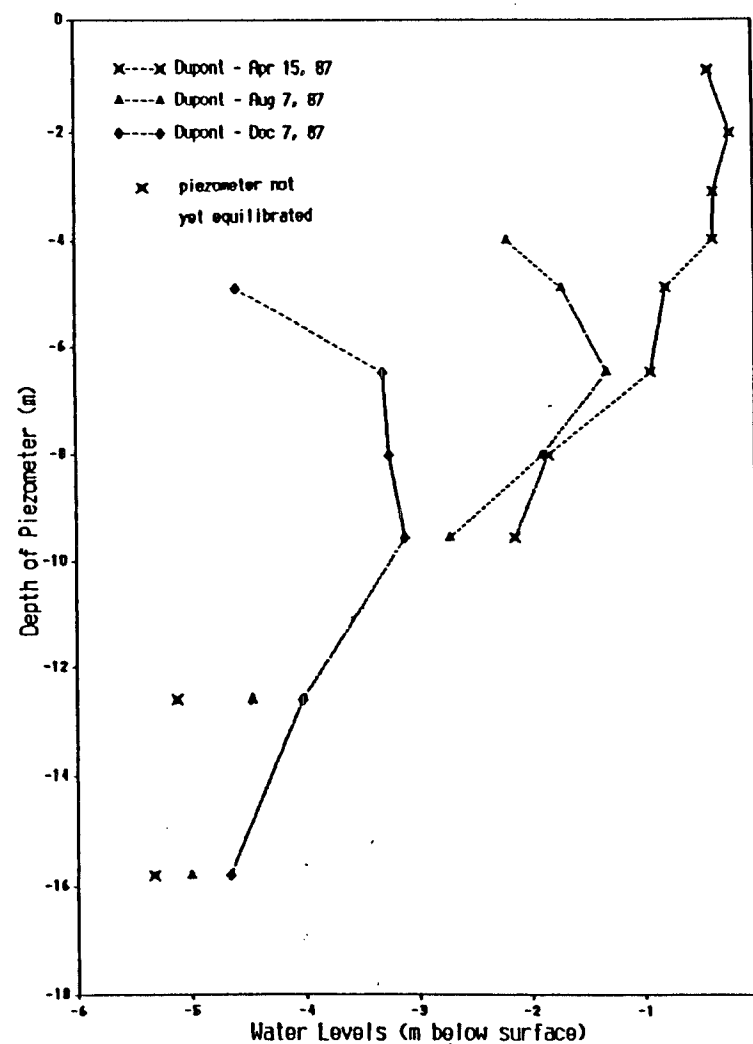
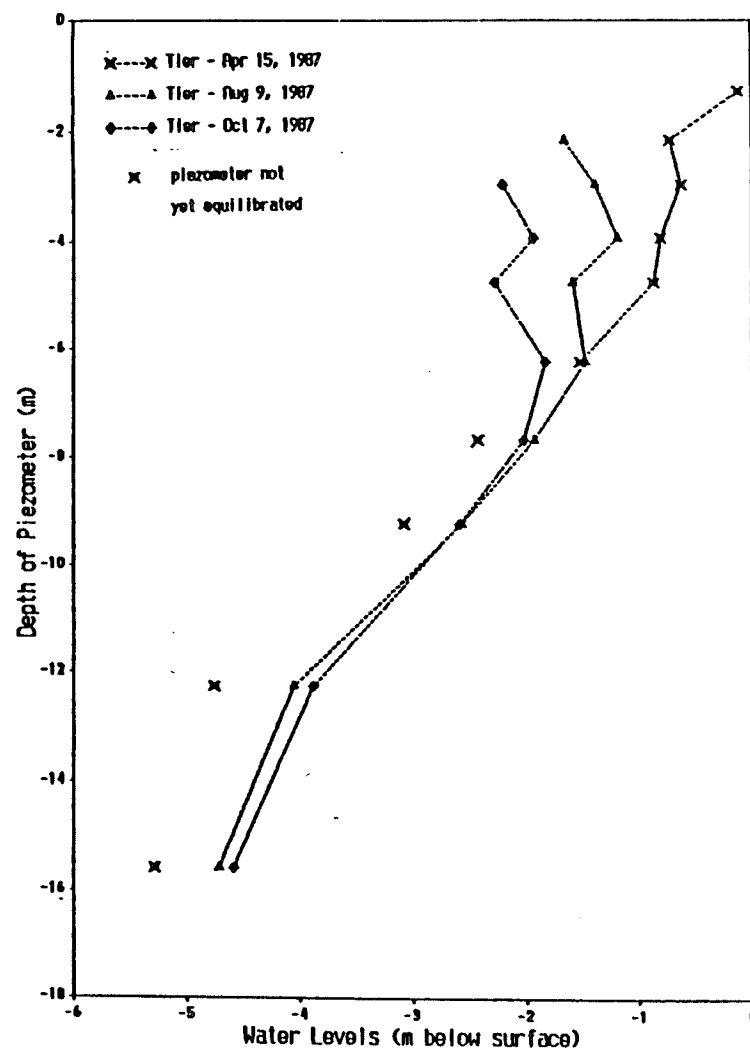


Figure 4e: Water level variations - Tiernay and Dupont sites

Oxygen-18 vs Deuterium Results Lambton County

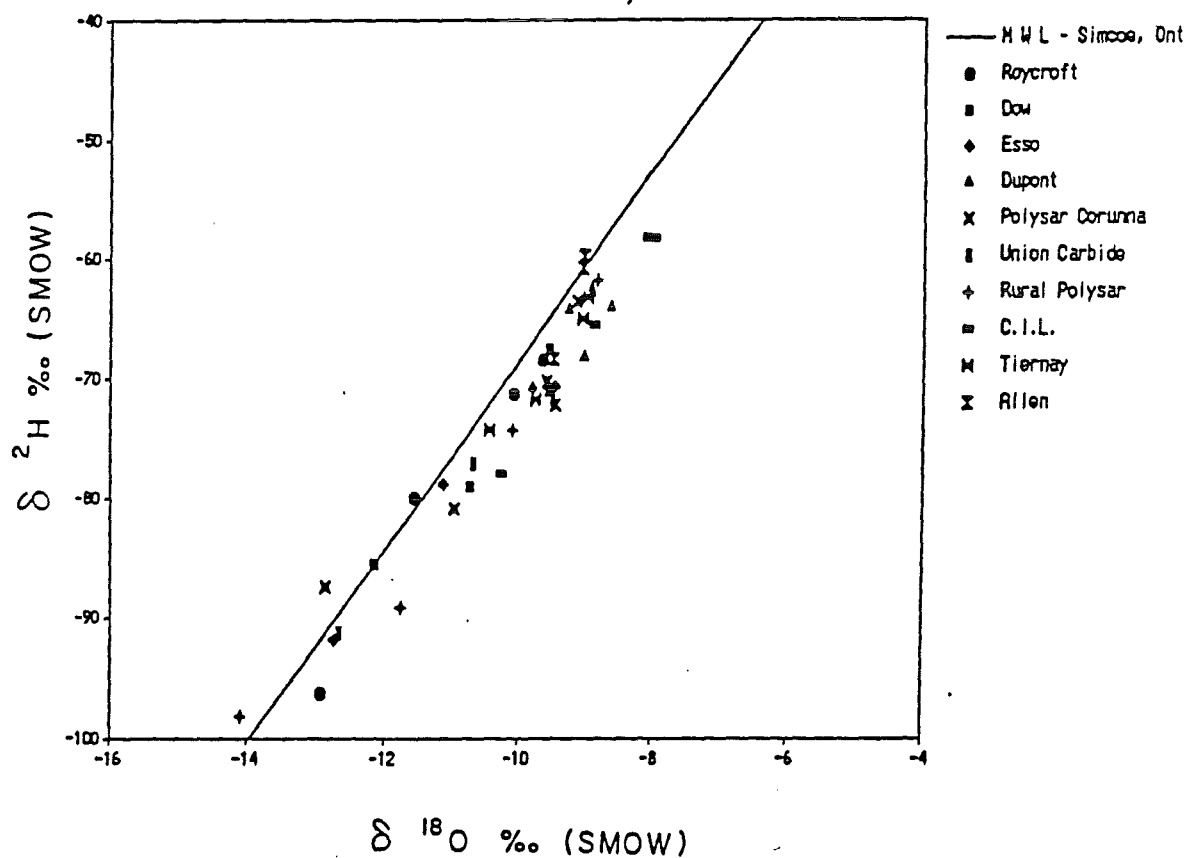


Figure 5: ^{18}O vs ^2H results

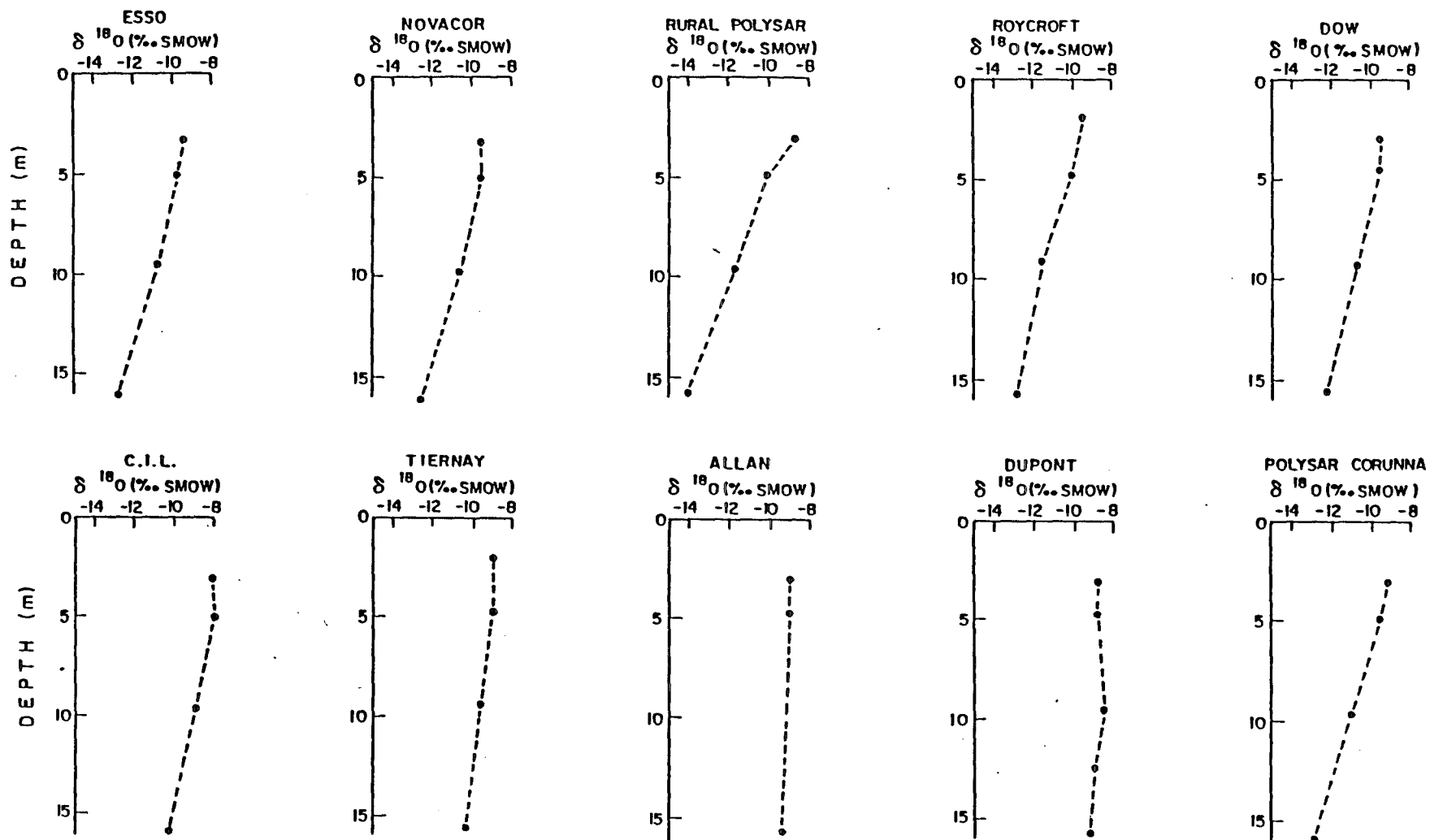
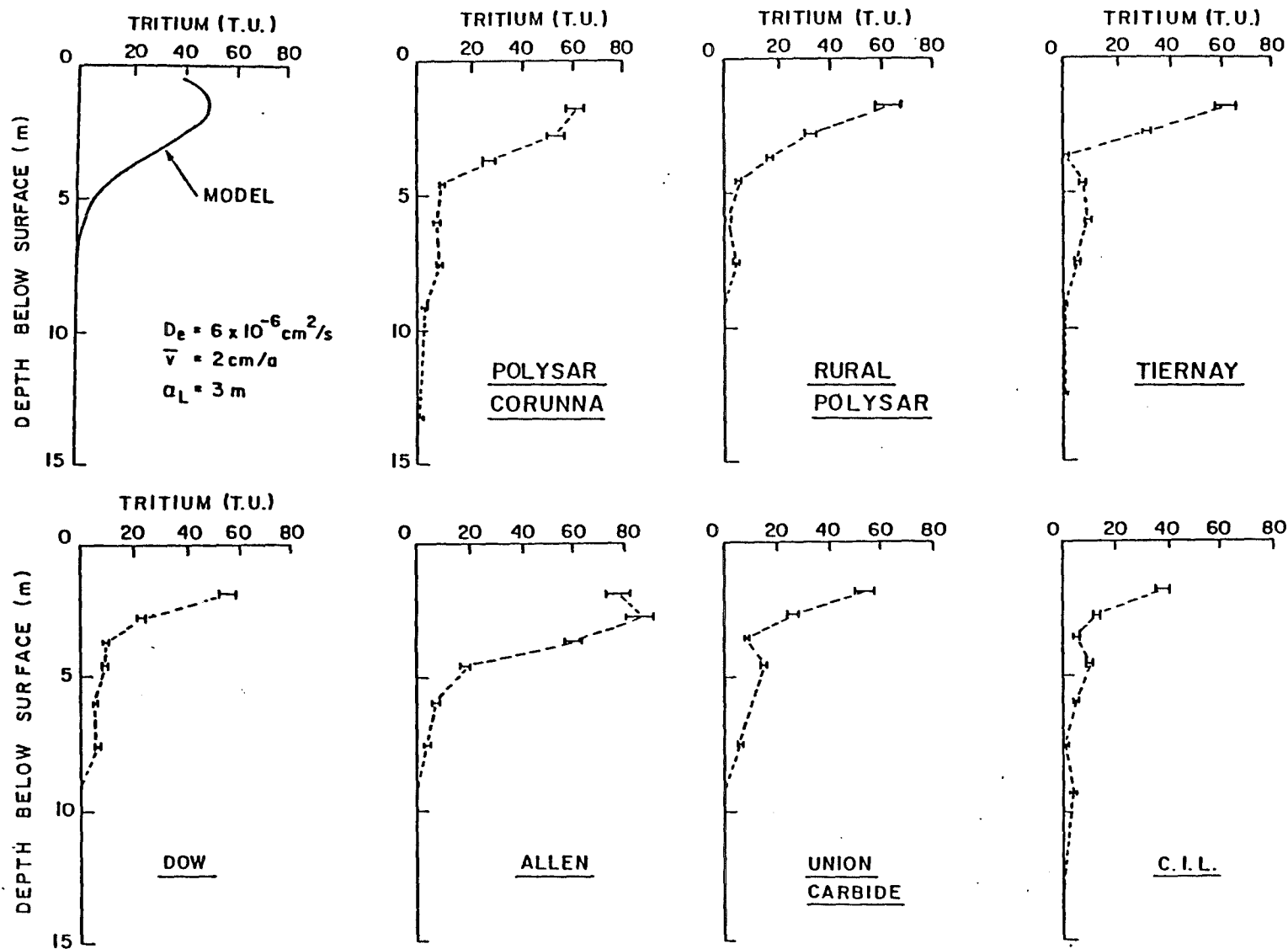
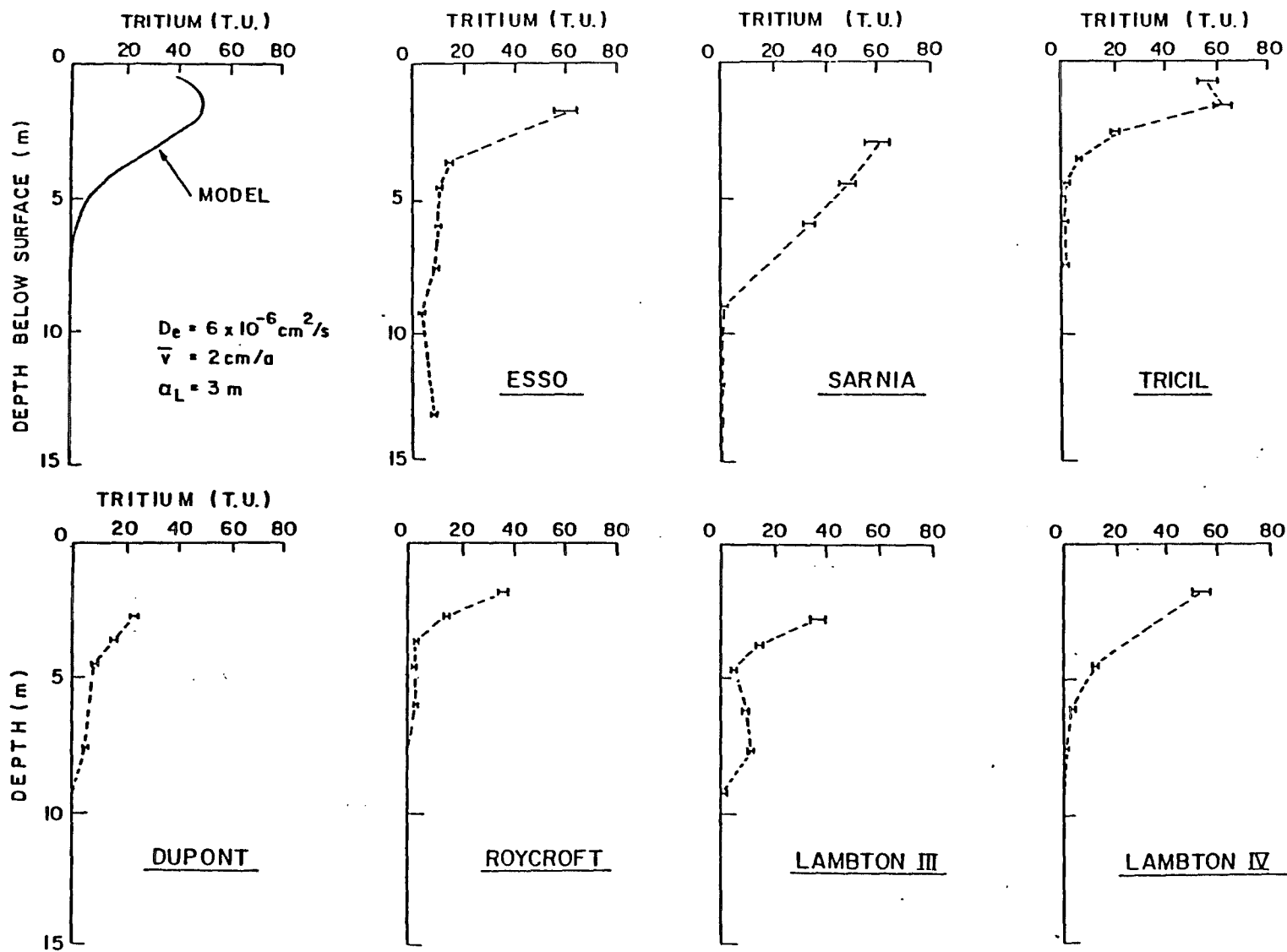


