
GEOTECHNICAL AND HYDROGEOLOGICAL

INVESTIGATION OF SITE A

PROJECT NO. 30000

PROJECT NO. 30000

REPORT TO

HALIFAX REGIONAL MUNICIPALITY

ON

**GEOTECHNICAL AND HYDROGEOLOGICAL INVESTIGATION
OF SITE A**

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1.0 INTRODUCTION

A hydrogeological and geotechnical investigation was carried out at the proposed site of a residual disposal facility (RDF) located between the communities of Lakeside-Timberlea and Goodwood, approximately 7.5 km west of the City of Halifax, N.S. (Figure 1.1). Work involved detailed geotechnical and hydrogeological investigations of the site between January and July, 1996.

1.1 Project History

A new site for long term, environmentally sustainable, disposal of municipal wastes is required by Halifax Regional Municipality (HRM) to replace the existing regional landfill site located at Sackville, Nova Scotia, which is scheduled to close by December 31, 1996. The proposed residuals disposal facility (RDF) is one of 13 elements within an integrated waste/resource management strategy adopted by HRM. Following the stipulations of the Nova Scotia Standards and Guidelines Manual for Landfills (NSDOE 1994), the RDF will be an engineered landfill for permanent secure storage of those components of the waste stream that cannot be diverted through recycling, reuse or composting and other waste diversion initiatives.

In 1995, a county-wide search for suitable sites was implemented under the direction of a siting Sub-Committee of the Community Stakeholders Committee. Ten options were identified within a 25 km radius of metropolitan Halifax. After preliminary site screening, Site A was selected for intermediate investigation to further delineate suitability as a residuals disposal site (Vaughan, 1995).

An intermediate level investigation of Site A was carried out in September 1995 (Vaughan Associates 1995), to collect site-specific subsurface data to assess the suitability of Site A for development of a RDF. This work involved field reconnaissance and limited intrusive investigation. The hydrogeological and geotechnical program consisted of four groundwater monitor well nests and 10 auger probes.

The intermediate level investigation indicated that the biophysical features of the site would not restrict site development for a residuals disposal facility. All facility components were considered to be constructible on this site. The intermediate investigation established that Site-A met all of the technical criteria required for further consideration as a candidate site for development of a residuals disposal facility. Further detailed investigation was required on the site to support preliminary and detailed design phases of any planned development.

1.2 Purpose and Scope

The purpose of the detailed investigation was to provide site-specific information on the hydrogeological and geotechnical properties to confirm the suitability of the site to host the proposed RDF and to provide design inputs.

The scope of work included:

- borehole program in the RDF foot-print;
- test pit program to assess borrow materials;
- installation of a perimeter groundwater monitoring well network;
- establishment of surface water monitoring stations;
- laboratory analyses of groundwater, surface water and soils to establish baseline conditions; and
- preparation of an environmental data base.

Tables 1.1 to 1.3 and Figure 1.2 summarizes the scope of work carried out at Site A.

Table 1.1 1996 Geotechnical Field Program

Component	Location	Identifiers	No.	Metres Drilled
Boreholes	RDF	RD-1 to RD-31	38	223.25
Temporary Monitor Wells Overburden Bedrock	RDF	RD-1 to RD-31	38 7 31	
Auger Probes	Drumlin	B1-B5	5	
Test Pits	RDF	TP-RD-1 to TP-RD-10, TP-RD-18, TP-101 to TP-117	28	-
	Perimeter	TP-118 to TP-138	20	-
	Drumlin	TP-B1 to TP-B2	2	-

Table 1.2 1996 Hydrogeological Field Program

Component	Location	Identifiers	No.	Metres Drilled
Monitor Wells Overburden Bedrock Multi-Level Nests	Perimeter	MW-1 to MW-23	43 15 28 16	446.5
Hydraulic Tests Slug Tests Packer Tests			77 33	
Water Level Surveys	RDF Perimeter		3 rounds	

Table 1.3 1996 Analytical Field Program

Component	No.	Location	Identifiers
Groundwater Quality		RDF Perimeter	MW-1 to MW-23; MW-95-1 to MW-95-4; 5 RD wells
Inorganic Chemistry	60		
Priority Pollutants - (EPA624,625, pesticides)	16		
PCBs	16		
Uranium and Radon	55		
Hydrocarbons	22		
Stream Water Quality		Nine Mile River	SW-1 to SW-12
Inorganic Chemistry	13	Site Drainage	
Priority Pollutants - (EPA624,625, pesticides)	3	Otter Lake	
PCBs	3		
Hydrocarbons	3		
Uranium and Radon	12		
Sediment Sampling		Nine Mile River	SED-1 to SED-12
Inorganic Chemistry	9	Site Drainage	
Priority Pollutants - (EPA624, pesticides)	4	Otter Lake	
EPA625 (BNAs)	1		
PCBs	9		
Hydrocarbons	1		
Soil Chemistry		RDF, Perimeter, Drumlin	Various samples
Total Uranium	11		
Cation Exchange Capacity	4		
Carbonate Content	5		
Trace Metals	5		
soil pH	5		
TOC	5		
Geotechnical Analysis		RDF, Perimeter, Drumlin	Various samples
Water Content	143		
Sieves	109		
Hydrometers	56		
Atterberg Limits	70		
Lab Hydraulic conductivity Tests	14		
Clay Mineralogy	6		

1.3 Site Description and Location

Site A is situated in the western sector of Halifax Regional Municipality approximately 7.5 km west of metropolitan Halifax on the east site of the Nine Mile River Watershed. The communities of Timberlea and Lakeside are 3 km to the north, and the community of Goodwood is 4 km to the South (Figure 1.1).