Figure 6: $\delta^{18}\text{O}$ vs. depth profiles for Lambton County



Figures 7a: Field and model tritium vs. depth profiles



Figures 7b: Field and model tritium vs. depth profiles

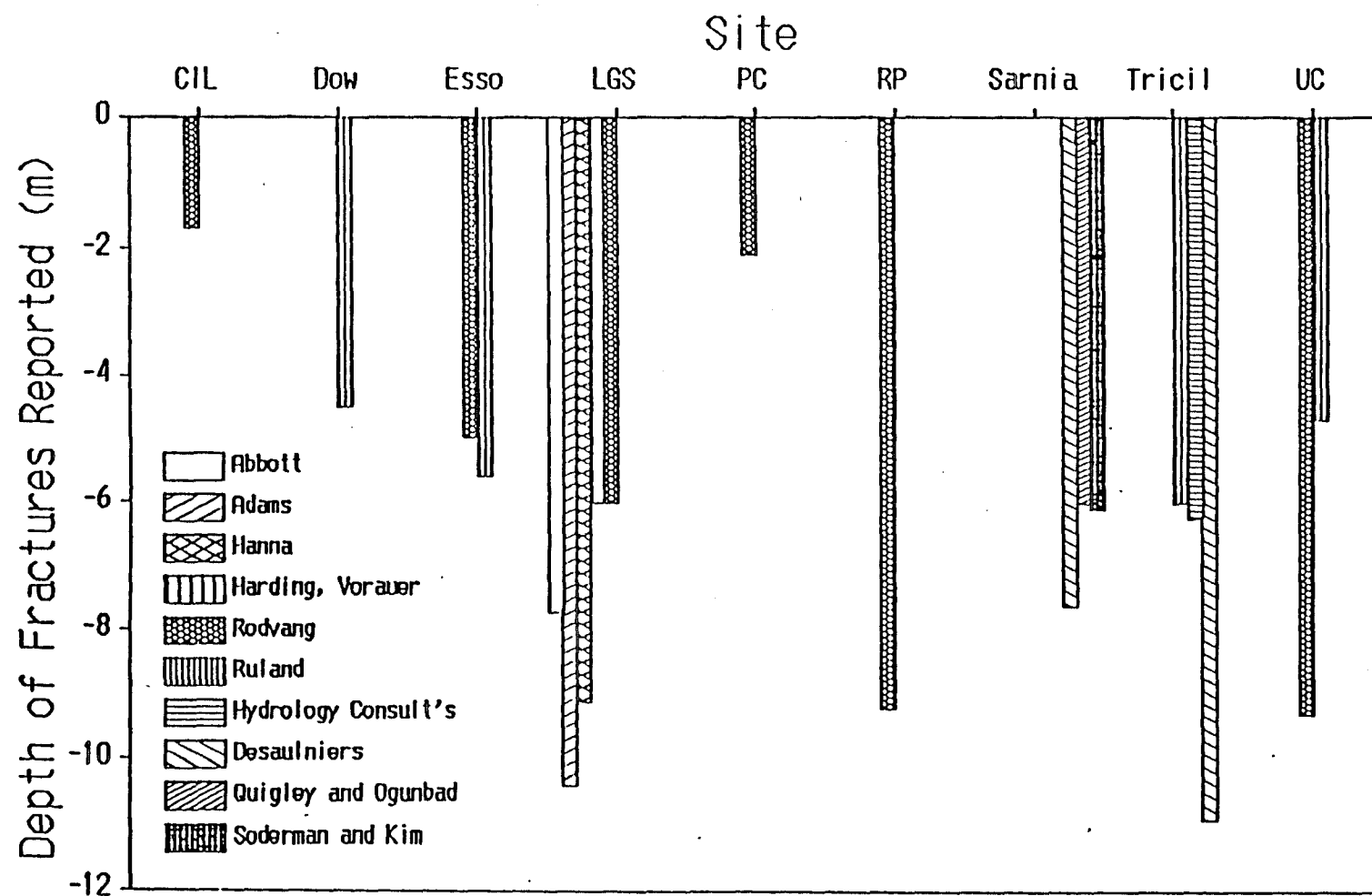


Figure 8: Maximum depth of fractures from drill cores
or excavations in Lambton County

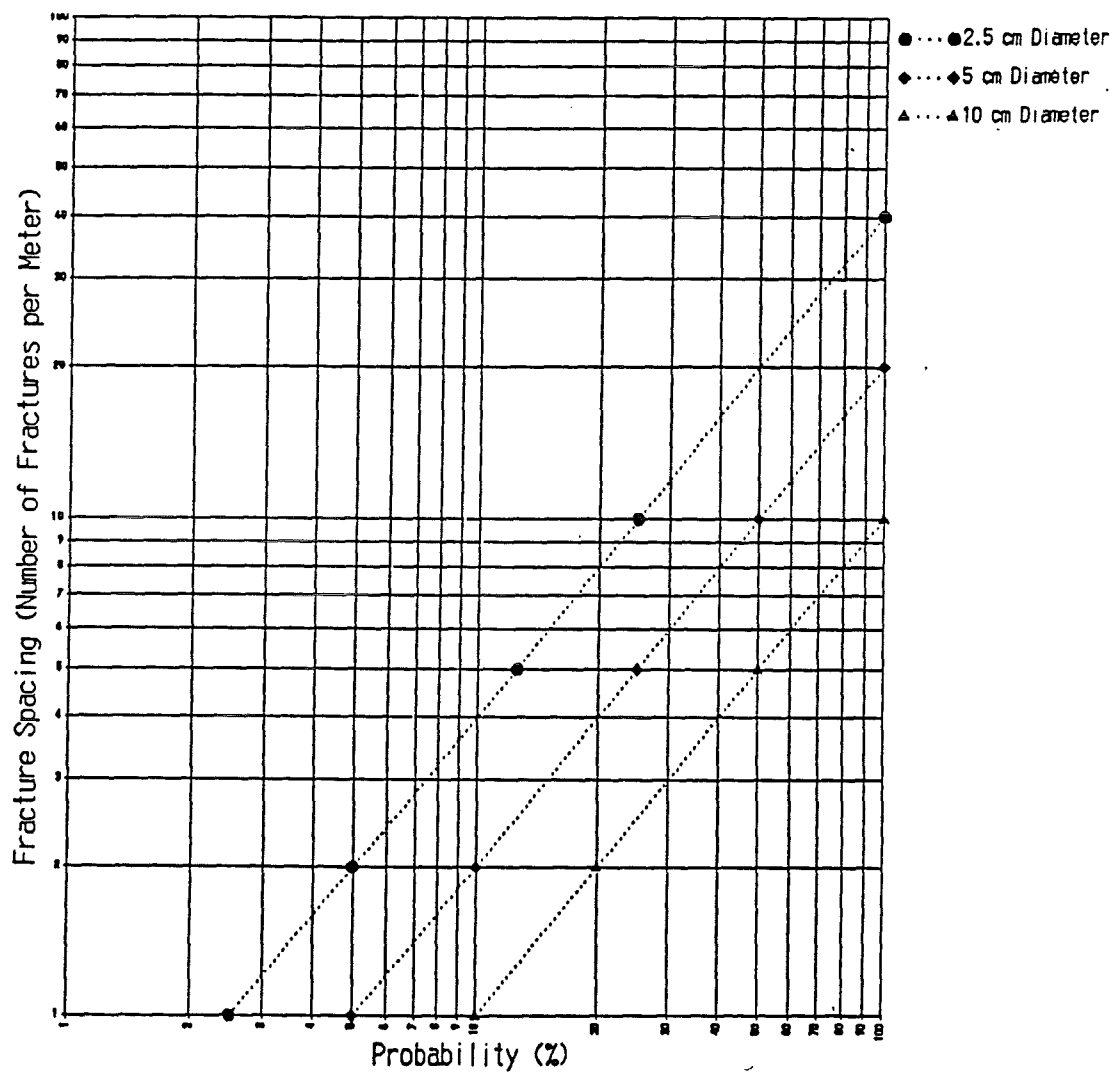


Figure 9: Fracture Spacing vs Probability of Encountering Fractures with Various Diameter Cores

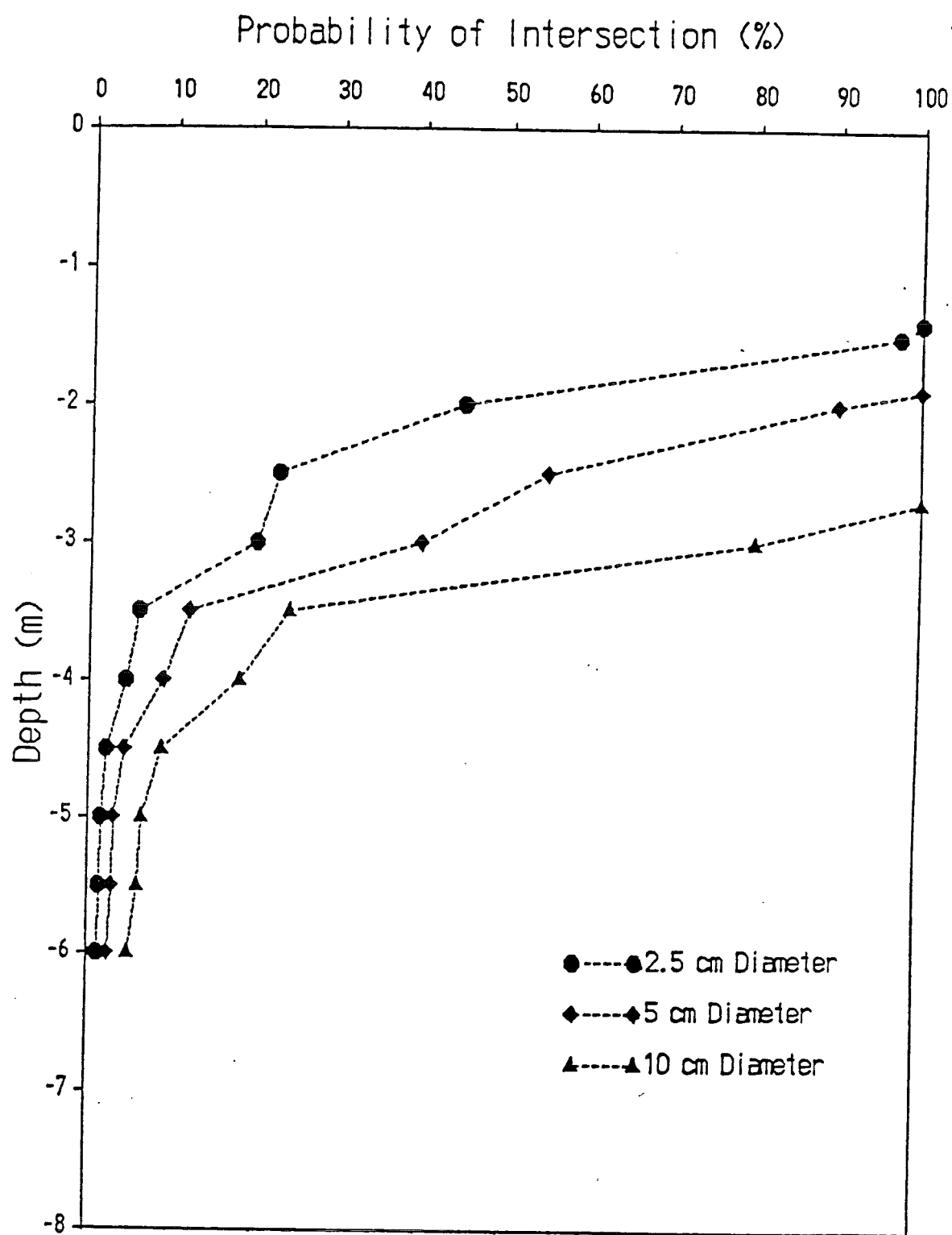


Figure 10: Probability of encountering fractures at various depths with drill cores of different diameters

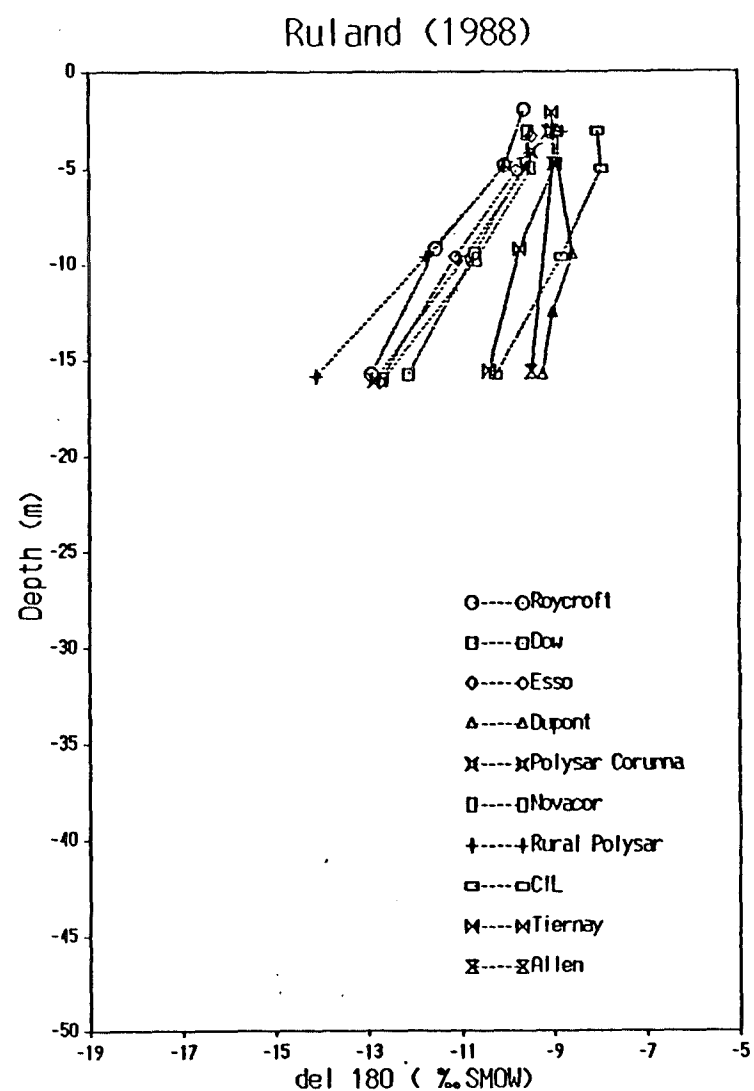
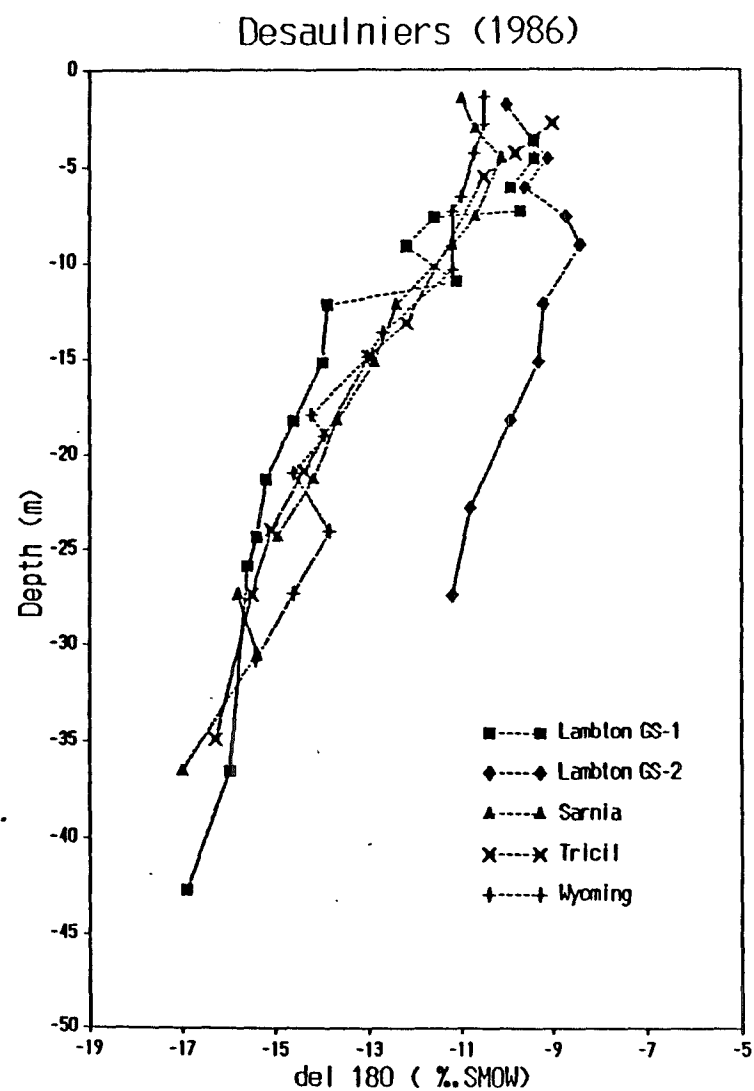


Figure 11: Comparison of $\delta^{18}\text{O}$ vs depth profiles

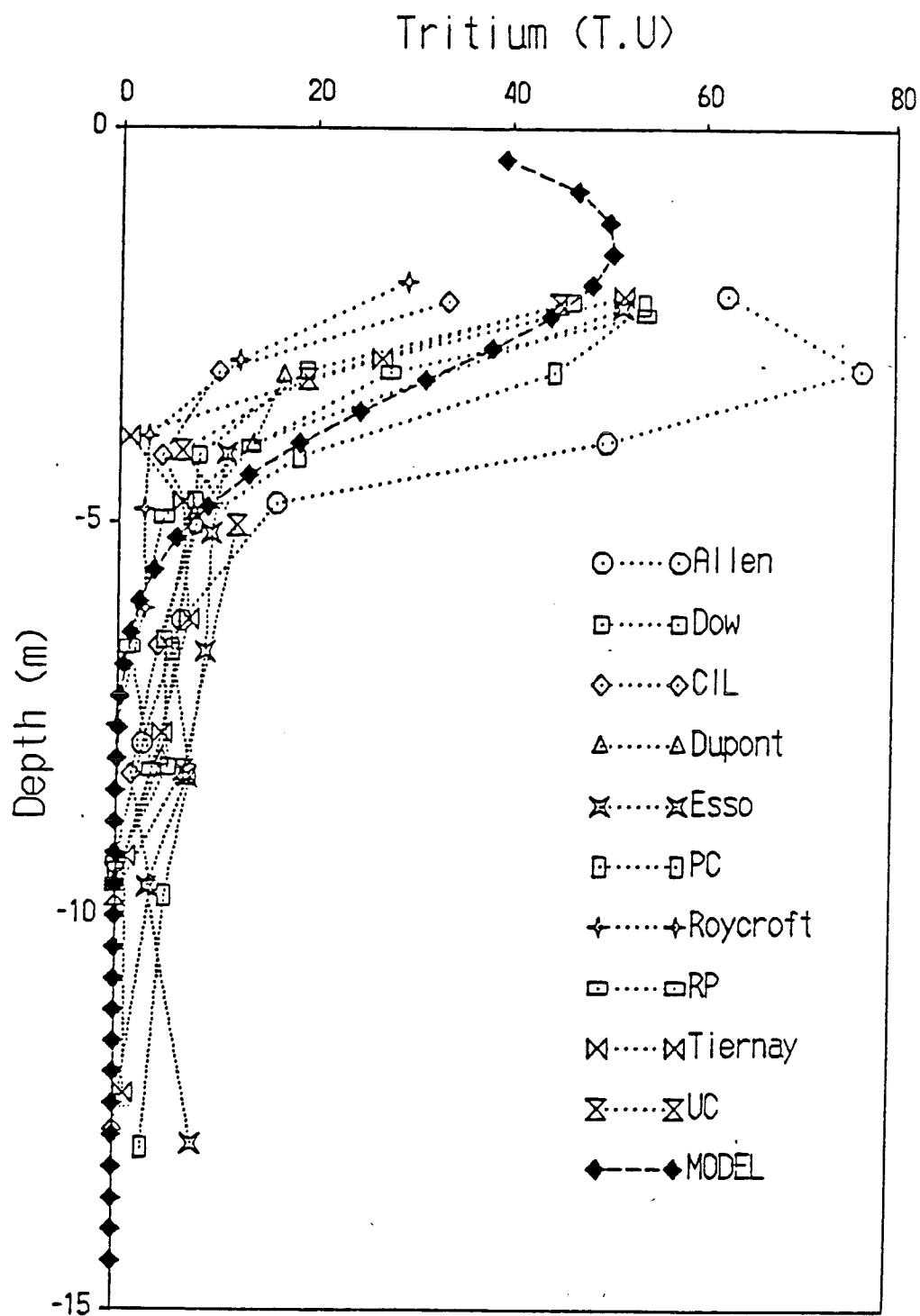


Figure 12: Profiles of tritium vs depth

with the best fit theoretical profile

APPENDIX OF DATA

The data used in preparing this project is presented on the following pages. Data on fracture dips, fracture spacing, and ^{18}O , deuterium, and tritium analyses and water level measurements have been transcribed directly from the original field notes or laboratory reports.