1.4 Environmental Setting

Site A is situated in a forested area within the Nine Mile River watershed. Detailed descriptions of ecological conditions are presented in Section 5 of the Phase 1 report (Vaughan, 1995). The site is located in granite terrain typical of the "Halifax Peninsula", which extends westward from Spryfield to St. Margaret's Bay. This area is characterized by thin, sandy overburden overlying fractured granitic bedrock. Several large drumlin hills consisting of clayey silt Lawrencetown Till are distributed throughout the area; the nearest drumlin occurs immediately southwest of the RDF.

1.5 Environmental Concerns

The main hydrogeological and hydrologic concerns posed by an RDF at this location involve water quality impacts to Nine Mile River from erosion and siltation, or leachate runoff via surface flow or groundwater pathways; and potential impacts on domestic water wells

1.6 Groundwater Users

As part of the siting process, Site A was situated so that the nearest year round domestic well water users are greater than 3 km from the site boundaries. Furthermore, groundwater flow beneath the site is directed towards Nine Mile River and not towards domestic well water users.

1.7 Report Structure

The remainder of this report is presented in seven sections. Section 2 describes field procedures and summarizes scope of work completed. Sections 3 and 4 present detailed interpretations of the site geotechnical properties and hydrogeology respectively. Section 5 presents the Baseline Chemistry, while Section 6 describes Contaminant Fate and Mobility. Overall conclusions are presented in Section 7, while geotechnical and hydrogeological recommendations are presented in Sections 8 and 9. Borehole logs, analytical results and other pertinent information are contained in the appendices, and summary tables are presented where appropriate throughout the report.

All resource information has been compiled into a database (Appendix 7) containing geological, water quality and analytical data.

2.0 FIELD PROGRAM

2.1 Approach and Rationale

An integrated geotechnical and hydrogeological field investigation was carried out between January and July 1996. The interpretations and conclusions of this study utilize all information from the 1996 geotechnical and groundwater work, as well as previous information from the intermediate level investigations in 1995.

In order to provide the maximum continuity of hydrogeological coverage of the site, the geotechnical boreholes were completed as standard groundwater monitoring wells to provide additional data on water level monitoring, hydraulic testing and water quality sampling. These wells were designed to be temporary, and will be removed and the boreholes grouted prior to liner emplacement. The resultant pattern of monitor wells provides an extensive grid coverage of the RDF and surrounds, which was used to generate the plans and cross-sections presented in this report.

2.2 Geotechnical Investigations

2.2.1 Scope of Investigation

The geotechnical field work for the project was carried out during the periods January 9 to February 28, April 11 to May 7, and July 11, 1996. Fifty-one test pits were excavated using a Cat 215 Excavator and 38 boreholes were drilled using a diamond drill. Boreholes RD-1 to RD-31 and Test Pits RD-1 to RD-10, RD-18, and TP-101 to TP-117 are situated within the foot-print of the residuals disposal facility (RDF). Boreholes B-1 to B-5 and Test Pits B-1 and B-2 are situated in the potential clay borrow source in the drumlin west of the foot-print. Test Pits 118 to 124 and 125 to 131 were excavated in the areas near the two sedimentation ponds. Test Pits 132 to 138 were excavated in the perimeter of the foot-print on the eastern side. Twenty eight probes were advanced using hand held probes in the swampy areas of the north and south sedimentation ponds. The locations of the boreholes, test pits and probes are shown on Figure 1.2.

2.2.2 Drilling Program

The boreholes in the drumlin – a potential borrow source – were drilled using B and N sized casing to depths of 16.7 m to 26.2. The boreholes within the foot-print of the RDF were drilled using B and H size casing to depths of 3.5 to 12.7 m. The soils were continuously sampled using a 50 mm OD split spoon sampler. Bedrock was proven by core drilling in BQ and HQ size. Detailed descriptions of the soil and bedrock encountered, and the sampling and testing carried out, are described on the Borehole and Test Pit Records in Appendix 1a and 1b.



All soil samples recovered were stored in moisture tight containers and returned with the rock core to our Dartmouth laboratory for classification and testing. Samples remaining after testing will be stored until further direction is obtained.

are these going to be properly abandoned or are they going to be stored?
\$23,000/well?

Within the foot-print of the RDF thirty-one piezometers were installed in the bedrock and seven piezometers were installed in the overburden. The piezometers are designated temporary monitoring wells RD-1 to RD-31 and are located at the corresponding borehole locations (Figure 1.2). PVC casing with diameters of 25 mm and 51 mm were used for the piezometer construction. Details of the piezometer construction are shown on the Borehole Records in Appendix 1a.

Borehole and test pit elevations and locations were surveyed by Dexter Construction Company Limited. Elevations are given with reference to Geodetic datum.

2.2.3 Previous Work

Ten auger probes were excavated as part of the intermediate investigation in 1995. Detailed descriptions of the soils encountered are included in the auger probe records in Appendix 1c.

2.3 Hydrogeological Investigations

2.3.1 Approach

The hydrogeological program was carried out in two stages. Stage 1 investigation, conducted between April 19 and May 24, 1996, involved drilling all of the deepest monitor wells (15 m bedrock holes) and selected bedrock holes first, at 12 locations around the site. Packer and hydraulic testing were done, water samples were collected for inorganic chemistry characterization, and water levels were measured. The information was combined with hydrogeological data from the geotechnical program, and a preliminary characterization of the hydraulic properties of the site was made.

The preliminary information was presented to the Project Technical Manager and the decision was made to proceed with Stage 2. Information collected from Stage 1 provided critical information for the design of Stage 2 monitor well nests, screen and sand pack settings, and individual monitor well depths, as well as preliminary information for the RDF design components. Stage 2 investigations, carried out from May 27 to July 12, 1996, involved construction of the remaining shallow monitor wells and monitor well nests, detailed water quality sampling, hydraulic testing, surveying, and stream sampling.

2.3.2 Drilling Program

A total of 446 m of drilling was carried out using a track-mounted, CME-55 rotary auger drill supplied by Lantech Drilling Limited.

The primary objective of the drilling program was the investigation of the soil-bedrock profile to a bedrock depth of 15 m. Additional deep drilling was conducted at three locations (MW-7, MW-13, MW-18) to investigate the hydraulic properties of deep bedrock to the elevation of Nine Mile River. Deep boreholes were cored to depths of up to 45 metres, and subjected to extensive packer injection testing to assess the degree of vertical variation in lithology, bedrock alteration, hydraulic conductivity and water levels.

2.3.2.1 Drilling Methods

Overburden drilling was advanced to refusal using 100 mm diameter solid stem flight augers. Split spoon sampling was conducted within the auger holes at regular intervals. At refusal drilling was changed to 100 mm diameter (HQ) core drilling methods. HW casing was then set into the top of bedrock. Bedrock drilling continued using a HQ size rotary diamond drill system. This method provides the benefit of continuous record of bedrock cores.

Upon completion of drilling, each borehole was pumped with a suction pump and/or bailer for 30 minutes at discharge rates up to 50 L/min to clear drilling fluid and debris, prior to hydraulic testing and installation of monitor wells. In addition to providing an indication of water bearing capacity for selection of screen settings, the procedure also promotes borehole development prior to screen emplacement with resultant higher confidence in subsequent hydraulic testing and water sampling work.

Drilling Conditions

Drilling at Site A required extensive road construction in the field for drill rig access. Where possible, existing roadways constructed during the RDF geotechnical program were utilized. A "ring road" was eventually constructed between the 19 monitor well nests surrounding the RDF. All access road construction was carried out by the land owner using a track-mounted excavator. All useable wood was recovered by the owner, and brush was removed from the access road ways.

Difficult drilling conditions were encountered southwest of the RDF in the vicinity of boreholes 4, 5, and 7. Deep saturated sand and gravel deposits containing very large boulders and cobbles were encountered in this area. In some cases, several attempts were needed to reach competent bedrock. Multi-level monitor well installations were located in these areas. Appendix 2 presents a typical multi-level monitor well construction diagram.

Drilling water for bedrock drilling was supplied by water tanker from Otter Lake (up-gradient wells), or sumps set in the shallow streams throughout the area. Several samples of drill water were collected, and analysed for general chemistry as part of the QA/QC program.

Overburden sampling was carried out in the same manner as the geotechnical program, using split spoon samplers. Representative samples of each geologic unit encountered were collected, described in the field, and stored in glass sample jars or polyethylene sample bags.

Bedrock core was recovered at up to 1.5 m intervals, stored in wooden core boxes provided by the drill contractor, labelled, and returned to JWEL in Dartmouth. An evaluation of bedrock cores was later conducted to assess zones of faulting and degree of alteration, and to establish correlations of these parameters between boreholes. Bedrock field logging focused on the degree of fracturing and water-bearing potential of the bedrock. The objective was to identify suitable permeable horizons for installation of sand packed monitor well screens. Field information for each borehole/monitor well included:

- All overburden and bedrock lithology and hydraulic information was compiled on borehole/monitor well records, which are presented in Appendix 1.

The approximately 600 m of core will be offered to the NS Department of Natural Resources for their core library.

2.3.3 Monitor Well Installation

A total of 23 permanent monitoring well stations comprising a total of 44 individual monitoring wells were installed outside the perimeter of the RDF foot-print between April 19, 1996 and May 27, 1996 designated MW-1 through MW-23. An additional 31 temporary monitoring well locations, designated as RD-1 through RD-31, with 38 individual piezometers (most locations have a single well, some have more than one) were installed within the RDF foot-print during the geotechnical investigations. At each perimeter monitor well location either monitor well nests of one, two or three wells were installed. Single wells are present at 7 locations; sets of 2 wells are present at 11 locations; and sets of 3 wells are present at 5 locations. Depths of monitor wells range from overburden wells (Series A), shallow (5 to 9 m) bedrock (Series-B), or deep (9 to 22 m) bedrock (Series-C).

Three of the 1995-series monitoring wells designated as MW-95-1, MW-95-2, and MW-95-4 will be integrated into the overall perimeter monitoring well network.

Table 2.1 summarizes the monitor well construction details. Monitor well locations are shown on Figure 1.2.

2.3.3.1 Monitor Well Locations

The locations for the 23 monitor well nests were determined through review of available mapping, field reconnaissance, anticipated drainage pathways, and consideration of site accessibility and equipment constraints. A total of 19 monitor well nests are located around the perimeter of the RDF; 4 more wells are situated west of the RDF between it and the river, and near proposed sedimentation ponds.

All monitor wells were installed in close proximity (about 50 m) from the RDF foot-print to act as the initial ring of monitor wells. A greater density of monitor wells, including multi-level installations, is located around the southwest down-gradient area and the northwest corner of the RDF where initial disposal operations will occur.

The borehole and monitor well locations were first reviewed with NSDOE to determine if the proposed monitoring strategy was consistent with the draft NSDOE Manual for Landfill Standards and Guidelines (1994). No changes to the monitoring plan were requested by NSDOE.