TABLE OF CONTENTS

OBSERVATIONS FROM TEST PITS

Fracture Dips, Tricil Site	49
Fracture Spacing	49

RESULTS OF ISOTOPIC ANALYSES

^{18}O and Deuterium Analyses	50
Tritium Analyses	51

WATER LEVEL MEASUREMENTS

Piezometer Installation Data	52
Roycroft Site	53
Dow Site	54
Esso Site	55
Dupont Site	56
Polysar Corunna (Petrosar) Site	57
Union Carbide (Novacor) Site	58
Rural Polysar Site	59
CIL Site	60
Tiernay Site	61
Allen Site	62

 Fracture Dips - Tricil Site

The results are from three test pits excavated at the Tricil Ltd. site in 1986.

Fracture Dip:

0-10° 10-20° 20-30° 30-40° 40-50° 50-60° 60-70° 70-80° 80-90°

No. of Observ's:

0 0 0 0 1 1 11 26 139

 Fracture Spacings

These results are from observations in 3 test pits excavated at the Tricil site in 1986, and from one test pit each at the Esso, Dow and Union Carbide (now Novacor) sites in 1987.

Fracture Spacing (no. of fractures per horizontal m)

Depth (m)	Tricil	Esso	Dow	Union Carbide
1	50	75	80	85
1.5		33	50	40
2.0	20	16	10	25
2.5		10	4	20
3.0	10	8	2.5	9
3.5		3.3	2	2
4.0	3.3	2	1.4	0.7
4.5		1.5	0.6	0.5
5.0	1.0	1.2	0	0
5.5		1.0	0	0
6.0	0.5	-	-	-

 Results of ^{18}O and ^2H Analyses

Information about ^{18}O and ^2H analysis results for 10 Lambton County sites is presented as follows (eg. Roycroft site, piezometer depth approx 6 ft) :

-9.6 - sample $\delta^{18}\text{O}$ (‰ SMOW)

-68.4 - sample $\delta^2\text{H}$ (‰ SMOW)

A dash (-) indicates no sample submitted for that depth

Approx. Piez. Depth (ft)	Lambton County Study Sites									
	Roy	Dow	Ess	Dup	PC	UC	RP	CIL	Tie	All
3	-	-	-	-	-	-	-	-	-	-
6	-9.6 -68.4	-	-	-	-	-	-	-	-9.0 -65.0	-
9	-	-9.5 -67.5	-9.5 -70.7	-8.9 -62.5	-9.1 -63.6	-9.6 -70.4	-8.8 -61.8	-8.0 -58.2	-	-9.0 -71.7
12	-	-	-	-	-9.5 -72.2	-	-	-	-	-
15	-10.1 -71.2	-9.6 -71.1	-9.8 -70.8	-8.9 -62.9	-9.6 -70.2	-9.5 -71.7	-10.1 -74.3	-7.9 -58.3	-8.9 -63.3	-9.0 -59.8
20	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-
30	-11.6 -80.0	-10.7 -79.0	-11.1 -78.8	-8.6 -68.2	-9.5 -72.2	-10.7 -77.0	-11.7 -89.2	-8.8 -65.5	-9.7 -71.7	-
40	-	-	-	-	-	-	-	-	-	-
50	-12.9 -96.2	-12.1 -85.6	-12.7 -91.8	-9.2 -64.3	-12.8 -87.4	-12.7 -91.3	-14.1 -98.1	-10.3 -77.8	-10.4 -74.2	-9.5 -68.3

Results of Tritium Analyses

Information about tritium analysis results for 10 Lambton County sites is presented as follows (eg. Roycroft site, piezometer depth approx 6 ft) :

29.5 - tritium concentration in sample (in T.U.)

2.1 - error margin (+/- ____ T.U.)

A dash (-) indicates no sample submitted for that depth

[illegible]

 WATER LEVEL MEASUREMENTS - DOW SITE

Water levels for the Dow site are presented below, all values are in meters below casing. Note the sampling event on July 18, '86 and note the following symbols:

dry - piezometer is dry
 n/a - no measurement possible (due to ice, breakage or obstruction)

Approximate Piezometer Depth (ft)

Date	50	40	30	25	20	15	12	09	06	03
1985										

O 29	13.48	12.78	10.15	8.62	7.01	5.15	3.16	3.53	2.70	1.46
N 27	8.61	10.18	9.56	7.72	6.03	3.90	1.50	2.83	1.92	1.18
D 22	6.48	9.41	8.65	6.62	5.12	3.18	1.41	2.40	1.56	1.27
1986										

J 19	5.21	6.92	7.70	5.95	4.34	2.71	1.49	2.11	1.52	1.43
M 14	4.14	5.07	5.96	4.56	3.25	2.03	1.28	1.61	1.23	1.11
A 14	3.93	4.51	5.23	4.00	2.85	1.81	1.22	1.45	1.18	1.16
M 16	3.83	4.13	4.66	3.57	2.56	1.71	1.36	1.42	1.32	1.23
J 13	3.75	3.91	4.29	3.30	2.42	1.71	1.51	1.49	1.51	1.69
J 18	3.71	3.74	3.91	3.10	2.33	1.80	1.87	1.67	1.88	2.13
18	5.71	5.76	5.90	5.25	4.64	4.08	4.18	3.22	2.48	2.13
A 22	4.36	4.72	5.06	4.46	3.83	3.42	2.75	3.02	2.90	dry
S 24	3.84	4.13	4.51	3.98	3.42	3.25	2.02	3.12	3.11	dry
O 23	3.70	3.88	4.13	3.63	3.08	2.77	1.88	2.72	2.41	1.45
N 19	3.68	3.72	3.81	3.31	2.73	2.35	1.58	2.30	1.76	1.46
D 17	3.66	3.60	3.53	3.02	2.45	2.05	1.40	1.99	1.42	1.29
1987										

J 15	3.63	3.49	3.27	2.78	2.21	1.80	1.30	1.72	1.25	1.21
F 07	3.59	3.41	3.10	2.62	2.09	1.71	1.32	1.62	1.30	1.31
M 02	3.57	3.35	2.96	2.50	2.01	1.62	1.31	1.53	1.26	1.01
A 15	3.55	3.31	2.83	2.40	1.94	1.54	1.28	1.43	1.23	1.12
M 01	3.54	3.29	2.74	2.32	1.88	1.49	1.27	1.38	1.25	1.50
J 06	3.52	3.26	2.68	2.29	1.91	1.60	1.59	1.52	1.69	dry
J 07	3.48	3.22	2.64	2.30	2.00	1.83	2.11	1.82	2.41	dry
A 07	3.45	3.20	2.65	2.37	2.18	2.23	2.87	2.32	dry	dry
S 04	3.44	3.20	2.69	2.48	2.45	2.71	3.63	3.07	dry	dry
O 07	3.36	3.16	2.75	2.60	2.71	3.23	4.26	dry	dry	dry
N 09	3.25	3.09	2.79	2.71	2.95	3.60	4.65	dry	dry	dry
D 07	3.30	3.14	2.87	2.84	3.10	3.65	4.19	3.90	2.47	1.30

 WATER LEVEL MEASUREMENTS - ESSO SITE

Water levels for the Esso site are presented below, all values are in meters below casing. Note the sampling event on July 18, '86 and the results of sampling in Dec. '86 in the 5 shallowest wells, and note the following symbols:

dry - piezometer is dry

n/a - no measurement possible (due to ice, breakage or obstruction)

Date	Approximate Piezometer Depth (ft)									
	50	40	30	25	20	15	12	09	06	03
1985										
O 29	9.88	8.14	6.25	5.00	4.81	3.25	1.83	3.06	1.13	1.13
N 27	8.82	7.16	5.48	4.32	4.22	2.54	1.26	2.49	0.95	0.94
D 22	8.08	6.48	4.91	3.80	3.74	2.12	1.15	2.13	1.15	1.28
1986										
J 19	7.36	5.81	4.38	3.40	3.36	1.89	1.22	1.92	1.17	1.09
M 14	6.20	4.77	3.58	2.76	2.70	1.50	1.15	1.54	0.97	0.91
A 14	5.70	4.34	3.28	2.54	2.43	1.37	1.10	1.40	1.15	1.12
M 16	5.27	3.97	3.02	2.35	2.36	1.36	1.20	1.36	1.69	1.76
J 13	5.02	3.71	2.88	2.31	2.17	1.43	1.42	1.41	1.51	1.08
J 18	4.75	3.52	2.77	2.26	2.08	1.50	1.43	1.44	2.01	2.03
18	6.50	5.20	5.07	3.91	4.42	3.89	3.75	3.13	2.97	2.03
A 22	5.78	4.59	4.29	3.31	3.77	3.19	2.31	2.80	2.40	dry
S 24	5.30	4.17	3.84	3.07	3.40	2.87	1.99	2.73	1.34	1.05
O 23	4.95	3.92	3.52	2.76	3.02	2.25	1.11	2.26	1.02	1.06
N 19	4.72	3.70	3.25	2.52	2.68	1.87	1.06	1.94	1.05	1.12
D 17	4.65	3.63	3.12	2.42	2.55	1.73	1.02	1.83	0.94	0.95
1987										
J 15	4.32	3.28	2.75	2.11	2.17	n/a	n/a	n/a	n/a	n/a
F 07	4.21	3.16	2.60	2.02	2.04	n/a	n/a	n/a	n/a	n/a
M 02	4.14	3.05	2.50	1.96	1.94	3.79	1.84	3.08	0.91	0.92
A 15	3.92	2.93	2.39	1.92	1.81	2.81	0.95	2.50	0.92	0.93
M 01	3.82	2.86	2.32	1.90	1.75	1.98	1.18	1.94	1.32	1.35
J 06	3.72	2.80	2.31	1.94	1.78	2.10	1.92	2.00	2.08	dry
J 07	3.66	2.78	2.32	2.04	1.88	2.16	2.40	2.08	2.60	dry
A 07	3.60	2.77	2.41	2.20	2.06	2.39	2.96	2.41	dry	dry
S 04	3.53	2.80	2.49	2.41	2.28	2.72	3.57	3.12	dry	dry
O 07	3.46	2.83	2.62	2.67	2.62	3.22	4.34	dry	dry	dry
N 09	3.38	2.88	2.79	2.98	2.97	3.58	4.59	dry	dry	dry
D 07	3.42	3.00	2.98	3.12	3.01	3.10	2.22	3.89	1.02	0.98

 WATER LEVEL MEASUREMENTS - DUPONT SITE

Water levels for the Dupont site are presented below, all values are in meters below casing. Note the sampling event on July 18, '86 and the result of sampling in the 9' and 15' deep wells in Dec. '86, and note the following symbols:

dry - piezometer is dry

n/a - no measurement possible (due to ice, breakage or obstruction)

Approximate Piezometer Depth (ft)

Date	50	40	30	25	20	15	12	09	06	03
1985										
O 29	15.41	13.06	10.12	8.44	6.80	5.15	4.44	dry	dry	dry
N 27	13.05	12.79	9.85	7.99	5.87	3.89	3.01	3.30	1.52	0.98
D 22	11.45	12.15	9.27	7.17	5.03	2.95	1.80	2.18	1.16	1.30
1986										
J 19	10.13	11.34	8.53	6.29	4.28	2.39	1.52	1.72	1.11	0.85
M 14	8.32	9.82	7.08	4.86	3.18	1.70	1.07	1.17	0.82	0.83
A 14	7.71	9.11	6.44	4.29	2.74	1.48	1.02	1.05	0.95	1.01
M 16	6.99	8.48	5.89	3.83	2.41	1.39	1.14	1.10	1.42	1.56
J 13	6.95	7.99	5.49	3.56	2.26	1.44	1.47	1.37	1.47	1.14
J 18	6.67	7.51	5.10	3.31	2.13	1.53	1.74	1.72	2.70	0.95
18	8.46	9.22	7.07	5.12	4.42	3.78	3.91	3.31	2.72	0.95
A 22	7.52	8.41	6.28	4.41	3.74	3.20	2.28	3.48	dry	dry
S 24	6.97	7.81	5.73	3.98	3.35	2.93	2.46	dry	dry	dry
O 23	6.69	7.39	5.33	3.68	2.96	2.53	1.72	3.31	1.39	1.36
N 19	6.51	7.06	5.05	3.40	2.60	2.17	1.31	2.36	1.23	1.26
D 17	6.50	6.93	4.92	3.29	2.48	2.03	1.20	2.03	0.89	0.85
1987										
J 15	6.25	6.45	4.42	2.88	2.02	4.26	1.25	2.54	n/a	n/a
F 07	6.17	6.23	4.20	2.73	1.88	3.47	1.11	1.60	n/a	n/a
M 02	6.09	6.03	4.04	2.62	1.76	2.89	1.05	1.21	n/a	n/a
A 15	6.02	5.81	3.84	2.51	1.64	2.32	1.02	1.06	n/a	n/a
M 01	5.96	5.64	3.70	2.45	1.55	1.99	1.03	1.05	n/a	n/a
J 06	5.90	5.46	3.58	2.42	1.58	1.85	1.28	1.55	n/a	n/a
J 07	5.81	5.30	3.49	2.45	1.71	1.98	1.94	2.50	n/a	n/a
A 07	5.70	5.15	3.42	2.56	2.03	2.40	2.84	dry	n/a	n/a
S 04	5.59	5.03	3.46	2.85	2.45	3.02	3.88	dry	n/a	n/a
O 07	5.47	4.91	3.55	3.24	3.12	3.88	dry	dry	n/a	n/a
N 09	5.39	4.84	3.68	3.62	3.71	4.87	dry	dry	n/a	n/a
D 07	5.36	4.71	3.81	3.92	4.00	5.28	dry	dry	n/a	n/a

 WATER LEVEL MEASUREMENTS - POLYSAR CORUNNA (PETROSAR) SITE

Water levels for the Polysar Corunna site are presented below, all values are in meters below casing. Note the sampling event on July 18, '86 and note the following symbols:

dry - piezometer is dry
 n/a - no measurement possible (due to ice, breakage or obstruction)

Date	Approximate Piezometer Depth (ft)									
	50	40	30	25	20	15	12	09	06	03
1985										
O 29	9.32	7.86	3.11	3.22	4.65	3.78	2.21	1.69	1.69	1.70
N 27	8.10	6.88	2.53	2.51	3.92	3.19	1.49	0.94	0.91	0.90
D 22	7.27	6.17	2.18	2.10	3.41	2.78	1.22	0.91	1.12	1.08
1986										
J 19	6.49	5.46	2.00	1.86	2.98	2.43	1.08	0.98	0.86	0.83
M 14	5.38	4.45	1.86	1.77	2.40	1.95	0.94	0.90	0.86	0.86
A 14	4.90	4.06	1.88	1.66	2.18	1.75	0.91	0.95	0.97	0.99
M 16	4.52	3.76	1.90	1.66	2.01	1.61	1.01	1.21	1.32	1.37
J 13	4.28	3.55	1.96	1.72	1.92	1.54	1.13	1.29	0.96	0.97
J 18	4.02	3.36	2.02	1.79	1.88	1.50	1.31	1.57	1.66	1.69
18	5.91	5.06	4.05	3.56	4.33	4.04	3.74	3.04	2.78	1.69
A 22	5.15	4.48	2.75	2.64	3.67	3.46	2.39	1.89	1.92	1.92
S 24	4.80	4.11	2.48	2.40	3.27	3.09	2.10	1.70	2.27	1.28
O 23	4.43	3.80	2.12	2.03	2.88	2.63	1.38	1.01	1.05	1.05
N 19	4.18	3.55	1.91	1.86	2.54	2.30	1.15	1.07	1.09	1.10
D 17	3.96	3.32	1.71	1.56	2.25	2.03	1.00	0.95	0.98	0.98
1987										
J 15	3.76	3.12	1.63	1.47	2.02	1.82	0.94	0.94	0.94	0.89
F 07	3.64	2.99	1.62	1.45	1.91	1.70	0.95	0.98	0.97	0.98
M 02	3.51	2.86	1.62	1.46	1.80	1.59	0.96	0.96	0.87	0.86
A 15	3.38	2.73	1.66	1.49	1.70	1.46	0.92	0.90	0.89	0.88
M 01	3.25	2.64	1.68	1.51	1.63	1.36	0.93	1.07	1.10	1.12
J 06	3.18	2.58	1.80	1.60	1.61	1.34	1.15	1.46	1.53	1.56
J 07	3.15	2.57	1.99	1.80	1.68	1.42	1.53	1.92	1.98	1.97
A 07	3.12	2.59	2.22	2.03	1.78	1.56	1.88	2.28	2.39	dry
S 04	3.11	2.60	2.49	2.31	1.92	1.74	2.33	2.86	dry	dry
O 07	3.08	2.62	2.75	2.65	2.18	2.07	2.95	3.46	dry	dry
N 09	3.05	2.65	2.98	2.97	2.46	2.38	3.22	3.02	2.80	dry
D 07	3.03	2.69	3.08	3.10	2.58	2.35	2.57	1.34	1.26	1.28

 WATER LEVEL MEASUREMENTS - UNION CARBIDE (NOVACOR) SITE

Water levels for the Union Carbide site are presented below, all values are in meters below casing. Note the sampling event on July 18, '86 and note the following symbols:

dry - piezometer is dry

n/a - no measurement possible (due to ice, breakage or obstruction)

Approximate Piezometer Depth (ft)

Date	50	40	30	25	20	15	12	09	06	03
1985										
O 29	7.04	7.33	6.82	5.86	5.39	2.99	3.99	3.56	2.61	1.50
N 27	6.18	6.46	6.01	5.16	4.81	2.55	3.68	3.24	1.53	0.95
D 22	5.68	5.79	5.38	4.67	4.34	2.23	3.40	2.96	1.28	1.36
1986										
J 19	5.27	5.25	4.81	4.19	3.89	2.12	3.16	2.74	1.36	1.01
M 14	4.74	4.46	3.96	3.45	3.24	2.03	2.76	2.35	1.17	0.91
A 14	4.55	4.19	3.67	3.19	2.97	1.96	2.56	2.13	1.09	1.17
M 16	4.43	3.99	3.44	2.98	2.79	1.89	2.36	1.91	1.05	1.11
J 13	4.39	3.89	3.32	2.90	2.70	1.90	2.25	1.79	1.56	1.15
J 18	4.35	3.81	3.22	2.86	2.70	1.92	2.15	1.71	1.67	2.08
18	6.19	5.79	5.12	4.78	4.98	4.22	4.50	3.31	2.71	2.08
A 22	5.37	4.94	4.41	4.03	4.19	2.81	3.94	2.85	2.58	dry
S 24	4.93	4.47	4.00	3.59	3.72	2.43	3.58	2.64	1.72	dry
O 23	4.66	4.15	3.70	3.26	3.32	2.13	3.28	2.39	1.12	1.19
N 19	4.50	3.97	3.60	3.02	3.01	1.89	2.99	2.18	1.22	1.30
D 17	4.36	3.79	3.23	2.78	2.73	1.73	2.75	2.01	1.04	1.11
1987										
J 15	4.26	3.66	3.06	2.62	2.52	1.68	2.56	1.87	0.95	0.93
F 07	4.20	3.57	2.94	2.53	2.40	1.69	2.42	1.72	1.06	0.90
M 02	4.16	3.51	2.85	2.44	2.30	1.71	2.30	1.61	0.99	dry
A 15	4.10	3.42	2.77	2.38	2.20	1.71	2.16	1.58	1.00	0.91
M 01	4.08	3.38	2.73	2.32	2.15	1.70	2.04	1.48	1.17	1.47
J 06	4.04	3.36	2.71	2.35	2.17	1.80	1.95	1.45	1.63	1.96
J 07	4.07	3.39	2.75	2.42	2.22	1.92	1.91	1.50	1.96	dry
A 07	4.08	3.41	2.82	2.49	2.28	2.05	1.90	1.52	2.26	dry
S 04	4.07	3.44	2.85	2.54	2.32	2.16	1.92	1.65	2.63	dry
O 07	4.62	3.41	2.86	2.55	2.36	2.30	1.95	1.82	dry	dry
N 09	3.99	3.38	2.85	2.56	2.40	2.51	2.05	2.11	dry	dry
D 07	3.96	3.37	2.86	2.55	2.42	2.62	2.15	2.33	1.62	1.11

 WATER LEVEL MEASUREMENTS - CIL SITE

Water levels for the CIL site are presented below, all values are in meters below casing. Note the sampling event on July 18, '86 and note the following symbols:

dry - piezometer is dry

n/a - no measurement possible (due to ice, breakage or obstruction)

Approximate Piezometer Depth (ft)

Date	50	40	30	25	20	15	12	09	06	03
1985										

O 29	7.77	7.25	6.67	5.64	4.21	3.57	3.25	3.10	dry	1.17
N 27	6.86	6.38	5.87	5.02	3.63	3.12	2.99	2.84	1.98	1.11
D 22	6.28	5.79	5.22	4.50	3.28	2.82	2.71	2.56	1.42	1.06
1986										

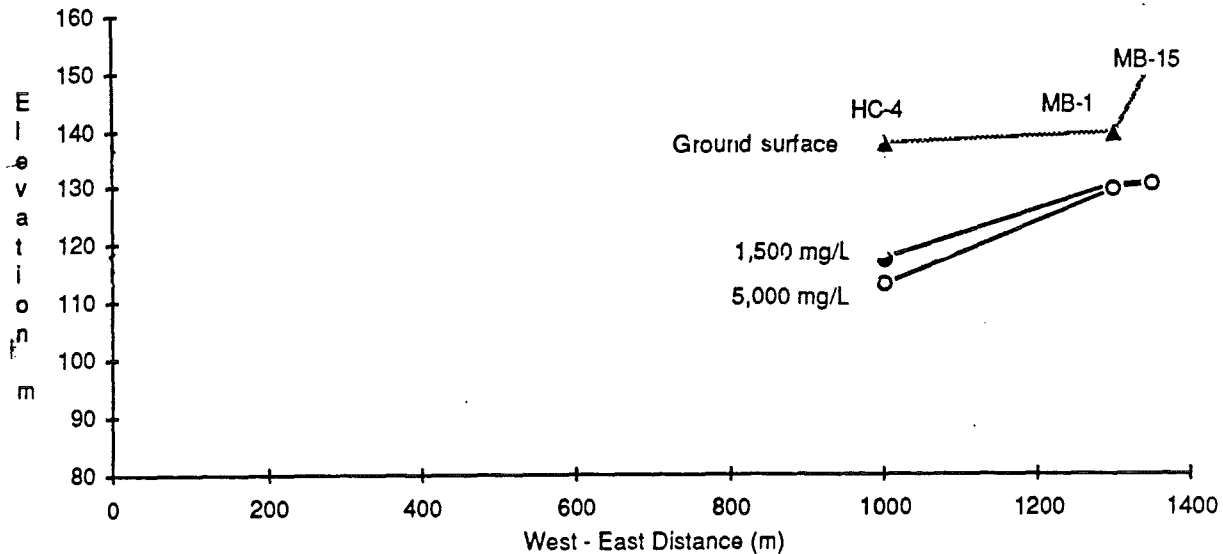
J 19	5.81	5.28	4.62	4.02	2.92	2.54	2.42	2.31	1.24	1.03
M 14	5.15	4.55	3.79	3.32	2.44	2.11	1.98	1.89	0.97	0.91
A 14	4.90	4.24	3.46	3.04	2.26	1.94	1.79	1.70	0.90	0.87
M 16	4.69	4.03	3.20	2.81	2.12	1.80	1.62	1.54	0.95	0.85
J 13	4.60	3.90	3.02	2.68	2.05	1.70	1.53	1.42	1.09	0.92
J 18	4.50	3.78	2.91	2.56	1.99	1.63	1.48	1.39	1.52	1.12
18	6.28	5.89	5.37	4.73	4.15	3.79	4.20	2.76	2.67	1.12
A 22	5.61	5.09	4.50	4.02	3.37	3.20	3.43	2.51	dry	dry
S 24	5.28	4.70	4.05	3.67	3.03	2.96	3.12	2.57	dry	dry
O 23	5.20	4.42	3.77	3.38	2.79	2.73	2.96	2.65	dry	dry
N 19	4.88	4.16	3.52	3.16	2.60	2.51	2.78	2.45	2.72	1.95
D 17	4.72	4.07	3.30	2.94	2.39	2.28	2.53	2.45	1.56	1.57
1987										

J 15	4.59	3.91	3.09	2.74	2.21	2.08	2.27	2.22	1.19	1.17
F 07	4.51	3.80	2.94	2.60	2.09	1.94	2.08	2.04	1.09	1.05
M 02	4.42	3.70	2.81	2.48	2.00	1.82	1.92	1.90	1.02	0.95
A 15	4.32	3.56	2.67	2.34	1.89	1.69	1.74	1.70	0.97	0.90
M 01	4.22	3.46	2.58	2.25	1.83	1.60	1.62	1.57	0.95	0.86
J 06	4.19	3.42	2.51	2.21	1.81	1.56	1.55	1.47	1.26	1.16
J 07	4.18	3.38	2.51	2.20	1.80	1.58	1.57	1.50	2.24	1.86
A 07	4.21	3.41	2.58	2.27	1.92	1.69	1.75	1.72	dry	dry
S 04	4.21	3.45	2.66	2.35	2.05	1.82	1.96	2.01	dry	dry
O 07	4.25	3.51	2.75	2.45	2.17	2.01	2.28	2.57	dry	dry
N 09	4.27	3.55	2.83	2.52	2.25	2.18	2.57	3.16	dry	dry
D 07	4.30	3.61	2.88	2.57	2.35	2.32	2.82	3.61	dry	1.06

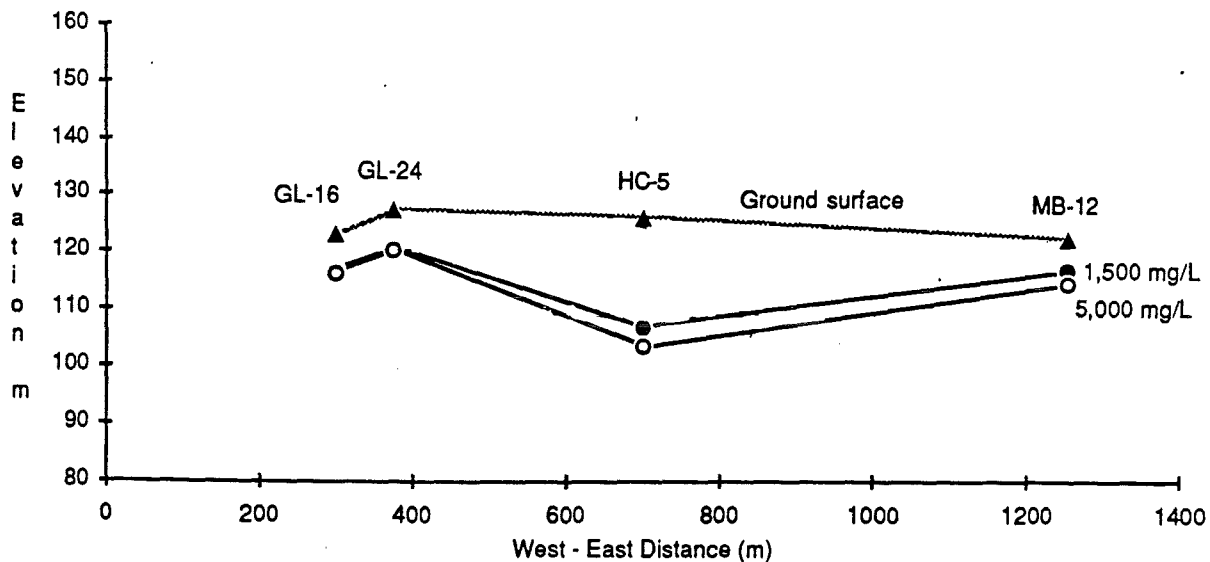
ATTACHMENT 3.

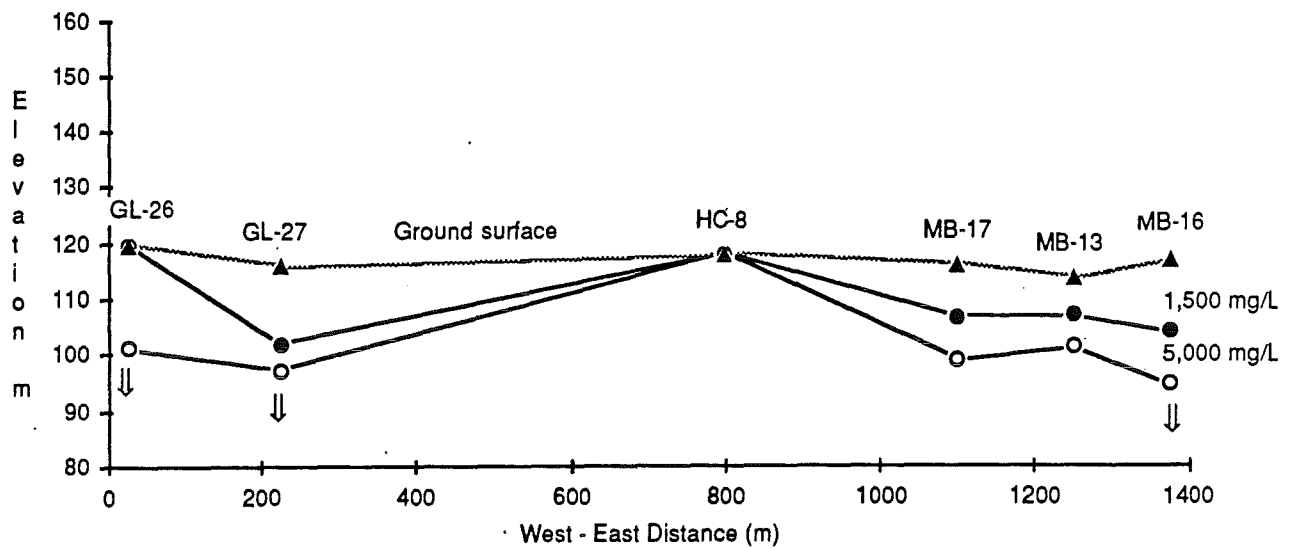
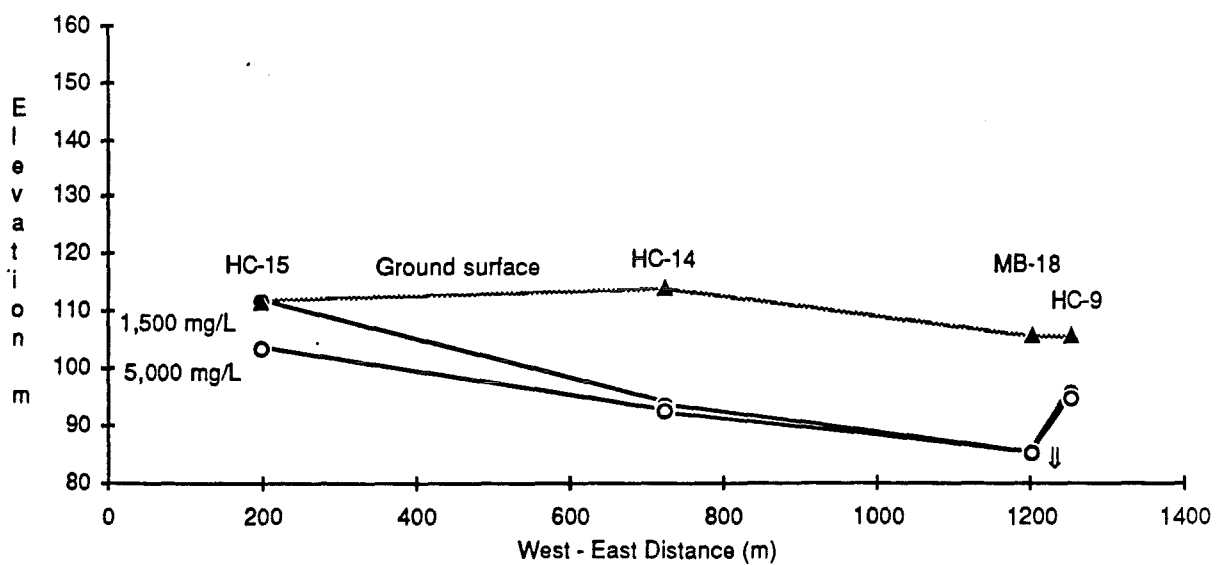
THE ELEVATION OF THE 1,500 mg/L and 5,000 mg/L CHLORIDE CONTOURS ALONG WEST - EAST CROSS-SECTIONS THROUGH SITE F.

ATTACHMENT 3a
CHLORIDE CONTOURS - SITE F NORTH



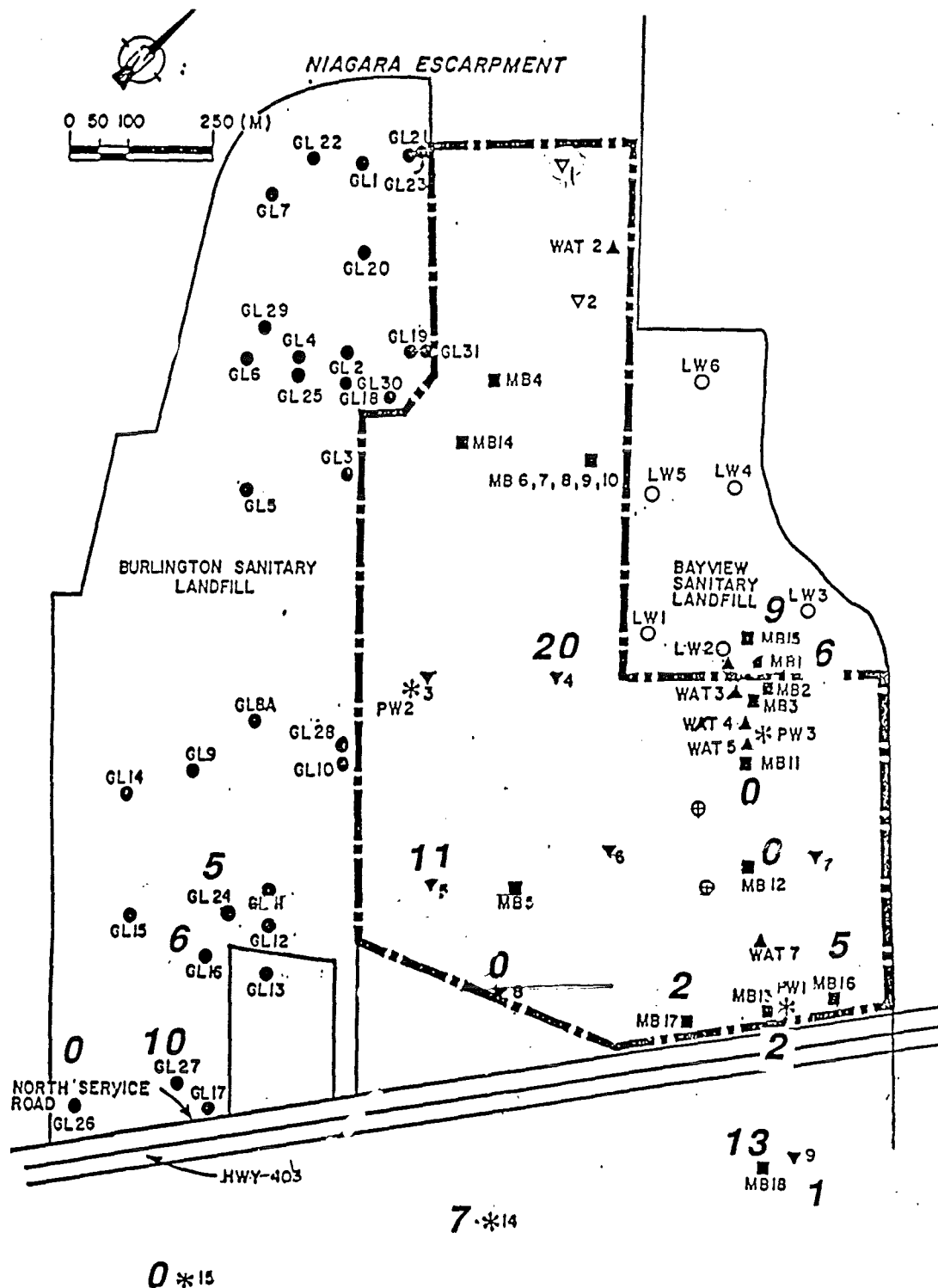
ATTACHMENT 3b
CHLORIDE CONTOURS - SITE F CENTRAL



ATTACHMENT 3c
CHLORIDE CONTOURS - SITE F SOUTHATTACHMENT 3d
CHLORIDE CONTOURS - SOUTH OF 403

ATTACHMENT 4

THE THICKNESS OF THE ACTIVE GROUNDWATER FLOW ZONE (m) DEFINED BY CHLORIDE CONCENTRATIONS LESS THAN 1,500 mg/L AT BOREHOLES ON SITE F AND SOUTH OF THE BURLINGTON AND BAYVIEW LANDFILLS.





1 of one or two of the preface pages and one is a sign-up
2 sheet which the university puts into all of its
3 projects on which the borrowers of the thesis have to
4 sign to indicate it had been borrowed.