Table 2.1 Summary of Geotechnical Borehole and Hydrogeological Monitor Well Construction Specifications

Location	Drill Date	Unit	Borehole Depth (mbgs)	Well Depth (mbgs)	Well Diameter		ELEVATION		Casing Stick-up (m)	Bedrock Surface		Screened Interval		Sand Packed Interval		Bentonite Solids Interval		Bentonite Grout Interval	
					Borehole (mm)	Screen (mm)	Ground Surface (m)	Top of Casing (m)		Depth (mbgs)	Elevation (m)	From (mbgs)	To (mbgs)	From (mbgs)	To (mbgs)	From (mbgs)	To (mbgs)	From (mbgs)	To (mbgs)
MW-95-1A	1995	Bedrock	15.30	15.30	100	51	62.17	62.70	0.53	11.25	50.92	13.80	15.30	12.90	15.30	12.30	12.90	-	-
MW-95-1B	1995	Sand Till	4.30	4.30	155	51	62.43	63.01	0.58	-	-	2.80	4.30	2.00	4.30	0.60	2.00	-	-
MW-95-2A	1995	Bedrock	12.60	12.60	100	51	108.25	108.99	0.74	9.14	99.11	11.10	12.60	9.70	12.60	9.10	9.70	-	-
MW-95-2B	1995	Clay Till	6.40	6.40	155	51	108.13	108.85	0.72	-	-	4.90	6.40	3.10	6.40	-	6.10	-	-
MW-95-3A	1995	Bedrock	15.70	15.70	100	51	101.20	101.65	0.45	10.08	91.12	14.20	15.70	14.20	15.70	13.60	14.20	-	-
MW-95-3B	1995	Clay Till	9.00	9.00	155	51	-	-	-	-	-	7.50	9.00	6.30	9.00	5.70	6.30	-	-
MW-95-4A	1995	Bedrock	13.80	13.80	100	51	92.05	92.72	0.67	3.76	88.29	12.30	13.80	8.50	13.80	8.10	8.50	-	-
MW-95-4B	1995	Clay Till	3.10	3.10	155	51	92.12	92.79	0.67	-	-	1.60	3.10	1.60	3.10	0.50	1.60	-	-
AP-1	Sept 11/95	Till	6.40	6.40	155	19	81.49	81.49	-	6.40	75.09	-	-	-	-	-	-	-	-
AP-2	Sept 13/95	Till	1.22	1.22	155	19	93.28	93.28	-	1.22	92.06	-	-	-	-	-	-	-	-
AP-3	Sept 13/95	Till	3.96	3.96	155	19	94.33	94.33	-	3.96	90.37	-	-	-	-	-	-	-	-
AP-4	Sept 13/95	Till	1.22	1.22	155	19	86.79	86.79	-	1.22	85.57	-	-	-	-	-	-	-	-
AP-5	Sept 13/95	Till	1.22	1.22	155	19	84.44	84.44	-	1.22	83.22	-	-	-	-	-	-	-	-
AP-6	Sept 13/95	Till	0.90	0.90	155	19	97.68	97.68	-	0.90	96.78	-	-	-	-	-	-	-	-
AP-7	Sept 13/95	Till	12.80	12.80	155	19	74.25	74.25	-	12.80	61.45	-	-	-	-	-	-	-	-
AP-8	Sept 19/96	Till	3.81	3.81	155	19	64.10	64.10	-	3.81	60.29	-	-	-	-	-	-	-	-
AP-9	Sept 19/96	Till	1.63	1.63	155	19	88.54	88.54	-	1.63	86.91	-	-	-	-	-	-	-	-
AP-10	Sept 19/96	Till	7.00	7.00	155	19	99.47	99.47	-	7.00	92.47	-	-	-	-	-	-	-	-
RD-1A	Feb 6/96	Granite	13.05	13.05	100	51	100.51	100.59	0.08	8.00	92.51	11.48	13.00	9.80	13.00	7.62	9.80	-	-
RD-1B	Feb 6/96	Till	4.20	4.20	100	51	100.51	100.63	0.12	-	-	2.68	4.20	3.80	4.20	1.98	3.80	-	-
RD-2A	Feb 7/96	Granite	8.09	8.09	100	51	97.18	97.34	0.16	4.93	92.25	6.57	8.09	6.25	8.09	5.69	6.25	-	-
RD-2B	Feb 7/96	Till	4.47	4.47	100	51	97.18	97.31	0.13	-	-	2.95	4.47	2.49	4.47	1.85	2.49	-	-
RD-3	Feb 12/96	Granite	3.83	3.83	100	51	90.07	90.21	0.14	0.81	89.26	2.31	3.83	1.98	3.83	1.22	1.98	-	-
RD-4	Feb 12/96	Granite	9.39	9.39	100	51	87.50	-	-	0.20	87.30	7.87	9.39	0.45	9.39	-	-	-	-
RD-5	Jan 9/96	Granite	7.15	7.15	100	51	83.24	83.45	0.21	1.16	82.08	5.58	7.10	5.10	7.10	4.50	5.10	-	-
RD-6	Feb 8/96	Granite	5.89	5.89	100	51	69.43	69.86	0.43	2.51	66.92	4.18	5.70	4.04	5.70	3.28	4.04	-	-
RD-7	Feb 27/96	Granite	7.60	7.60	100	51	98.19	98.31	0.12	4.11	94.08	6.08	7.60	5.38	7.60	4.78	5.38	-	-
RD-8	Feb 21/96	Granite	7.90	7.90	100	51	97.83	97.94	0.11	3.88	93.95	6.38	7.90	5.54	7.90	4.93	5.54	-	-
RD-9A	Feb 13/96	Granite	10.59	10.59	100	51	95.96	96.12	0.16	4.04	91.92	9.08	10.60	8.40	10.60	-	-	-	-
RD-9B	Feb 13/96	Till	3.10	2.50	100	51	95.96	96.09	0.13	-	-	-	-	-	-	-	-	-	-
RD-10A	Feb 19/96	Granite	5.81	5.81	100	51	91.57	91.73	0.16	2.90	88.67	4.29	5.81	3.83	5.81	2.95	3.83	-	-
RD-10B	Feb 19/96	Till	1.97	1.97	100	51	91.57	91.74	0.17	-	-	0.45	1.97	0.71	1.97	0.10	0.71	-	-
RD-11	Feb 16/96	Granite	7.31	7.31	100	51	83.21	83.35	0.14	1.14	82.07	5.79	7.31	4.06	7.31	3.45	4.06	-	-
RD-12	Feb 15/96	Granite	5.81	5.81	100	51	78.90	79.07	0.17	1.27	77.63	4.28	5.80	2.82	5.81	2.21	2.82	-	-
RD-13A	Feb 21/96	Granite	5.79	5.79	100	51	95.16	95.47	0.31	2.70	92.46	4.08	5.60	3.10	5.63	2.34	3.10	-	-
RD-13B	Feb 21/96	Till	2.50	2.50	100	51	95.16	95.35	0.19	-	-	0.98	2.50	0.81	2.49	0.21	0.81	-	-
RD-14A	Apr 11/96	Granite	13.72	13.72	75	38	103.23	103.89	0.66	10.67	92.56	12.20	13.72	10.66	13.72	-	-	-	-