5 Q. Does that include us?

6 A. No. I did not include those pages,
7 but the actual -- the technical data and discussion in
8 the thesis is complete as the project was prepared.

9 I would like to show the first overhead
10 here from the research project.

11 Q. For the record, this is page 31, I
12 believe?

13 A. Page 31 of Attachment 1. This map
14 simply shows the locations of the various sites studied
15 by Mr. Ruland. You will see the Sarnia area, the
16 Lambton -- this is much of Lambton County and the
17 Sarnia clay plain extends over this entire map area for
18 a total of thirteen sites, mainly at different
19 industrial locations in the Sarnia area. The original
20 research conducted by the University of Waterloo in the
21 Sarnia area was restricted largely to the area of the
22 Tricil hazardous waste facility and the Lambton
23 generating station. This work largely expanded the
24 number of sites that were considered at this time,
25 compared to the original work which began in the late



1 In the test pits dug at the Dow Chemical
2 site, the Esso site, the Union Carbide site and three
3 test pits at the Tricil site, fractures were identified
4 at the bottom limits of the test pits, so at 4.5 metres
5 at the Dow site and the Union Carbide site, fractures
6 were identified at the base of the test pit and
7 likewise at Esso and Tricil, the test pits went to a
8 depth of 5.6 metres and fractures were identified at
9 that bottom depth.

10 DR. KINGHAM: When you refer to the Dow
11 site, is that the current Dow site, do you know?

12 MR. FEENSTRA: I believe that that is
13 correct.

14 DR. KINGHAM: The new one?

15 MR. FEENSTRA: Yes. There are some red
16 marks on my overhead which are a bit different from the
17 table in the attachment. You will see adjacent to the
18 4.5 metre depth at Dow and Union Carbide, there is a
19 greater than and for Tricil, which was not originally
20 listed on this table, there is a greater than 5.6. If
21 one looks at the discussion on page 8 of Attachment 1,
22 one gets a written description of the observations at
23 these test pits and I spoke to Mr. Ruland on Friday to
24 clarify this matter and he indicated indeed that these
25 numbers should say greater than to consistent with the



1 description in the text on page 8 and Tricil should
2 probably be added onto this list, which also indicated
3 fractures at 5.6 metres, which is the deepest extent of
4 the test pits.

5 MR. HODGSON: I think, Mr. Chairman,
6 because of those additions, I think we should mark
7 this as an exhibit and perhaps it could be H-936-T2r to
8 indicate a revised Table 2.

9 MR. LANCASTER: H-936-T2r. All right.

10 --- EXHIBIT No. H-936-T2r: Revised Table 2 to
11 Exhibit H-936.

12 MR. FEENSTRA: In addition to the visual
13 evidence of fractures and the core samples of the test
14 pits, the detailed nests of piezometers indicated at
15 these various sites the depth of maximum tritium
16 penetration ranged from 6.1 metres at the Roycroft site
17 to approximately 13 metres at the Polysar site.

18 Now, I will be showing some typical
19 graphs of those findings in a moment. Similarly,
20 looking at the water level fluctuations in these nests
21 of detailed piezometers, there were suggestions of good
22 hydraulic connection between piezometers located at
23 depths from 4.8 metres to actually as much as 15 metres
24 at the Allen site. To give you some indication of what
25 this data from the tritium results and the water level
results look like, I have a few overheads also taken



1 from the Ruland project.

2 First we will look at the tritium
3 concentrations in the nests of piezometers. This is
4 page 42 of the Ruland project in Attachment 1. In the
5 upper righthand corner there is a profile for Tricil
6 and, as you can see on the Tricil profile, there is
7 detectable tritium which penetrates to a depth of just
8 over 5 metres and this is a profile that is very
9 typical of many of the previous profiles that were
10 developed for the Tricil site. On this basis it was
11 originally assumed that the depth of tritium
12 penetration and therefore the depth of active
13 groundwater flow, just coincided with the weathered
14 zone in the upper 4 or 5 metres of the till.

15 However, on developing profiles at a
16 variety of other sites in the Sarnia area, you can see
17 that very different results were derived from different
18 sites. Some of the sites are actually very similar to
19 Tricil, the Roycroft site which is quite similar;
20 Lambton IV not too dissimilar, but there are a variety
21 of other sites such as the Sarnia site, Lambton III,
22 DuPont and Esso, which show tritium penetration much
23 below the weathered zone.

24 DR. KINGHAM: Before you take that off
25 and so we can understand it, your model, the first



1 diagram, is that based on a uniform media with a
2 uniform hydraulic conductivity?

3 MR. FEENSTRA: It is.

4 MS. CRONK: I didn't hear the question.

5 DR. KINGHAM: I wanted to know if the
6 model was based on a uniform medium with a uniform
7 hydraulic conductivity and the answer was yes.

8 MR. FEENSTRA: Any further questions?

9 DR. KINGHAM: No.

10 MR. FEENSTRA: Similarly water levels
11 were monitored in each of those piezometers and Mr.
12 Ruland developed a curve such as this for each of the
13 sites. This shows a vertical profile of the water
14 levels in the various piezometers and this is the
15 variation in the water level below ground surface
16 compared to the depth of the piezometer. You can see
17 in the upper zones, each curve was developed for a
18 different time period going from April to August to
19 November. This is Figure 4a in Attachment 1 and you
20 can see there is a considerable seasonal fluctuation in
21 water levels in the piezometers in the weathered zone
22 and many of these variations are also reflected in
23 piezometers quite a bit -- in some cases deeper than
24 the interpreted upper fracturing in the weathered
25 zone. Mr. Ruland considered fluctuations of greater



1 than a metre that occurred in concert with the
2 fluctuations in the weathered zone to reflect hydraulic
3 connection with the weathered zone and evidence of
4 fracturing. For example, at the Union Carbide site,
5 fluctuations of greater than half a metre occurred at a
6 depth of 5 metres below ground surface and that was his
7 basis for the estimate of the depth of maximum
8 fracturing.

9 I will now show you another profile
10 which show some different results. This is Figure 4c
11 from page 36 of Attachment 1, and which shows water
12 levels fluctuations at the Polysar site and the Rural
13 Polysar site and you can see the water level
14 fluctuations occur in concert with the fluctuations or
15 related to the fluctuations in the weathered zone to a
16 depth of approximately nine and a half metres at this
17 site. Actually the fluctuation at this particular
18 level is as much as a metre. In general, the profiles
19 at all the sites show downward hydraulic gradients
20 during the winter and spring and in the summertime in
21 response possibly to evapotranspiration effects, the
22 gradients diminish and in some cases become upward
23 gradients, indicating a movement of water upward
24 through the weathered zone.

25 DR. KINGHAM: Again there is something I



1 don't understand about that pair of diagrams and I
2 didn't on the previous one either, but you have a line
3 that corresponds to April '87 denoted by Xs and on the
4 lefthand side of 4c you have as well including a
5 piezometer not yet equilibrated and you have had that
6 on an earlier graph also and I cannot tell which X is
7 which.

8 MR. FEENSTRA: The X which is not
9 equilibrated does not have a line connected to it.

10 I think that's all I need to say at this
11 point with respect to what we have -- what Mr. Ruland
12 presented in his Masters research.

13 Based on the findings of Mr. Ruland in
14 the clay till in the Sarnia area and the expectation
15 that the till at Site D will be largely similar with
16 respect to the nature of weathering at the ground
17 surface, the mineralogy is very similar to the Sarnia
18 area, the Sarnia area clay tills have a slightly higher
19 clay content; but in general the Halton till at Site D
20 would be expected to behave in a reasonably similar way
21 to the clay in the Lambton County area. It was on the
22 basis of prior discussion between Mr. Estrin and Mr.
23 Petrie regarding several other sites and the most
24 recent findings at the Tricil site which lead me to the
25 conclusion that the possibility of fracturing in the



1 an abandoned borehole nearby, an abandoned borehole
2 being 20 to 40 metres distant laterally, which would
3 still have to be in some way connected to the
4 piezometers in which he monitored the response.

5 One hypothesis is that that response in
6 the piezometer is due to vertical connection through
7 the Maryhill till. With an adjacent unsealed borehole,
8 if that were to have an effect, there would have to be
9 some kind of horizontal connection through the Maryhill
10 till. Either way, it indicates there is some kind of
11 secondary permeability or hydraulic conductivity in
12 that clay unit. I think what Mr. Petrie indicates in
13 terms of his caution is probably correct, that the
14 numerical value of hydraulic conductivity calculated
15 for the Maryhill till should be taken with some
16 caution, but I think the fact that the Maryhill till
17 did in fact respond to pumping is a very significant
18 observation.

19 I think the main point to note from the
20 study of the Maryhill till is the possibility that open
21 fractures may exist, permeable fractures may exist in a
22 clay till material, and even a clay till material that
23 is not a surfacial deposit or a material that is
24 actually ~~varied~~ ^{buried} by other strata and occurs at a depth
25 of 10 to 20 metres. There is much discussion by geo-



1 technical engineers that, on a theoretical basis, once
2 you get below a certain depth, lateral and vertical
3 stresses exerted on a fracture or other discontinuity
4 in clay material will actually be closed because the
5 stresses are greater as you increase in depth. The
6 findings on the Maryhill till and likewise the findings
7 on the Vandalia till, which is situated in a very
8 similar setting to the Maryhill till, being at a depth
9 of 10 to 15 metres, those tests indeed suggest those
10 fractures may be open at that considerable depth and
11 that is a significant observation.

12 Q. You have spoken about your concerns
13 about fracturing in the till at Site D and you referred
14 to Mr. Ruland's research and the importance of Mr.
15 Ruland's research, but to what extent do you also make
16 use of Mr. Petrie's research in this regard?

17 A. I think the main use I made of Mr.
18 Petrie's work and largely the confirming work performed
19 by Mr. Usher as described in M-721, that was also
20 presented to Mr. Petrie during cross-examination by Mr.
21 Estrin, suggests that one should seriously consider the
22 possibility of fracturing in clayey materials at a
23 depth considerably deeper than the surfacial weathered
24 zone.

25 Q. With regard to the papers on the



1 Vandalia till, what use do you make of those?

2 A. The use I make of the reference or
3 the previous research on the Vandalia till is very
4 similar to my considerations of the Maryhill till. The
5 Vandalia till is a much older till deposit than the
6 tills we are dealing with in Ontario and may have
7 undergone quite a different geological history. So the
8 actual nature and occurrence of the fractures may be
9 different, but I think the fact the fractures can be
10 shown to exist at a significant depth below the
11 weathered zone is a very important observation.

12 Q. Those discussions of the Vandalia
13 till are from M-710 and M-711?

14 A. And M-711, correct.

15 Q. And the evidence we have discussed
16 so far from Ruland and Petrie, Usher and about the
17 Vandalia till is all evidence that relates to sites
18 other than Site D. Is there any direct evidence from
19 Site D to which you want to draw the Board's attention?

20 A. As I mentioned earlier and as Mr.
21 Petrie indicated in his cross-examination, there is no
22 direct evidence for fracturing at Site D and
23 specifically the studies undertaken by Trow weren't
24 directed at obtaining that type of evidence. Test pits
25 were not dug and angled boreholes were not drilled. A



1 pumping test of the type Mr. Petrie conducted on the
2 Maryhill till was not performed on Site D. There is,
3 however, some evidence from Site D from the
4 investigations that have been done that probably relate
5 to the possibility of fracturing at Site D. Some of
6 this evidence is confirming evidence and some of it is
7 contradictory evidence and I don't think any of it is
8 particularly direct or particularly conclusive, but I
9 think for the purpose of completeness, I would like to
10 mention those other bits of evidence. Actually many of
11 the pieces of evidence I am going to discuss now have
12 been raised previously, in previous testimony.

13 The first additional evidence relates to
14 the findings in the Comcor boreholes that were drilled
15 on Site D by Comcor during 1985. It was pointed out to
16 Mr. Petrie, and unfortunately I don't have a transcript
17 reference, that there was evidence of weathering and
18 fracturing noted in the Comcor borings, or in one of
19 the Comcor borings. With a closer examination of the
20 Comcor borehole logs, and this is an overhead of the
21 borehole log for CC-1 which comes from M-438, Appendix
22 D. I don't actually recall which borehole log Mr.
23 Petrie was referred to, but on close examination of all
24 three Comcor borehole logs, there is evidence of
25 weathering and fracturing in all three and not just in



1 can I take you back to page 29562 of the same
2 transcript and Mr. Estrin asked this question:

3 "Mr. Petrie, let's look still at your
4 project document, page 36."

5 That project was made an exhibit in
6 these proceedings, and I am sorry I have forgotten the
7 number, Mr. Chairman.

8 A. 707.

9 Q. M-707. And it was a project or
10 thesis of Mr. Petrie's:

11 "Q. Mr. Petrie, let's look still at
12 your project document, page 36. What
13 this project as you have written it up
14 demonstrates is that lab and field
15 investigations such as field
16 investigations carried on at Site D
17 could easily miss the vertical
18 fracturing that could occur in an
19 unweathered clay till?

20 MR. PETRIE: A. You can conclude that."

21 Can you comment on that, Mr. Feenstra?

22 A. On that particular point I would
23 agree with Mr. Petrie that the field investigations
24 that were performed at Site D could easily miss
25 identifying the presence of fairly widely spaced



1 vertical fractures through the unweathered upper till.

2 Q. Could you, in the context of that
3 question and answer, describe for the Board the state
4 of the art in terms of what hydrogeologists in Ontario
5 thought they had understood about the extent of the
6 fracturing of tills in Ontario?

7 A. Yes. I think as an indication of
8 what hydrogeologists consider the state of
9 understanding was with respect to fractured tills in
10 Ontario, it is probably best to refer to page 47 of
11 Trow's original hydrogeology report for Site D, H-39,
12 and I can just read a few sentences from page 47.

13 "An upper weathered and fractured zone
14 in the Upper Till is interpreted to
15 extend from ground surface to an
16 approximate depth of 4 to 5 m. Freeze
17 and Cherry (1979) note that deposits of
18 clayey or silty till in Southern Ontario
19 contain networks of hairline fractures
20 which are essentially vertical and which
21 are responsible for hydraulic
22 conductivities one to three orders of
23 magnitude greater than in unfractured
24 materials. Assuming this, the
25 (fractured) zone is estimated to



1 A. It would be more homogeneous.

2 Q. Are you familiar with the work that
3 is going on at the OWMC site?

4 A. I actually had the opportunity to
5 visit the site on Friday. The consultants for OWMC
6 were digging some deep test pits to examine the
7 presence of fractures in the upper portion of that
8 silty clay material. I believe the public was invited
9 to come out and look and there were various groups that
10 would be represented in the upcoming hearing were also
11 invited to come down and examine the test pits, as was
12 the University of Waterloo. Along that line I also
13 went along and examined the test pit on Friday.

14 Q. What did you see?

15 A. In both test pits dug to a depth of
16 five and a half or six and a half metres, there was
17 evidence of fractures along which there had been
18 chemical weathering; in other words there were fracture
19 surfaces that were identifiable as being different
20 colours. In the deepest test pit at approximately six
21 and a half metres, there was also evidence of roots of
22 some age, probably geological age roots. What remains
23 is simply the dry relics of the root material.

24 Q. Is it more or less likely that you
25 would find fractures and roots as you have described in



1 that lacustrine clay as opposed to the Milton clay?

2 A. That is a difficult question to
3 address. One might imagine that in a lacustrine clay,
4 which are clay materials deposited in the bottom of a
5 lake, one would find one would have vegetation growing
6 on the bottom of the lake during most of its deposition
7 in history. On the other hand, the clay till deposits
8 were deposited as fairly thick units and although there
9 may be some intervals during the deposition of those
10 tills where the ground surface was exposed and some
11 vegetation developed and some weathering occurred, the
12 most significant degree of weathering had just occurred
13 at the present ground surface. The fractures that are
14 evident in lacustrine clays in West Lincoln seem to be
15 fairly continuous vertically over distances of, in one
16 particular case, two metres, more than two metres. It
17 is difficult to tell how continuous the root systems
18 are. The nature of the roots at the different levels
19 down to a depth of six and a half metres all seemed
20 very similar. I am still not quite sure how to
21 interpret that. That will also be a topic of much
22 future research.

23 Q. In reference to the opinion that
24 you have reached as to the likelihood of there being
25 the deeper fractures at Milton, does the work at West



1 Lincoln support or detract from your hypothesis?

2 A. There would be some additional
3 supporting evidence that there is a reasonable
4 possibility that fractures exist at depths of 4 to 8
5 metres on Site D.

6 MR. LEITCH: Thank you.

7 MR. LANCASTER: Ms. Cronk.

8 CROSS-EXAMINATION BY MS. CRONK:

9 Q. Mr. Feenstra, I don't propose to be
10 very long, but I do have one or two questions arising
11 from part of your discussion this morning with Mr.
12 Tidball and as well a number of items referred to in
13 the body of your reply report which was filed with the
14 Board.

15 As I read the report and heard your
16 evidence, Mr. Feenstra, with respect to Site D, it
17 seemed to me and I would ask whether this is an
18 accurate view of the essence of the opinion that you
19 have given the Board with respect to Site D, is that
20 what you are saying is that you now, based on all of
21 the information available to you to date, have two
22 concerns with respect to Site D.

23 The first relates to, as you have
24 explained at some length, the possibility that the
25 unweathered upper till at Site D is fractured and the



1 that?

2 Secondly, I have a distinct recollection
3 that I cross-examined Dr. Charlesworth on the subject
4 of the hydraulic conductivity of the till at Site D and
5 I can't off the top of my head remember whether he gave
6 evidence in chief and I haven't reviewed his report to
7 see, but it seems that since he has given evidence on
8 this subject then his evidence to be fair to everyone
9 should be included with Dr. Rowe's evidence.

10 MR. ESTRIN: I plan to take the
11 witnesses through this exhibit and any corrections that
12 appear obvious we will make, but in the meantime, if I
13 may continue, I plan to take the witnesses through it.

14 Q. Mr. Petrie, let's look still at
15 your project document, page 36. What this project as
16 you have written it up demonstrates is that lab and
17 field investigations such as field investigations
18 carried on at Site D could easily miss the vertical
19 fracturing that could occur in an unweathered clay
20 till?

21 MR. PETRIE: A. You can conclude that.

22 Q. If it could happen in Waterloo
23 with a clay content of 54 per cent...

24 A. The clay content of 54 per cent
25 was not from Waterloo but a general description of the

1. *Chlorophyll a*

Figure 1

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1. *Explain the importance of the following:*

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1

Journal of Management Education 36(8)

$\rho_{\text{eff}} = \frac{\rho}{1 - \beta}$

1

1000

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100

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1000

1

1. *Chlorophyll a* (Chl a) and *Chlorophyll b* (Chl b) are the primary photosynthetic pigments in green plants. They are responsible for capturing light energy and converting it into chemical energy through the process of photosynthesis. Chl a is the most abundant pigment, while Chl b is present in smaller amounts. Both pigments are found in the chloroplasts of green plants.

1



1 you discussed be done at Site D before it were
2 approved, if at all, for landfilling?

3 A. Yes, I think that follows from my
4 statement that on the basis of attachment 5 to my
5 witness statement I feel that there is a reasonable
6 possibility that fracturing does indeed exist in the
7 unweathered upper till at Site D. I would not reject
8 that hypothesis without further investigation or
9 modification of the design and monitoring angles at
10 Site D.

11 Q. The issue as to whether or not that
12 till unit is fractured goes to the very integrity of
13 Site D for a landfill site, would you agree, Mr.
14 Feenstra, the very fundamental issue regarding the
15 integrity of that site?