Table 2.1 Summary of Geotechnical Borehole and Hydrogeological Monitor Well Construction Specifications

Location	Drill Date	Unit	Borehole Depth (mbgs)	Well Depth (mbgs)	Well Diameter			ELEVATION		Casing Stick-up (m)	Bedrock Surface		Screened Interval		Sand Packed Interval		Bentonite Solids Interval		Bentonite Grout Interval	
					Borehole (mm)	Screen (mm)	Ground Surface (m)	Top of Casing (m)	Depth (mbgs)		Elevation (m)	From (mbgs)	To (mbgs)	From (mbgs)	To (mbgs)	From (mbgs)	To (mbgs)	From (mbgs)	To (mbgs)	
RD-14B	Apr 12/96	Till	6.00	5.96	155	38	103.23	103.23	0.00	-	-	4.44	5.96	3.86	5.96	3.25	3.86	-	-	
RD-15A	Apr 12/96	Granite	6.40	6.40	75	38	95.54	95.84	0.30	3.02	92.52	4.88	6.40	3.66	6.40	3.05	3.66	-	-	
RD-15B	Apr 12/96	Till	2.69	2.69	155	38	95.54	95.87	0.33	-	-	1.17	2.69	0.84	2.69	0.13	0.84	-	-	
RD-16	Apr 16/96	Granite	4.22	4.22	48	25	86.51	86.64	0.13	1.14	85.37	2.90	4.42	2.41	4.42	1.70	2.41	-	-	
RD-17	Apr 16/96	Granite	4.42	4.42	48	25	78.17	78.37	0.20	1.09	77.08	2.90	4.42	1.37	4.42	0.30	1.37	-	-	
RD-18	Apr 16/96	Granite	3.71	3.71	48	25	67.33	67.72	0.39	0.84	66.49	1.68	3.20	0.91	3.71	0.30	0.91	-	-	
RD-19	Apr 19/96	Granite	3.89	3.89	48	25	88.21	88.60	0.39	0.81	87.40	2.36	3.89	1.83	3.89	1.22	1.83	-	-	
RD-20	Apr 19/96	Granite	6.27	6.27	48	25	82.64	83.07	0.43	3.07	79.57	4.75	6.29	4.19	6.29	3.35	4.19	-	-	
RD-21	Apr 18/96	Granite	4.01	4.01	48	25	75.64	76.20	0.56	1.02	74.63	2.49	4.01	1.22	4.01	0.46	1.22	-	-	
RD-22	Apr 18/96	Granite	5.56	5.56	48	25	64.41	64.85	0.44	2.27	62.14	4.04	5.56	3.53	5.56	2.92	3.53	-	-	
RD-23	Apr 20/96	Granite	5.26	5.26	48	25	86.30	86.67	0.37	1.75	84.55	3.74	5.26	2.97	5.26	2.26	2.97	-	-	
RD-24	Apr 22/96	Granite	5.11	5.11	48	25	83.97	84.33	0.36	1.83	82.14	3.59	5.11	3.28	5.11	2.67	3.28	-	-	
RD-25	Apr 23/96	Granite	5.33	5.33	48	25	81.46	81.70	0.24	1.73	79.73	3.81	5.33	3.58	5.33	2.87	3.58	-	-	
RD-26	Apr 23/96	Granite	4.04	4.04	48	25	77.30	77.73	0.43	0.41	76.89	2.52	4.04	1.52	4.04	0.81	1.52	-	-	
RD-27	Apr 22/96	Granite	5.18	5.18	48	25	65.70	66.30	0.60	2.21	63.49	3.66	5.18	1.83	5.18	1.21	1.83	-	-	
RD-28	Apr 25/96	Granite	5.51	5.51	48	25	83.70	83.92	0.22	2.34	81.36	3.81	5.33	3.25	5.51	2.59	3.25	-	-	
RD-29	Apr 25/96	Granite	5.28	5.28	48	25	83.01	83.46	0.45	1.83	81.18	3.76	5.28	3.10	5.28	2.44	3.10	-	-	
RD-30	Apr 24/96	Granite	3.81	3.81	48	25	72.97	73.37	0.40	0.81	72.16	2.29	3.81	1.83	3.81	1.21	1.83	-	-	
RD-31	Apr 24/96	Granite	9.04	9.04	48	25	61.23	61.67	0.44	5.84	55.39	7.52	9.04	6.53	9.04	5.92	6.53	-	-	
MW-1B	May 30/96	Granite	6.96	7.31	100	51	76.30	76.83	0.53	0.91	75.39	5.46	6.96	3.96	6.96	3.81	3.96	0.00	3.81	
MW-2B	Apr 23/96	Granite	9.14	9.14	100	51	71.57	72.18	0.61	0.15	71.42	7.62	9.14	6.10	9.14	6.00	6.10	0.00	6.00	
MW-3A	Jun 01/96	Sand Till	3.20	3.20	100	51	62.92	63.57	0.65	-	-	1.68	3.20	0.91	3.20	0.00	0.91	-	-	
MW-3B	Feb 28/96	Granite	8.86	8.86	100	51	62.98	63.63	0.65	2.61	60.37	7.16	8.86	5.38	8.86	4.78	5.38	0.00	4.78	
MW-3C	Apr 22/96	Granite	15.55	15.39	100	51	62.94	63.46	0.52	3.05	59.89	13.87	15.39	12.34	15.39	12.19	12.34	0.00	12.19	
MW-4A	Jun 2/96	Sand Till	4.57	4.57	100	51	63.90	64.32	0.42	-	-	3.81	4.57	3.05	4.57	2.90	3.05	0.00	2.90	
MW-4B	Apr 25/96	Granite	12.20	12.20	100	51	63.83	64.14	0.31	3.35	60.48	10.67	12.20	9.14	12.20	9.01	9.14	0.00	9.01	
MW-5A	Jun 4/96	Sand Till	2.74	2.44	100	51	65.15	65.80	0.65	-	-	1.68	2.44	0.91	2.44	-	-	0.00	0.91	
MW-5B	Apr 27/96	Granite	8.08	7.01	100	51	65.20	65.93	0.73	3.20	62.00	5.49	7.01	3.66	7.01	3.50	3.66	0.00	3.50	
MW-5C	Jun 3/96	Granite	15.49	14.94	100	51	65.20	65.77	0.57	2.74	62.46	13.41	14.94	11.89	14.94	-	-	0.00	11.89	
MW-6A	Jun 5/96	Sand Till	7.32	6.10	100	51	64.00	64.56	0.56	-	-	5.33	6.10	4.57	6.10	3.35	4.57	0.00	3.35	
MW-6B	Apr 28/96	Granite	12.65	12.34	100	51	63.83	64.36	0.53	6.40	57.43	10.82	12.34	9.14	12.34	9.01	9.14	0.00	9.14	
MW-7A	Jun 5/96	Sand Till	4.11	3.96	100	51	52.69	53.48	0.79	-	-	3.20	3.96	2.44	3.96	1.22	2.44	-	-	
MW-7B	May 3/96	Granite	12.65	12.65	100	51	52.79	53.68	0.89	8.22	44.57	10.67	12.20	9.45	12.20	9.35	9.45	0.00	9.35	
MW-7C	Apr 30/96	Granite	21.54	21.33	100	51	53.05	53.37	0.32	8.23	44.82	19.20	20.73	17.22	20.73	17.17	17.22	0.00	17.17	
MW-8A	Jun 5/96	Sand Till	2.59	2.44	100	51	49.66	50.18	0.52	2.59	47.07	1.68	2.44	1.22	2.44	0.61	1.22	-	-	
MW-8B	May 5/96	Granite	6.45	6.45	100	51	49.70	49.70	-	2.44	47.26	4.98	6.45	3.05	6.45	2.95	3.05	0.00	2.95	
MW-8C	Jun 6/96	Granite	12.34	12.34	100	51	49.63	50.19	0.56	2.59	47.04	10.82	12.34	9.30	12.34	9.25	9.30	0.00	9.25	