16 A. It's a very fundamental issue for
17 the site and the monitoring program, as previously
18 stated, yes.

19 Q. I understood at least by your
20 inference, if not expressly, the suggestion made to you
21 this morning by Mr. Tidball that perhaps these further
22 investigations could be carried out as a required
23 condition of any approval of Site D and coincident in
24 point of time with other site preparation or
25 investigation work.



1 that the implementation of any of these other
2 alternatives as a condition of the investigations or as
3 an outcome of the investigations would certainly be
4 subject to the review and approval of the director of
5 the Ministry of the Environment.

6 As I indicated, I don't know precisely
7 what avenues individuals would have to challenge,
8 review or comment on those decisions.

9 Q. Let us take a look then at the
10 three scenarios you have put out in your decision tree.
11 If I could ask you just to look at it, dealing with the
12 rejection scenario of the hypothesis, you have already
13 told Mr. Leitch and Mr. Tidball that that is not the
14 course of action you would recommend to the Board?

15 A. That is not what I would recommend.

16 Q. I take it that that is so because
17 to take that route with respect to this whole issue of
18 the possibility of fracturing is essentially to gamble
19 that they are not there at all?

20 A. That is correct.

21 Q. In that scenario, what you are
22 really gambling with is public health and safety, isn't
23 that so?

24 A. At this particular site, yes.

25 Q. Then of the two remaining ones, the



1 Petrie and Mr. Bowen has been superseded by the reply
2 evidence of Mr. Feenstra.

3 Mr. Feenstra has introduced into the
4 discussion, three new hypotheses.

5 First, that significant fracturing
6 exists in the unweathered upper till at Site D.

7 Second, that landfilling may induce
8 fracturing or open up existing closed fractures.

9 Third, that there may be insufficient
10 recharge to maintain the hydraulic trap at Site D.

11 With respect to the second hypothesis,
12 that had to do with landfilling actually inducing
13 fracturing, Mr. Feenstra emphasized that he is not a
14 geotechnical engineer and that only the latter, i.e. a
15 geotechnical engineer, could carry out a proper
16 evaluation of this hypothesis.

17 With respect to the first hypothesis,
18 Mr. Feenstra emphasized that there is no direct
19 evidence currently existing which either confirms or
20 disconfirms the hypothesis.

21 Referring to his decision tree, that is
22 Attachment 5 in Exhibit H-936, it is Mr. Feenstra's
23 evidence that the hypothesis should not be rejected but
24 as to whether it should be tested or accepted, you will
25 recall there were three choices across the top, that
that was not, in his view, a hydrogeological question.



1 you would do with it or what I would do with it,
2 frankly, but it strikes me we don't have a lot of
3 evidence on it one way or the other. I don't think the
4 conditions are necessarily in conflict and the EA
5 condition simply requires Halton to operate it and do
6 the best they can to allow for an agricultural after-
7 use and if it's impossible because of the need to pump
8 leachate, then I think that that is a higher priority
9 item in any event and would take precedence.

10 I come now to Mr. Feenstra's hypothesis
11 on fracturing of the unweathered upper till. You will
12 recall Mr. Feenstra's position was that there was a
13 real possibility that fractures extend through the
14 unweathered upper till all the way to the lower till.
15 The issue that that raises you will recall is simply
16 that if the trap fails the result could be very rapid
17 movement of contaminants to the upper granular unit and
18 the critical item is that this is a zero discharge
19 site. We can't allow anything to get into the upper
20 granular unit and move off-site through that unit and I
21 put to Mr. Feenstra that issue at Volume 172, pages
22 42766 to '7 and Mr. Feenstra agreed that that was the
23 issue here, that this wasn't necessarily an issue for
24 every other site in the province, but simply because of
25 the nature of this site and because of the marginal, I



1 guess, quality of the groundwater in a sense that you
2 couldn't allow any impact, that is what created the
3 critical problem for him. I would note there is no
4 direct evidence of deeper fracturing at Site D.
5 However, given the potential consequences of fracturing
6 if it does exist, it is my submission to you that the
7 hypothesis cannot be rejected and if we turn to
8 Mr. Feenstra's decision tree I would simply say that
9 the third option on the right should not be considered
10 by the Board. The only real issue is whether to
11 further test or accept the hypothesis and it's my
12 submission that the hypothesis ought to be accepted.
13 Mr. Hodgson has put all of the transcript references on
14 this item as to Mr. Feenstra's opinion to you and he
15 has read them extensively and I see no need to re-
16 plough that ground. Mr. Feenstra was cross-examined
17 extensively by me and by Mr. McQuaid on what would be
18 involved in a testing program and I would refer you to
19 my cross-examination in any event at Volume 172, pages
20 42778 to 42794. Mr. Hodgson has laid out I guess what
21 might be termed the economic rationale for accepting
22 the hypothesis and that is what leads his client to
23 take the position that the hypothesis should be
24 accepted. In my submission another item you have to
25 consider is the real possibility that a testing program



1 pass the test of acceptability under that criterion.

2 It is likely that only through a liner
3 could it pass, but even then we don't know. CRA's
4 position was similar to Trow's originally with regard
5 to the importance of the unweathered upper till. They
6 said, either Mr. Crutcher or Mr. Petrie:

7 "Under a failed case we have a very good
8 unweathered upper till. It provides a
9 high level of confidence in the
10 integrity of the site under our failure
11 situation."

12 and that was volume 113, 27199 to 27200.

13 Mr. Feenstra made the point in reply
14 that Mr. Sobanski indicated in his evidence that there
15 are times of the year where the hydraulic trap wouldn't
16 work because the head in the UGU may be less than the
17 head of leachate in the landfill and that originally
18 this was not a major issue as it was assumed the till
19 was not fractured, but if it is, to quote him:

20 "...even seasonal localized failures of
21 the hydraulic trap taken (sic) on much
22 more significance."

23 That was at page 42124.

24 While Mr. Feenstra went on in his
25 witness statement and his evidence to indicate there



1 the base of the landfill."

2 So what has Mr. Feenstra said? He has indicated that,
3 first of all, piped water supply might be an
4 alternative and Mr. Leitch will deal with the potential
5 problems with that from a planning perspective and
6 indeed from a legality perspective at the present time
7 in his submissions. The point is a piped water supply
8 would not deal with the potential and eventual
9 contamination of the lower granular unit as well as
10 off-site impacts that could be caused through
11 contamination of the upper granular unit which may feed
12 creeks, streams and ponds in the area.

13 Mr. Feenstra said in that context, just
14 to go back over the lines I was reading from, when they
15 talked about the piped water supply he said you could
16 have:

17 "... piped water with a purge well
18 system as a contingency to prevent off-
19 site migration which might impact more
20 existing users or surface water or some
21 other receptor..."

22 In my respectful submission Mr. Feenstra does not
23 recommend rejecting his hypothesis, it is clear. To do
24 that at this site is to gamble with public health and
25 safety, and Ms. Cronk made that point at volume 172,



1 page 42869.

2 He agreed with Ms. Cronk that two of his
3 three methods of dealing with fractures are reactive
4 and Mr. Hodgson brought that out in his submissions and
5 they don't prevent contamination of the existing
6 groundwater, and simply to bring in piped water does
7 not prevent off-site contamination. This is all at
8 volume 172, pages 42872 to 76.

9 Mr. Feenstra made it clear that Site D
10 is especially sensitive if fractures are present and he
11 rejected the notion that such fracturing will generally
12 be revolutionarily significant. Mr. McQuaid wanted
13 Mr. Feenstra to agree that this was some revolutionary
14 theory that was being espoused and somehow Site D --
15 this would affect how we locate any landfill site on a
16 till plain. I think it is important the Board remember
17 what Mr. Feenstra said about that. He didn't agree.
18 He said at volume 174, page 43294 to 5:

19 "The example at Site D, I believe, is
20 reasonably unique in the fact that we
21 have, with the proposed landfill design,
22 a fairly thin unit underlying the
23 landfill of between three and four
24 metres of what was considered to be
25 unweathered, unfractured till overlying



1 the thin, granular unit, in which there
2 is very little potential for dilution to
3 clean water or a cross-flow beneath the
4 site. We have got potential receptors
5 or private wells that would be
6 potentially impacted by off-site
7 migration relatively close to the site
8 boundaries. I think those are fairly
9 unique conditions."

10 He then continued:

11 "If one took a hypothetical Site D ..."

12 And this is at page 43295:

13 "...where the granular units were at a
14 depth of 15 metres, rather than eight
15 metres, given that we would expect the
16 depth of fracturing or the frequency of
17 fracturing to diminish with increasing
18 depth, I think we have a much more
19 difficult time imagining fractures
20 extending to granular units at that
21 depth ... in terms of lateral flow away
22 from the landfill site..."

23 And this is the hypothetical site he was talking about:

24 "...you are dealing with distances that
25 are much greater than just the three or



1 four metres we are talking about from
2 the bottom of the landfill to the
3 granular units."

4 He goes on:

5 "At Site D, the lateral distance of flow
6 would be 100 metres to the site
7 boundary. Over a distance of 100
8 metres, matrix diffusion will be a very
9 important process and will minimize any
10 impacts on off-site ... So, just the
11 fact that there might be fracturing
12 extending to depths of eight or possibly
13 ten metres, I don't think necessarily
14 has implications at a great many sites."

15 In other words, Mr. Chairman, even if the Feenstra
16 hypothesis about fracturing is accepted, not only at
17 Site D but at other till plain sites, there may be some
18 of those other till plain sites A, B, C or E that
19 nevertheless would be suitable. We don't know. They
20 may be suitable without complex engineering and
21 suitable without a liner; we don't know.

22 Mr. Feenstra continued in the same vein
23 at page 43300:

24 "In the deeper fractured zones if the
25 bulk hydraulic conductivity is 10^{-7} or



1 could recharge it. Don't worry about that particular
2 problem. Where is the water coming from? Mr. Feenstra
3 didn't tell us, no one told us. There is no evidence
4 that there is such a supply and there is no evidence
5 that if there was such a supply taking it out and
6 putting it back in at Site D won't affect present users
7 or future users.

8 Then, Mr. Feenstra went on to point out
9 that if the trap failed due to mounding, even if you do
10 go to purge wells, you won't get back what has already
11 left the site because it is on its way to the site
12 boundary and you may also be contaminating the lower
13 granular unit, and that is volume 175, pages 43591-2
14 and volume 172, page 42798.

15 With regard to the fracturing hypothesis
16 Mr. Feenstra made it clear in cross-examination by
17 Ms. Cronk that he would not reject that hypothesis
18 "without further investigation or modification of the
19 design and monitoring at Site D", and that is volume
20 172, page 42863 and then a question by Ms. Cronk at
21 that page:

22 "Q. The issue as to whether or not that
23 till unit is fractured goes to the very
24 integrity of Site D for a landfill site,
25 would you agree, Mr. Feenstra, the very



1 fundamental issue regarding the
2 integrity of that site?

3 A. It's a very fundamental issue for
4 the site and the monitoring program, as
5 previously stated, yes."

6 Ms. Cronk went on to point out in cross-examination by
7 Mr. Tidball -- of Mr. Feenstra, it was suggested that
8 perhaps these further investigations could be carried
9 out as a required condition of any approval of Site D
10 and coincident at point in time with other site
11 preparation or investigation work, and

12 Mr. Feenstra was asked:

13 "Q. Is it correct... if these further
14 investigations were undertaken that
15 clearly you can't predict in advance how
16 extensive the fracturing in the
17 unweathered till unit might be if it is
18 there at all? You can't tell that in
19 advance?

20 A. No, you can't tell that in advance,
21 you have no information from the site
22 itself.

23 Q. Nor can you tell the direction or
24 the location in which the fracturing
25 might exist?



1

A. That is also true, yes.

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Pages 42864-65. She continued at line 24:

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"Q. I suppose what I am really suggesting to you is that approval today, both of a further investigation program coupled with one or more of the proposals that you make on the decision tree to take place in the event that fracturing is discovered, assumes that those people or those persons whose interests stand to be affected by fracturing, would be content to accept, without further challenge or opportunity to challenge, that those proposals are adequate in the circumstances? It assumes that there would be no basis for those who would be affected by the fact



1 it is a reasonable and prudent approach in evaluating
2 sites to see what happens if we have done it wrong?
3 What happens if our predictions aren't quite right?
4 What happens if things don't quite perform the way we
5 hope they will?

6 In my submission when you analyze these
7 sites in this way, the preference for Site F is clear.

8 Mr. Feenstra in his reply evidence -- at
9 the conclusion of his evidence in chief said in volume
10 70 that Site F is definitely preferable to Site D for
11 landfill in the Region of Halton. That was the emphasis
12 that he placed on it in his oral evidence.

13 Mr. Feenstra in his reply evidence also raised
14 concerns that there was a reasonable possibility that
15 there is significant fracturing of the unweathered
16 upper till at Site D and much attention focused on this
17 hypothesis at the conclusion of the hearing and this,
18 Mr. Chairman, I submit, leads to the argument I will be
19 developing in a moment, that you do not have before you
20 an appropriate conceptual design for Site D that is
21 approveable.

22 However, in my submission, the outcome
23 of this case does not turn on whether or not you accept
24 Mr. Feenstra's hypothesis, or whether in fact you can
25 conclude you have an appropriate conceptual design



1 before you at Site D. It is my submission that even if
2 both of these sites were approveable, and even if both
3 were considered acceptable from the hydrogeological
4 point of view, the result of the other factors in this
5 case makes Site F a clear choice, and I will be
6 developing my argument on those other factors following
7 this discussion of hydrogeology.

8 Notwithstanding that position,
9 Mr. Chairman, it is my position that this Board should
10 accept the hypothesis advanced by Mr. Feenstra and
11 conclude that Site D would not be hydrogeologically
12 suitable for landfill with Mr. Hiraishi's proposed
13 conceptual design. To do otherwise would be to gamble
14 with public health and safety in the face of the
15 proponent's own evidence of what is necessary at the
16 site. I think, Mr. Chairman, it is significant that
17 this is not someone in opposition to the site raising
18 concerns that the Board might conclude are unfounded or
19 can be discounted. This is the Region's own
20 hydrogeologist, the Region's own application which it
21 is putting before you. The Region's own witness is
22 telling you that their original conceptual design for
23 Site D is deficient and inadequate.

24 No evidence was called by any other
25 party to oppose that evidence and any party was free,



1 Mr. Chairman, to bring a motion before you to call
2 evidence or for permission to call evidence to
3 contradict that point and no one even asked for the
4 right to call evidence to rebut that point.

5 Mr. Feenstra was cross-examined about
6 the support for his hypothesis and the difference
7 between the Sarnia tills and the Site D tills and so on
8 at great length. In my submission it is clear from his
9 answers that all of the matters, all of the substantive
10 matters that were put to him in cross-examination, were
11 carefully considered and evaluated by Mr. Feenstra
12 prior to him giving his evidence when he formulated his
13 hypothesis. I would like to read an extract from
14 volume 175 at page 43666. This is at the conclusion of
15 Mr. Feenstra's cross-examination by all of the various
16 parties and in response to some questions from the
17 Board, starting at line 3, Dr. Kingham asks Mr.
18 Feenstra:

19 "The final question I have for you,
20 Mr. Feenstra, has to do with what, for a
21 lack of a better name, I would call the
22 Eureka Syndrome. We heard in the last
23 few days a lot of reference to papers
24 holding various views about fracturing
25 of clay. Papers produced presumably so



1 that this Board would have various
2 opinions, or an opinion on the weight to
3 be accorded to the hypothesis. When you
4 first received Mr. Ruland's paper, but
5 before you... expressed your concerns to
6 Mr. Hodgson, did you either actively or
7 mentally or whatever, go through the
8 various competing hypotheses before you
9 presented this hypothesis to Mr. Hodgson
10 for presentation to the Board?
11 THE WITNESS: By competing hypothesis I
12 am not clear what you mean. Certainly,
13 I both mentally and in terms of scanning
14 other literature, I looked at
15 information that would either support or
16 contradict that hypothesis.
17 DR. KINGHAM: Did you review all or
18 some of the documents that were brought
19 to your attention on Tuesday, Wednesday
20 and Thursday, Tuesday, Wednesday and
21 today, I am sorry?
22 THE WITNESS: With respect to Site D and
23 the hypothesis of fracturing, I believe
24 those documents would be Exhibit N-254,
25 the paper by Dr. Quigley which I



1 certainly examined.

2 DR. KINGHAM: Before you spoke to
3 Mr. Hodgson?

4 THE WITNESS: That was actually a prior
5 exhibit. That was put to me last year.

6 DR. KINGHAM: Yes, quite right.

7 THE WITNESS: I can't recall whether
8 there was another document related to
9 fracturing that has been presented to me
10 in the last few days during cross-
11 examination. There have actually been
12 some other papers that I have also
13 looked at with regard to, basically the
14 question of whether fractures can even
15 exist within clay type materials at a
16 significant depth.

17 DR. KINGHAM: What I am trying to get
18 at is that you had a paper presented to
19 you which in and of itself made sense to
20 you, obviously, you presented it to
21 Mr. Hodgson. It was another
22 individual's thesis project. It
23 expounded upon ideas that individual had
24 and findings that individual had. You
25 explained to us it was your thesis to



1 transfer those results to another area
2 of till in Ontario. You had reasons for
3 doing so and you explained those reasons
4 to us. In the course of the cross-
5 examination it has been drawn to our
6 attention, through you, that there are
7 some differences, and the question
8 simply is before you approached Mr.
9 Hodgson on the subject, did you ask
10 yourself, well, what are the
11 similarities and what are the
12 differences, what do I know about clay
13 content, about depositional, about age
14 of sediments that would temper my
15 presentation of this and at the end of
16 that result, you say, okay, I am
17 satisfied this is really something that
18 -- I want to know what went on in your
19 mind.

20 THE WITNESS: Actually many of those
21 questions you are suggesting, the clay
22 content, the mineralogy, the chemical
23 composition of the till, I had already
24 evaluated last year in my assessment of
25 migration of contaminants through the



1 weathered upper till. It was on that
2 basis that I was presented with, for
3 example, Dr. Quigley's paper and
4 Exhibit N-254. I had already been asked
5 under cross-examination to compare the
6 nature of the till in the Lambton County
7 area with the till in the Site D area.
8 So, I had already gone through much of
9 that comparison process last fall during
10 my first visit here."

11 Mr. Feenstra in my submission during his reply evidence
12 made it clear that the available data at Site D
13 including the limited tritium data that is available is
14 simply inadequate to allow for the hypothesis to be
15 rejected. The available data does not prove the
16 hypothesis, but it is also insufficient to disprove it.
17 It is the proponent's case to prove the suitability of
18 Site D and what they are telling you is that their
19 available evidence cannot disprove Mr. Feenstra's
20 hypothesis that the site is unsuitable according to the
21 original conceptual design.

22 It is my submission that where public
23 health and safety is at risk the way it would be at
24 Site D, the Board must err on the side of caution.
25 This is the proponent's own evidence and in my



1 submission the only prudent course for the Board is to
2 accept it. In fact, Mr. Chairman and Dr. Kingham, I
3 don't believe that there is any evidence upon which the
4 Board could reasonable found a decision to reject this
5 hypothesis.

6 Mr. Feenstra outlined from a
7 hydrogeological point of view some design options that
8 he believed were necessary to respond to this
9 situation, assuming his hypothesis was suggested.
10 Mr. Hodgson in his argument suggested a variation in
11 the sense that he asked his Board to accept the
12 hypothesis but to allow for a testing program to occur
13 during the construction of the site.