Table 2.1 Summary of Geotechnical Borehole and Hydrogeological Monitor Well Construction Specifications

Location	Drill Date	Unit	Borehole Depth (mbgs)	Well Depth (mbgs)	Well Diameter		ELEVATION		Casing Stick-up (m)	Bedrock Surface		Screened Interval		Sand Packed Interval		Bentonite Solids Interval		Bentonite Grout Interval	
					Borehole (mm)	Screen (mm)	Ground Surface (m)	Top of Casing (m)		Depth (mbgs)	Elevation (m)	From (mbgs)	To (mbgs)	From (mbgs)	To (mbgs)	From (mbgs)	To (mbgs)	From (mbgs)	To (mbgs)
MW-9A	Jun 6/96	Silty sand Till	3.05	3.05	100	51	64.37	64.91	0.54	3.05	61.32	2.24	3.05	1.22	3.05	0.00	1.22	-	-
MW-9B	May 7/96	Granite	6.86	6.86	100	51	64.08	64.58	0.50	2.44	61.64	4.73	6.25	3.05	6.25	2.95	3.05	0.00	2.95
MW-10B	June 7/96	Granite	7.16	7.16	100	51	77.82	78.34	0.52	1.57	76.25	5.64	7.16	4.11	7.16	0.00	4.11	0.00	4.11
MW-10C	May 15/96	Granite	15.54	15.54	100	51	77.89	78.36	0.47	1.22	76.67	13.72	15.24	11.79	15.24	11.67	11.79	0.00	11.66
MW-11B	Jun 8/96	Granite	9.60	9.60	100	51	94.82	95.21	0.39	0.46	94.36	6.55	9.60	4.42	9.60	4.32	4.42	0.00	4.42
MW-12B	Jun 8/96	Granite	8.99	8.99	100	51	97.59	97.93	0.34	0.61	96.98	5.94	8.99	4.32	8.99	4.22	4.32	0.00	4.22
MW-13B	May 20/96	Granite	6.22	6.10	100	51	95.27	95.58	0.31	1.37	93.90	4.57	6.10	3.05	6.10	2.90	3.05	0.00	2.90
MW-13C	May 19/96	Granite	45.03	12.19	100	51	95.32	95.81	0.49	1.52	93.80	10.67	12.19	9.14	13.41	8.99	9.14	0.00	8.99
MW-14A	Jun 9/96	Clay Till	5.79	5.33	100	51	107.42	107.79	0.37	-	-	3.81	5.33	2.13	5.33	0.31	2.13	-	-
MW-14B	Jun 11/96	Granite	19.66	19.66	100	51	107.42	107.70	0.28	13.10	94.32	18.14	19.66	16.46	19.66	16.41	16.46	0.91	16.41
MW-15A	Feb 26/96	Silt Till	4.16	4.16	155	51	108.58	108.88	0.30	-	-	2.65	4.17	2.13	4.17	1.37	2.13	-	-
MW-15B	Feb 26/96	Granite	11.51	11.51	100	51	108.51	108.97	0.46	5.56	102.95	10.00	11.50	8.68	11.50	5.43	8.68	-	-
MW-15C	Apr 20/96	Granite	17.98	17.70	100	51	108.57	109.05	0.48	7.62	100.95	16.20	17.70	14.30	17.98	14.17	14.30	0.00	14.17
MW-16A	May 29/96	Clay Till	4.72	4.72	100	51	100.39	100.93	0.54	4.60	95.79	3.96	4.72	3.20	4.72	1.83	3.20	0.00	1.83
MW-16B	May 29/96	Granite	10.67	10.67	100	51	100.40	100.91	0.51	4.42	95.98	9.14	10.67	7.62	10.67	7.52	7.62	0.00	7.52
MW-17A	May 28/96	Granite	3.66	3.66	100	51	97.47	98.01	0.54	1.22	96.25	2.90	3.66	2.13	3.66	1.98	2.13	0.00	1.98
MW-17B	May 27/96	Granite	8.08	8.08	100	51	97.45	98.00	0.55	1.07	96.38	6.55	8.08	5.18	8.08	5.08	5.18	0.00	5.08
MW-18B	May 27/96	Granite	9.60	9.45	100	51	95.80	96.57	0.77	2.51	93.29	7.92	9.45	6.40	9.45	6.32	6.40	0.00	6.40
MW-18C	May 22/96	Granite	39.01	17.80	100	51	96.00	96.59	0.59	1.83	94.17	16.28	17.80	14.73	18.70	14.63	14.73	0.00	14.63
MW-19A	May 30/96	Sand Till	3.83	3.16	100	51	82.10	82.69	0.59	-	-	2.40	3.16	1.66	3.16	1.51	1.66	0.00	1.51
MW-19B	May 30/96	Granite	9.97	9.14	100	51	82.10	82.77	0.67	3.13	78.97	7.87	9.37	6.37	9.37	6.22	6.37	0.00	6.22
MW-20A	Jun 02/96	Sand Till	3.83	3.05	100	51	67.97	68.53	0.56	3.13	64.84	2.29	3.05	1.53	3.05	1.38	1.53	0.00	1.38
MW-20B	Jun 02/96	Granite	9.50	9.50	100	51	68.05	68.54	0.49	2.36	65.69	7.98	9.50	6.45	9.50	6.30	6.45	0.00	6.30
MW-21	Jan 29/96	Granite	3.45	3.45	100	51	64.02	64.84	0.82	0.78	63.24	1.95	3.45	1.09	3.45	0.00	1.09	-	-
MW-22	Jun 01/96	Silty sand Till	7.00	2.74	100	51	62.90	63.17	0.27	>7.0	<55.90	1.22	2.74	0.61	2.74	0.00	0.61	-	-
MW-23	Jun 4/96	Sand Till	5.18	3.81	100	51	62.63	63.12	0.49	5.18	57.45	3.05	3.81	2.29	3.81	0.00	2.29	-	-

2.3.3.2 Monitor Well Construction

Two types of monitoring wells are present on Site A. A series of twenty-three permanent monitor well nests consisting of grouted depth-specific sampling zones and heavy-duty locking well protectors are distributed around the perimeter of the RDF. A series of thirty-eight shallow temporary monitoring wells with minimal screen isolation are distributed throughout the RDF in geotechnical borehole locations to provide continuity across the site and a more reliable assessment of hydrogeological conditions underlying the proposed RDF. The temporary wells are designed to be subsequently abandoned by removal of the well materials and grouting of the boreholes prior to liner emplacement.

Permanent Perimeter Monitoring Wells

All perimeter wells in bedrock were constructed with 51 mm ID, flush-threaded, schedule 40 PVC pipe and screen, with 1.5 m of No. 20 slot screen typically set in 3.0 m to 4.0 m of sand pack set across pre-developed fracture zones. The bottom of each installation was completed with either flush-threaded or push-on PVC end caps; no glues or solvents were used in the well construction. Overburden wells were completed with 0.76 m screens typically set in 1.0 m to 1.5 m long sandpacks; this allows maximum use of limited available saturated thickness.

The annulus between the monitor well screen and the borehole wall was filled with clean No. 2 silica sand. Sand levels were confirmed during emplacement. The sand extended to a point generally 1.5 m above the top of the screen. The sand packed interval was isolated with solid bentonite compressed pellets. The remaining annulus between the borehole wall and the monitor well casing was grouted to the surface with liquid bentonite grout pumped down the hole via a tremie pipe.