14 In my submission, Mr. Chairman and
15 Dr. Kingham, that is simply unacceptable for several
16 reasons. Firstly, Mr. Feenstra himself in his reply
17 evidence rejected the notion that a testing program was
18 a worthwhile exercise. His evidence, in my submission,
19 was very clear, that not only would investigations have
20 to be extensive, but also they would likely not be
21 conclusive of the issue.

22 So, for Mr. Hodgson to now suggest that
23 there is some worthwhile reason for conducting these
24 investigations, rather than simply designing according
25 to the assumption the way Mr. Feenstra suggested in my



1 fractures and the nature of the fracture network and
2 the hydraulic conductivity which controls flow through
3 those fractures, the disappearance of tritium at a
4 particular depth could take place and be accounted for.
5 It was his evidence, Dr. Kingham and Mr. Chairman, that
6 only further investigation of the weathered and
7 unweathered upper till units at Site D would provide
8 sufficient information to allow a determination on this
9 issue to be made. That is Volume 175, pages 43636 to
10 43641.

11 In our submission, Mr. Chairman and
12 Dr. Kingham, that is the uncontradicted evidence of
13 Mr. Feenstra and, in accordance with the general
14 principles defined in the case law that we discussed
15 yesterday, that type of evidence should not be lightly
16 disregarded. The absence of tritium in those granular
17 units at Site D can be explained by any number of
18 viable mechanisms having nothing to do with the absence
19 of fracturing. It cannot be taken from the absence of
20 tritium in our respectful submission that those
21 fractures do not exist and we would ask you to accept
22 Mr. Feenstra's evidence in this regard which is
23 uncontradicted by any other expert. We note in this
24 regard, and it really applies to all of the evidence
25 you have heard from Mr. Feenstra, Mr. Chairman, that



1 once that reply evidence came in it was open to any
2 party at this proceeding including the City of
3 Burlington and the Burlington ratepayers' group to move
4 before you for leave to call additional evidence to
5 respond to the hypotheses that had been presented by
6 Mr. Feenstra and to recall Mr. Petrie, Mr. Crutcher,
7 Mr. Bowen, anyone qualified to speak to the issue to
8 contradict the possibilities of the hypotheses
9 Mr. Feenstra had put before you. That was not done
10 and, indeed although Mr. McQuaid at one point indicated
11 he was contemplating doing so, he in the end decided
12 not to. That means on the evidence on the record
13 before you that the evidence of Mr. Feenstra on these
14 issues is uncontradicted by any other expert.

15 I would remind the Board as well with
16 the very greatest of respect what the consequences are
17 of rejecting this hypothesis. You have heard from
18 Mr. Feenstra that he does not recommend its rejection.
19 It was his evidence in cross-examination that the issue
20 of whether the unweathered upper till unit at Site D is
21 fractured is a very fundamental issue for Site D. He
22 also told you that to reject the hypothesis of
23 fracturing is to gamble that fractures are not there at
24 all and that at Site D to do that is to gamble with
25 public health and safety. It is our submission that in



1 the face of that evidence, the only proper finding that
2 can and should be made on the evidence is that the
3 hypothesis should be accepted for the purposes of
4 evaluating at this time the suitability of Site D for
5 landfilling.

6 We wish to address as well very
7 briefly...

8 DR. KINGHAM: Just before you do so just
9 so I can understand clearly what your argument has been
10 vis-a-vis tritium penetration, I think what you told us
11 was various factors like upward gradients from the
12 bedrock or matrix diffusion could account for the non-
13 finding of tritium.

14 MS CRONK: That is correct, on the
15 evidence of Mr. Feenstra.

16 DR. KINGHAM: On Mr. Feenstra's
17 evidence, and those are some factors and you enumerated
18 some that could account for that absence and then you
19 argued that because that opinion was not contested that
20 it should not be dismissed, that those are factors
21 which could account for the absence?

22 MS CRONK: That is correct.

23 DR. KINGHAM: I think then your argument
24 is by implication, is it not, that since those factors
25 could account for the non-finding of tritium at depth



1 they could support the existence of fractures. Is that
2 essentially what you would have us believe?

3 MS CRONK: I don't think you can make
4 that leap.

5 DR. KINGHAM: I thought that was the
6 essence of your submission.

7 MS CRONK: I started the submission by
8 saying I thought it was a neutral factor and what I
9 mean is on the state of the evidence you have, on the
10 state of the data before you, the absence of tritium
11 doesn't tell you one way or the other and doesn't help
12 you one way or the other in deciding whether that
13 hypothesis is in fact a fact at the site. So, you
14 can't take the absence of tritium as meaning there are
15 no fractures because you have evidence that that
16 absence can be explained by various other factors but,
17 conversely, you can't use it the other way, it's a
18 neutral factor.

19 DR. KINGHAM: I was actually focusing in
20 on your observation that since the opinion offered with
21 respect to reasons for non-penetration of tritium was
22 not in your view contested by other experts, then those
23 reasons ...

24 MS CRONK: I meant the entire hypothesis
25 and the danger of rejecting it, because what he has



1 contaminants through the granular units thus
2 jeopardizing, on Mr. Feenstra's evidence and in perhaps
3 as little as a year, the water resource at Site D.
4 That is a consequence of the fracturing hypothesis if
5 accepted in the event of trap failure. But we have as
6 well not only Mr. Feenstra's evidence but some evidence
7 from Mr. Petrie given in another connection which, in
8 my submission, bears on this issue as well. Mr. Petrie
9 said repeatedly that hydrogeologists in general "do not
10 have a good handle on infiltration into fractured
11 media." He gave that evidence in reply to a question
12 Dr. Kingham had put to him with respect to the
13 weathered upper till at Site D and he said they really
14 don't have a good handle on infiltration into fractured
15 media and he then gave on any number of occasions
16 evidence in the context of Site F which had to do with
17 what he described as the uncertainty of the scientific
18 community regarding infiltration and flow in fractured
19 media. If you accept as I am urging you to do
20 Mr. Feenstra's evidence that the unweathered upper till
21 at Site D is fractured, all of that evidence by
22 Mr. Petrie bears as much on the Site D case as it does
23 on the Site F case and I would like to remind the Board
24 of what it is he said. He said, again in the context
25 of Site F:



1 as well to the issue of a need for a liner at Site F.
2 In our submission, however, it is no less relevant at
3 Site D. At Site F the issue is is a liner required?
4 At Site D Mr. Petrie told the Board that CRA used the
5 figure of 9.6 millimetres as the exfiltration figure
6 for penetration through the unweathered upper till. He
7 said that that value was not calculated or determined
8 by CRA but was taken from Trow. It was Mr. Petrie's
9 evidence that this was an appropriate value.

10 I would ask you to go to Exhibit B-618,
11 the Site D report commencing at page 47. At the bottom
12 of page 47 of this report, dealing with the groundwater
13 flow system, CRA indicates:

14 "CRA is in general agreement with Trow
15 that groundwater flow at this site is
16 predominantly directed downwards with
17 the bedrock being the receptor of the
18 bulk of the infiltration at the site.
19 The water balance presented by Trow
20 (Figure 3, p. 66, Exhibit H-39)
21 indicates that 22.8 percent of
22 infiltration at the site migrates
23 laterally off site, while 71.5 per cent
24 migrates down to the bedrock."

25 That means, Mr. Chairman and Dr. Kingham, even



1 accepting for the moment the calculations that were
2 done, that almost 72 per cent of infiltration at Site D
3 will migrate through the unweathered upper till unit,
4 and if you go to the reference CRA indicates, H-39,
5 page 66, and it's really page 64 -- they are referring
6 to Figure 3 on page 66, but if you go to page 64 you
7 will find the impact assessment Trow did for Site D and
8 it starts with their calculation of a water balance, a
9 water budget. As CRA points out, the calculation that
10 was done -- I'm sorry -- perhaps there is a better way
11 to come at this.

12 The issue of infiltration through the
13 landfill and hence exfiltration out the bottom of the
14 landfill at Site D is related to the continuity of the
15 granular units. If the upper granular unit is not
16 continuous, which is what CRA has asked you to accept,
17 there will be even more infiltration passing through
18 the unweathered upper till to the underlying bedrock.
19 For proof of that I would refer you to the second
20 paragraph at page 48 of CRA's report in which they
21 indicate that Trow's calculation of infiltration was
22 based on the assumption that the upper granular unit
23 was continuous. CRA maintains it's not continuous
24 beneath the whole site and indicate that if it is not,
25 then it has the effect of reducing the amount of



1 lateral off-site flow with the resulting increase in
2 the percentage of infiltration that reaches the lower
3 units. In other words you will have more. If CRA is
4 right and the unit is not continuous, you will have
5 more infiltration through the granular units.

6 In preparing its water budget Trow
7 assumed that the unweathered upper till unit was
8 unfractured. In critiquing Trow's work, CRA assumed
9 that the unweathered upper till unit was unfractured.
10 The amount of groundwater recharge estimated by Trow
11 based on its water budget was 9.6 or approximately ten
12 millimetres per year. CRA indicated and Mr. Petrie
13 confirmed in his evidence that this value was low but
14 that it might reasonably represent the infiltration
15 rate through the unweathered upper till, assuming that
16 it wasn't fractured. I would ask you, if you would, to
17 go to page 64 of the Trow Site D report, H-39, and just
18 look at the water budget set out there. You will see,
19 sir, at the top of page 64 is the commencement of a
20 discussion on impact assessment and the very first
21 thing dealt with is the water budget and if you go over
22 to page 65 you will see the calculations made by Trow
23 and it indicates groundwater recharge, ten millimetres
24 per annum.

25 Now, what I am coming to, Mr. Chairman



1 and Dr. Kingham, is this; a very great portion of this
2 hearing was devoted in the case of Site F to an inquiry
3 and a strenuous, if I might suggest, examination of
4 exfiltration calculations through the bottom of the
5 landfill at Site F. All of the work done by Trow on
6 their impact assessment at Site D and on their water
7 budget was predicated on no fracturing in the
8 unweathered upper till unit. In the closing days of
9 this hearing the Board received material evidence that
10 that unit may very well be fractured, and that came
11 from Mr. Feenstra. I have urged on you for all the
12 reasons I have outlined that you should accept that
13 hypothesis, but let us assume for the moment at the end
14 of the day you conclude it is appropriate to do that
15 and you have accepted that hypothesis. That means you
16 must then step back, in my respectful submission, and
17 look at the suitability of this site in consequence of
18 knowing that the unweathered upper till unit is
19 fractured and to do your impact assessment -- to review
20 the impact assessments that have been done by others
21 and put before you for acceptance you must look at the
22 water budget and you must look at what they say about
23 the amount of exfiltration down through the landfill at
24 Site D in the event of failure. That means you have to
25 know what the leachate quantities are and you must know



1 what the water balance is, what the water budget is,
2 and I say to you with the greatest of respect where is
3 the new water budget at Site D recognizing fracturing
4 in the unweathered upper till unit? You don't have it.
5 You have no evidence as to how that hypothesis impacts
6 on the quantities, the amount of escape in the event
7 of failure at that site. I recall for you in the
8 strongest of terms that the impact assessment done on
9 Site D by Trow was premised on the assumption of no
10 fracturing in the unweathered upper till unit and on a
11 water balance set out on these pages of H-39 that is
12 based on assumed hydraulic conductivities through that
13 unit and the amount of water that will move through is
14 directly dependent on the hydraulic conductivity that
15 applies.

16 What I am suggesting is that if the
17 unweathered upper till unit is fractured, the unit can
18 accommodate more water. It can receive more water. If
19 it can do that, it will affect the quantities that are
20 available for leakage in the event of trap failure.
21 You have Mr. Feenstra's evidence before you that the
22 primary consequence of acceptance of this hypothesis is
23 the speed at which contaminants will move, the rate of
24 transport, and I accept that and I urge you to accept
25 that that is the primary consequence, but there is



1 another half to the equation in my submission and that
2 is how much are we talking about? There was no
3 evidence put to you by the close of this hearing as to
4 what the consequences are of fracturing in that unit on
5 the impact assessment performed by Trow, on the water
6 balance performed by Trow, and you must recall that CRA
7 adopted Trow's numbers. I would ask you to contrast
8 that with what happened at Site D -- Site F, and the
9 emphasis that has been placed on that by the Region.

10 Finally for confirmation of the
11 significance of that point, in my submission at page 65
12 of Trow's H-39 report on Site D, Trow indicates:

13 "The calculations indicate that the
14 actual recharge that the hydrogeologic
15 system accommodates is 9.6 mm per
16 annum... Water removal from the
17 hydrogeologic system by lateral flow in
18 the overburden is about 28 percent of
19 the recharge. The remainder moves to
20 the bedrock."

21 What I am saying to you is that the impact assessment
22 done by Trow derives from their water balance. Their
23 water balance assumes no fracturing and assumes
24 permeability conditions which dictate how much water
25 that unit can accommodate. Accommodation of water is



1 dependent upon permeability, hydraulic conductivity and
2 how many fractures there are. In the end I'm not
3 urging you to accept or even to believe that there will
4 be a vastly different water balance budget at Site D in
5 the event of fracturing. There is no evidence upon
6 which I can make that submission to you, but what I do
7 urge you to accept is that you haven't been told what
8 in fact that water balance -- water budget will be and
9 what the water balance will be. It hasn't been looked
10 at and no one has stood before you and given you
11 evidence and said "I have addressed this and I have
12 examined what the consequences of this fracturing means
13 in terms of exfiltration and this is my opinion and
14 this is how I got there." That evidence is not before
15 you.

16 I would like to turn then to what I
17 suggest is the ninth uncertainty because I have now
18 covered what were in my submissions the seventh and
19 eighth, the seventh being the hydrogeologic
20 characteristics of the unweathered upper till unit
21 including its permeability and fractures and the eighth
22 being the amount of exfiltration through the
23 unweathered upper till in the event of fracturing. The
24 ninth, in my submission, relates to the possible effect
25 on the water levels in the granular units of the

[illegible]

In the Matter of the Halton Region Landfill Undertaking

Ex. M-962

WITNESS STATEMENT
OF NICHOLAS EYLES, Ph.D
Associate Professor of Geology
University of Toronto

September 22, 1988

Fractures Observed in a Test Pit, Proposed Site D, Milton

In April 1988, one test pit was dug on the lands of the proposed Site D, Milton. The test pit was located beside a fence line in the northwestern area of the site, approximately 160m in from First Line and 275m from the northerly site boundary.

The test pit was excavated through the glacial till to a maximum depth of approximately 8.2m. The main trench, oriented northeast-southwest, was, at the base, 1.5m wide and 6 to 7 m long. A short side trench was dug at a right angle on the southern side of the main trench.

The stratigraphy observed in the trench agreed with the general descriptions in the THCL Site D Hydrogeology Report (Exhibit H39). From surface, the overburden was:

- | | |
|------------|---|
| 0 - 0.6m | Topsoil, sand and silt (Peel Ponding) |
| 0.6 - 3.5m | Red-brown clayey silt till; weathered, heavily fractured; |
| 3.5 - 5.1m | Red-brown clayey silt till; occasional fractures; groundwater seeping from below approx. 4.5m on south side of pit from a silty sandy gravel "lens" |

or phase of the till;

5.1 - 7m Grey clay till; occasional fractures (described below)

7 - 8.2m Red-brown sandy clayey silt till.

8.2m Base of Test Pit.

Several naturally occurring fractures were observed in the red-brown clayey silt till and grey clay till below the heavily fractured upper 3 to 4m of the test pit. One major fracture was observed in the northern wall of the test pit and was marked by some oxidation (brown colouration) on the fracture face where it penetrated the grey till. The fracture extended through the grey clay till into the lower red-brown till at about 7m depth. The fracture appeared to be trending north-northeast, roughly sub-parallel to the northern test pit wall and could be traced across the trench to the southwest face of the pit.

Other fractures were observed on the southern side of the test pit, about 3 - 4m away from the major fracture. These extended from the upper red-brown till into the grey till and appeared to terminate before reaching the base of the grey till. The trend of these fractures appears to be north-northwesterly, intersecting the trend of the previous fracture.

Due to the nature of the exposure (i.e. the geometry of the test pit), it was not possible to trace a particular fracture from the

ground surface to depth.

On the basis of this test pit, it appears that at Site D there are fractures extending from the weathered zone through the grey clay till (upper till) and that some of these extend into the red-brown sandy clayey silt till (lower till). On the basis of the one test pit, it is not possible to determine the frequency, spacing, nor ultimate depth penetration of such fracturing.

Photograph of the Major Fracture
in Northern Wall of Test Pit
Taken at a Depth of 6-7 Metres



O'CONNOR, LEITCH, HAYS, GANGBAR & SHERIDAN
BARRISTERS, SOLICITORS, NOTARIES

000146

TERRANCE P. O'CONNOR, O.C.
FREDERICK E. LEITCH, O.C.
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OAKVILLE, ONTARIO
CANADA L6L 3G8

September 28, 1988.

Weir & Foulds
Barristers & Solicitors
1600 Exchange Tower
2 First Canadian Place
P.O. Box 480
Toronto, Ontario
M5X 1J5

ATTENTION: M. J. McQuaid, O.C.

Dear Mr. McQuaid:

Re: Halton Landfill Hearing

You requested information by way of interrogatories in your letter of September 26, received by us by FAX at 3:17 p.m. September 26, 1988.

I will deal with your numbered paragraphs, Page 2, in the same sequence as follows:

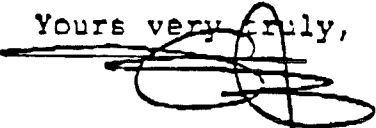
1. I am enclosing a copy of a freehand document entitled "Plan sketch of test pit, Site 'D'". The sketch is not to scale but shows various dimensions and the approximate location of the test pit in relation to First Line and certain physical features of Site "D".
2. The test pit was under the supervision of David Charlesworth. The pit was dug using a backhoe. No additional test equipment was on site with the exception of hand tools.
3. Permission was obtained from Mr. and Mrs. Martin, the owners of the land. The location was chosen for its ease of access from First Line. David Charlesworth selected the location.
4. The purpose of the test pit was to view the subsurface conditions in the fill area of proposed Site "D". The pit was not part of an overall test program but was a discrete

-4-

stand alone test. No other test pits were considered as part of any program.

5. Over a two day period various persons were in attendance including David Charlesworth, Janet Haynes and Dr. Nicholas Eyles. David Charlesworth directed the test program. Instructions in respect of the test pit were all oral. Professor Eyles was not retained by the Town of Milton. He was in attendance at the invitation of Dr. Charlesworth. Dr. Charlesworth and Professor Eyles were working together for the Region of Peel in respect of its search for a new landfill and the investigations in Peel dealt with Halton Till. There is no correspondence, there are no reports, memoranda or documents reporting on the result of any kind whatsoever save and except the plan sketch which we have included and the attached field notes dated April 7, 1988 and entitled "Memo to File re test pit Site "D"". There are some other photographs of the pit which we will produce to you prior to the commencement of the motion.
6. The test pit excavation commenced at 11:50 a.m., Wednesday, April 6, 1988 and was fully open at 5:00 p.m. on Wednesday, April 6, 1988. No other inspections or tests of any kind whatsoever were undertaken at the same time. No pumping test of any nature was taken in connection with the test pit and accordingly, there are no pumping test results. There were no other investigations of any kind conducted by the Town of Milton. The test pit was closed commencing 3:30 p.m. Thursday, April 7, 1988. mmmm
7. This is not an appropriate interrogatory. It is a matter for submissions in respect of the motion and we will make our submissions on the motion.

Yours very truly,



FREDERICK E. LEITCH, Q.C.

FEL/jh

Enclosures.t

c.c. H. G. Hodgson

E. A. Cronk

David Estrin

Stephen S. Garrod

John Tidball

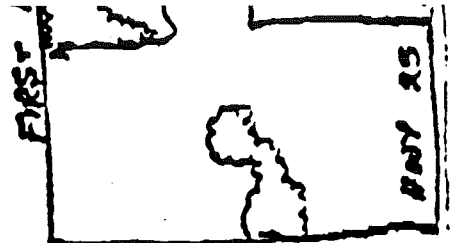
T. Vigod

Post Script:

At the time of writing this letter, Dr. Charlesworth is in England. My answers to the interrogatories are a result of previous conversations with him.

STREAM / BURY AREA

↑
~100m
↓



SKETCH OF TP LOCATION

TOP
SOIL
PILE

SPILL

CAVE

fine granular
facer

RAMP
FOR
ACCESS

Face to 7.2 m
at end / side of
side trench.

SPILL
Bench

A - A'
FACE

Pool Ponding 0.6m
oxidised
red clay till
heavily fractured
8-10m
red-brown
clayey till
4.5-5

Fracture
1-1.5m long
in grey clay
till
terrace in
red-brown
till below

FACE ~8.2m high
grey
clay (till)
Till Cove 6.7m

TO SCALE

PLAN SKETCH OF TEST-PIT, SITE D.

MEMO TO FILE:

April 7/88

Re: Test Pit Site D

Schedule

Wed. April 6/88 - clear, cool

Arr. 11:00am at Martin Property, First line

Backhoe Arrive 11:40am

on site and start digging 11:50am

11:50 - 12:00am backhoe operate

12:00 - 12:30am lunch

12:30 - 2:30 pm backhoe operate

2:30 - 4:30pm " broken down

4:30 - 5:00pm deepen excavation

5:00 - 6:00pm examine excavation/photograph

Thurs. April 7/88

7:00 - 12:30am backhoe on standby

12:30 - 3:30pm examine hole in detail/backhoe deepen & widen

3:30 - 5:00pm test pit infilled/ topsoil replaced

Test Pit

located along fence row(south side), approx. 150m from First Line, just west of stream; on Martin property, central part, north quadrant of Site D

0 - 0.6m - Topsoil(sandy; Peel ponding)

0.6 - 3/3.5 m - red-brown clayey silt till; oxidized; heavily weathered; fractured; various precipitations; evidence of gleying, etc. suggests active water table zone

3/3.5 - 4.5 /5.1m - red-brown clayey silt till; occasional fractures; some cobbles

4.5 - 5.1m - on south side silty sandy gravel phase; showed some seepage from this zone; irregular form-(lens-like); appear to run most of the length of the excavation

5.1 +/- m - 6.7/7m - grey clay till; occasional fractures; some showing brown to grey-brown colouration along fracture length; one fracture go through grey till and appear

to terminate in lower red till; this fracture definitely show brown colouration; other fractures not marked by discolouration;

6.7/7 - 8.2m red-brown sandy clayey silt till

8.2m end of test pit

Fractures

- upper 3.5-4m heavily fractured; oxidized

- below this appear that several fractures do extend; observed one fracture trending roughly north that extended down to the lower red-brown till at approx. 7 m depth; could not trace it further; observed several other fine fractures (closed prior to excavation) extending from upper red till into gray till and appearing to terminate before reaching the base of the gray till; these were not a single specific fracture that could be traced from surface but fractures that apparently extended down from the upper heavily fractured zone;

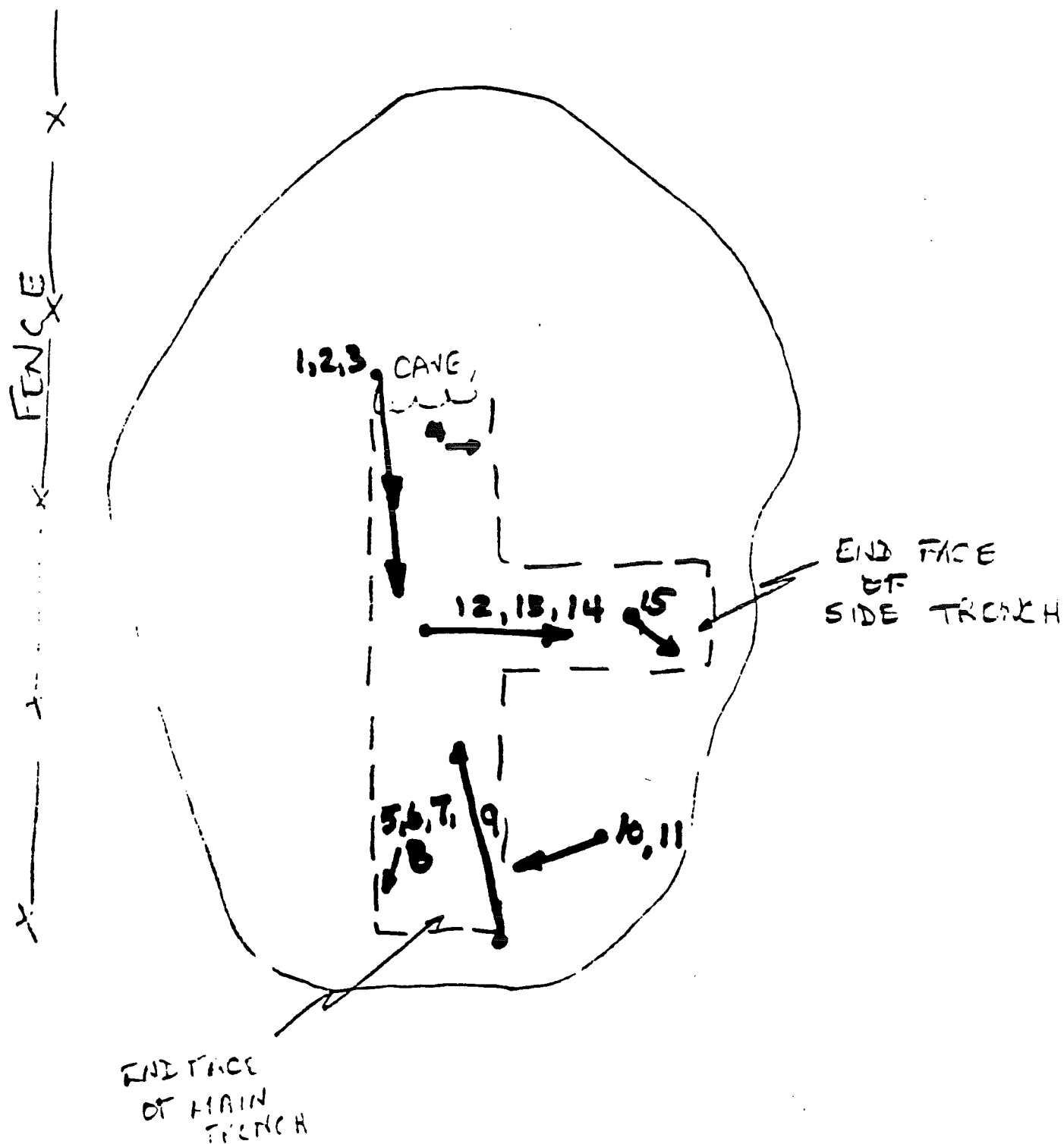
orientation - larger fracture roughly trend north; second set of fractures intersect at acute angle roughly trending north-northwest;

See also attached sketch

92%

PHOTOGRAPHS TAKEN AT A TEST PIT, PROPOSED SITE D, MILTON,
APRIL 1988

1. Dr. D. Charlesworth in base of test pit, at main fracture
2. Close-up of (1)
3. Base of pit, at end face of main trench
4. Minor seepage from sandier lens in till
5. Close-up of main fracture
6. - ditto -
7. - ditto -
8. - ditto -
9. Dr. N. Eyles and Dr. D. Charlesworth examine pit
10. Dr. D. Charlesworth in base of pit on Day 2; some cave in base
11. - ditto -
- 12,13,14. Three overlapping photos covering top to base of end face of side trench
15. Seepage from base of red-brown till



SKETCH SHOWING PHOTOGRAPH LOCATIONS

Abstract

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14. *Chlorophyll a* (100%)

1. *Staphylococcus aureus*

1973) and a number of other authors (e.g. Bannister 1966, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2

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Figure 1

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1 ---- Upon resuming at 2:35 p.m.

2 MR. LANCASTER: Thank you, please be
3 seated.

4 It has been suggested a number of times
5 throughout this hearing that the purpose of the
6 Environmental Assessment Act is to ensure that the
7 Board hearing an application has all the information
8 necessary to make its decision on behalf of all parties
9 concerned.

10 Mr. Garrod re-emphasized that purpose
11 this morning when he suggested that this forum should
12 not be a dispute between parties. In this case,
13 between municipalities ⁱⁿ and Halton. In gathering this
14 information we understand that the Regional
15 Municipality of Halton has acted in the spirit of the
16 Act and in particular with respect to hydrogeology,
17 they allowed for observations and participation by the
18 other parties to the hearing. This helped the Board
19 to have a clear understanding of the evidence brought
20 before us.

21 The Board now understands that
22 additional hydrogeological studies were undertaken on
23 April 6th and 7th of this year. With the exception of
24 the Milton parties, other parties were not informed of
25 the test and this result and were not invited to



1 participate in it. Within 30 hours the T-shaped hole,
2 more than eight metres deep had been dug, examined and
3 filled in again. In subsequent days, particularly on
4 April 12th, 1988, counsel for the party on whose behalf
5 the test pit had been dug was cross-examining a witness
6 on the hypothetical existence of fractures in clay
7 tills across southern Ontario. The witness stated
8 that he had no evidence to support such a hypothesis,
9 but that "If evidence were provided by yourself or the
10 proponent, one would have to consider that fracturing
11 with respect to assessing site suitability."

12 It was not suggested to the Board at
13 that time or at any time since then that such evidence
14 was available. When the expert witness for the
15 proponent, Mr. Feenstra, proposed an hypothesis about
16 fracturing in such tills, he also stated that he had no
17 data to support such a hypothesis in the vicinity of
18 Site D. Again, it was not suggested to the Board that
19 such data might exist. When cross-examined about his
20 hypothesis by counsel for the City of Burlington about
21 the extent of the testing necessary to prove his
22 hypothesis, Mr. Feenstra gave evidence that conclusive
23 evidence could not be assured with even five test pits.

24 Additional tests of a different kind
25 would be needed to clearly support or refute that



1 hypothesis.

2 Now the Board has been asked to consider
3 a motion to admit additional evidence, evidence that
4 was known to the party since on or about April 7th of
5 this year, evidence that was collected in the absence
6 of experts for the other parties, evidence that has not
7 been alluded to in the months since it was gathered,
8 evidence for which the hydrogeologist in charge is not
9 present to testify.

10 The witness statement of Dr. Eyles
11 confirms the general hydrostratigraphy in the area, it
12 describes some fractures and concludes that a single
13 test pit is inadequate to define the frequency, spacing
14 and ultimate depth of the penetration of such
15 fractures. The first observation is not at issue and
16 the second is itself qualified by the inadequacy of the
17 data base. This confirms the evidence of the proponent
18 of the hypothesis, Mr. Feenstra, about the
19 insignificance of a single test pit result.

20 As previously, throughout this hearing,
21 the Board has considered whether the admission of
22 evidence would materially assist in its deliberations.
23 We are mindful of precedents brought to our attention
24 by Ms Cronk that suggest that such evidence could be
25 admitted although our acceptance of this approach is



1 tempered by the suggestion in Sopinka and Lederman, and
2 I quote:

3 "... the evidence must be newly
4 discovered evidence which reasonable
5 diligence could not have discovered
6 during the trial, ..."

7 We are mindful as well of Ms Vigod's
8 reference to cases where such evidence has not been
9 admitted.

10 Taking all these factors into account
11 and especially the discretion allowed us under the
12 legislation, we conclude that the evidence proposed to
13 be introduced by Dr. Eyles should not be admitted
14 because it will not clearly assist us in arriving at
15 our decision. We rule against the motion to have such
16 evidence introduced at this late date.

17 The Board will adjourn this hearing
18 until Tuesday, October 11th, at 9:30 a.m.

19 MR. LEITCH: Mr. Chairman, with respect
20 to the witness statements which were handed forward and
21 which you have had an opportunity to look at before
22 your ruling, could you mark those for identification
23 purposes, not as exhibits, but rather for
24 identification for the public record which is being
25 created here.



1 I suppose A for identification or B for
2 identification, some such thing as that.

3 MR. LANCASTER: We could now mark it as
4 an exhibit.

5 MR. LEITCH: That would be satisfactory
6 as well.

7 MR. LANCASTER: That will become Exhibit
8 M-962.

9 --- EXHIBIT NO. M-962: Witness statement, and
10 supporting documents of
Nicholas Eyles

11 --- Adjournment at 2:43 p.m.

12
13 CERTIFIED CORRECT:

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15 
16 P.D. McQueen

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1 geologist/hydrogeologist, I am quite aware of the
2 processes, but I am not capable of doing a detailed
3 evaluation of their significance at Site D. However, I
4 felt it was appropriate at this time to point out my
5 concerns on this particular point.

6 Given the assumption that fractures
7 extend downward through the upper till and so that
8 fractures exactly exist in the upper till, the nature
9 of the fractures, that is the aperture, and because
10 their aperture relates to hydraulic conductivity, the
11 hydraulic conductivity of these fractures is controlled
12 largely by the horizontal stresses and the vertical
13 stresses acting in the subsurface. When the upper four
14 metres of upper till are removed, you will basically
15 change the stress conditions in the upper till
16 underlying the landfill. You have removed some of the
17 overburden, reduced the vertical stress and the
18 horizontal stresses are going to act to try and move
19 the till around and to compensate for the removal of
20 the overlying material. A very common observation in
21 many excavations is heaving in the base of the
22 excavation caused by stress relief and in some cases
23 groundwater pressures from below. If there are indeed
24 fractures through the lower part of the upper till, on
25 excavation of the 4 metres of upper till for the



1 landfill, many of these cracks could be opened more
2 significantly than they were previously.

3 When the landfill is actually
4 constructed, again you can imagine that you are
5 reloading the base of the landfill and when the
6 landfill is actually completed, the load on this
7 underlying upper till will probably be slightly higher
8 than previously existed. To some degree the cracks
9 that may have opened during excavation will reclose,
10 but there is some question as to whether they will
11 reclose completely. Likewise there should also be the
12 consideration that excavation such as this actually
13 induces new fractures in that relatively thin, three or
14 four metre thickness of unweathered upper till. It
15 would certainly be my recommendation that this type of
16 phenomenon and this type of consideration be given
17 careful attention by a geotechnical engineer prior to
18 the construction of a landfill at Site D. I believe we
19 also have copies of that.

20 MR. HODGSON: Oh yes. If that overhead
21 could be marked as the next exhibit.

22 MR. LANCASTER: H-939.

23 --- EXHIBIT No. H-939:

24 Chart: Possibility for
25 Heaving and Stress Relief
in Unweathered Upper Till
due to excavation for
landfill.



1 Q. If borne out, you proposed three
2 options, any one of which could be introduced to
3 respond to the fracturing problem?

4 A. That is correct.

5 Q. Those are the same three options
6 that would apply were the Board simply to accept it,
7 your hypothesis, without authorizing or requiring any
8 further investigation?

9 A. That is correct.

10 Q. The second possibility if those
11 further investigations are conducted is that the
12 hypothesis of fracturing in the unweathered upper till
13 unit would not be borne out and would not be
14 demonstrated, correct?

15 A. That is correct.

16 Q. That leads you then, based on your
17 decision tree or flow chart, to a second hypothesis,
18 does it not, and that is the possibility of the
19 landfill itself inducing fractures.

20 A. I guess you could regard that as a
21 second hypothesis, that is true.

22 Q. We will just test that suggestion
23 and move over to the rejection scenario. If the Board
24 were to reject today your main hypothesis that
25 fractures exist in the upper weathered till unit they



1 if I took from it the suggestion that further
2 examination of the groundwater flow system is required
3 before what you have referred to as a rigorous
4 evaluation of the effect of landfilling could be
5 assessed in terms of the impact on groundwater levels
6 beneath the landfill?

7 A. That is correct.

8 Q. Would you agree with me, Mr.
9 Feenstra, if that type of examination of the ground-
10 water flow system at Site D were undertaken, it is
11 possible at least that it could disclose that the
12 recharge conditions were such that there would be
13 insufficient recharge to maintain the hydraulic trap
14 once the landfill is introduced; that is a possible
15 result?

16 A. That might be possible, yes.

17 Q. Insofar as that is a possibility,
18 that is a result, I suggest, that could not be lived
19 with insofar as the design of Site D is premised on the
20 maintenance and continued maintenance of a hydraulic
21 trap?

22 A. Unless the mechanism by which the
23 groundwater levels in the underlying geological units
24 could be recharged or surcharged artificially, that is
25 correct.



1 from that we would have three options similar to the
2 three that are on the hypothesis on the overhead; in
3 other words, we could either accept it or reject it and
4 test it?

5 A. That is correct, yes.

6 Q. Perhaps you wouldn't mind just very
7 quickly drawing those three circles with an A, T and an
8 R in it just for short form.

9 First of all, if we were to reject that
10 hypothesis, would you agree with me that the logical
11 conclusion would be that the landfill could proceed as
12 designed and proposed to this Board, assuming all of
13 the other evidence is acceptable?

14 A. That is correct.

15 Q. I understood from your evidence
16 that you don't believe we are in a position to reject
17 this hypothesis on the available data that is before
18 the Board without some further investigation of some
19 sort?

20 A. That is true, I do not think we
21 could reject that hypothesis.

22 Q. So you don't advocate that option
23 in this case for Site D?

24 A. I don't think we can reject that
25 hypothesis without bearing in mind the eventuality that



1 Q. It may in fact be that the trap
2 would never function right from the beginning,
3 depending on the degree to which the recharge would be
4 cut off?

5 A. That is possible, but the degree to
6 which the recharge is cut off and the rate at which the
7 water level declines beneath the site.

8 Q. In any case you would agree with me
9 a new design would be required?

10 A. Certainly the design would have to
11 be re-evaluated to prevent offsite migration of
12 contaminants, that is correct.

13 Q. The landfill would have to be
14 redesigned, how about that wording?

15 A. There would have to be changes to
16 the design, yes.

17 Q. Is it not fair to say that the old
18 design would be inappropriate, the existing design
19 would be inappropriate?

20 A. The existing design without the
21 implementation of contingencies would be inappropriate,
22 that is correct.

23 Q. The existing design as a primary
24 engineering line of defense would not be helpful?

25 A. I guess to some degree one has or I



1 Q. Perhaps we could put it this way, Mr.
2 Feenstra. Would you agree with me that the present
3 design would be insufficient to ensure protection of
4 offsite wells and to ensure that the Ministry's
5 reasonable use policies would be met?

6 A. That is correct. Without some other
7 engineering feature to control offsite migration, that
8 is correct.

9 Q. Can we perhaps summarize that by
10 saying present design is insufficient. Would you be
11 happy with that summary? If we accept that
12 hypothesis?

13 A. Yes, I think I would concur with
14 that.

15 Q. Thank you. How about/inadequate?

16 A. I'll accept that.

17 DR. KINGHAM: I would like to be clear
18 on this point whether you, Mr. Garrod or you, Mr.
19 Feenstra, are talking the same language in terms of
20 sufficient recharge to maintain the hydraulic trap.
21 You put the hypothesis on and the witness has agreed.
22 Since then you have used the term "recharge was cut
23 off". I understood the witness to be referring to a
24 drought kind of circumstance where there is not enough
25 rainfall, as it were, on the surrounding area to