The PVC casing was extended to approximately 0.6 metres above grade. Each monitor well was completed at grade with a 127 mm ID steel casing with locking cover. The casing typically extends approximately 0.9 m below grade, and 0.6 m above grade. In areas where bedrock was near surface the well casing was secured with quick-set cement. All well heads were painted for easy visibility, and clearly labelled. Heavy-duty brass locks with a common key were used to secure each well.

Multi-level monitor well nests were completed in separate boreholes. The screened intervals are vertically separated by approximately 3 to 6 m in shallow (overburden), intermediate (upper few metres of bedrock) and deeper bedrock zones. This type of completion is suitable for Site A because hydraulic conductivity testing and borehole logging indicates relatively uniform hydraulic continuity throughout the upper 20 m of bedrock.

Temporary RDF Monitor Wells

The 38 monitor wells within the RDF foot-print had variable diameters (51 mm, 38 mm and 25 mm); typically had 0.6 m thick bentonite seals; were not grouted to ground surface; were completed within 0.2 m of grade; and were sealed with locking "J-plug" well seals.

Grout should be pumped down hole before each of the temporary monitor well casings and screens are removed, and the boreholes permanently sealed. An approved grout mixture should be emplaced with a pressure grouting system.

2.3.3.3 Monitor Well Development

The purpose of well development is to remove drilling fluids, solids, or other particulates which may have been introduced into the aquifer or deposited on the boring wall during drilling. Properly developed monitoring wells enable the collection of groundwater samples which are chemically and physically representative of the aquifer.

Prior to hydraulic testing or sample collection, each well was subjected to vigorous pumping with a Hydrolift III inertial pumping system to remove as much water as practical, with a minimum of three casing volumes of groundwater, from each newly constructed well. Table A6.1, Appendix 6 summarizes combined pre-construction and post-construction volumes of groundwater removed during the development process, and observations for hydraulic testing. The combination of borehole pumping prior to monitor well installation, and the post-construction well development should minimize water quality influences from drilling and well construction.

2.3.4 Hydraulic Testing

More than 135 hydraulic response tests were performed on the perimeter wells and RDF wells. Three types of hydraulic tests were performed to estimate hydraulic conductivity at each borehole:

- Water level recovery measurements were made after well development on all open bedrock boreholes (hydraulic conductivity is representative of the saturated borehole interval).
- Multiple packer injection tests were performed on the deepest hole at each location (is representative of depth-specific intervals).
- Slug tests were performed on each completed monitor well (Hydraulic conductivity is representative of the sand-packed zone).

All methods provide an estimate of in-situ hydraulic conductivity for bedrock or overburden. Analysis was performed using AQTESOLV® (version 2) aquifer analytical software (Gerraghty & Miller 1993), using appropriate solutions for unconfined overburden and bedrock conditions. Results are presented in Section 4; output plots for representative monitor wells are presented in Appendix 3.

2.3.4.1 Bail Testing

Bail down tests were performed on all bedrock boreholes prior to monitor well installation and on some monitor wells completed in very low hydraulic conductivity clay tills. Upon completion of core drilling, each borehole was flushed with water and then developed by either bailing, or suction pumping for a period of about 30 minutes. The well was bailed to the bottom of the screen, or to a known point. At the cessation of bailing (initial displacement), water level recovery was monitored for a minimum of 15 minutes. Results were tabulated and returned to JWEL for later interpretation.

2.3.4.2 Packer Testing

A total of 47 packer tests were performed on 8 of the deepest (15 to 50 m) bedrock holes. Solid packers were used in the granite boreholes due to efficient and simple use as well as the potential for damage to inflatable packers in fractured bedrock. Packer intervals of 1.52 and 3.20 m were generally used.

Packer calibration was carried out at various pumping rates to determine the pipe and packer assembly pressure losses due to friction or flow restriction. Calibration curves of flow rate versus input hydraulic pressure were subsequently used to correct data in the hydraulic conductivity calculations.

Results of the packer testing are presented in Table 4.5. Packer testing theory and procedures are discussed in Nielsen (1991).

2.3.4.3 Slug Testing

A total of 88 slug tests were performed on the permanent monitor wells and temporary RDF wells. A custom-made PVC slug of known volume with an initial displacement of 1.08 m in 51 mm diameter monitoring wells was used on all 1996-series monitoring wells. This slug was introduced below the water table and changes in relative water level with time (displacement) were monitored. Other sizes of slugs were used to test the 25 mm and 1.5 mm diameter geotechnical boreholes within the RDF.

In-situ slug tests are performed on developed wells or piezometers to determine the hydraulic conductivity of the soil or rock intersected by the sand-packed interval. The geometric mean of numerous measurements on a site provides a useful indication of the hydraulic conductivity for the porous media encountered. All slug tests were performed on developed wells after static water level

had recovered, using the following procedure. Total well depth and static water level was measured to the nearest 0.1 cm. The slug was quickly introduced below the water table, resulting in a typical water level change of 1 m, and measurements of water level and time since the slug was introduced were made for a minimum of 15 minutes, or until water level equilibrium was achieved.

Where rapid water level response was obtained (e.g. the well returned to equilibrium within a few minutes of initiation of testing), the solid slug was quickly removed from the well, and time-water level measurements were made in the same manner as the falling head slug test. The average of the two tests or the rising head results were used in data compilation.

The slug test data was analysed via AQTESOLV® using the Bouwer and Rice et al (1976) and Cooper et al (1967) methods for unconfined overburden materials and semi-confined fractured bedrock respectively.

2.3.5 Water Level Monitoring

Water levels were measured on all available boreholes several times throughout the investigation. Two complete sets of water level measurements involving all available monitor points were performed on June 19 and July 24, 1996.

2.3.6 Surveying

Surveying was carried out by Dexter Construction Company Ltd. UTM Coordinates were determined, and top of ground elevations were made at one location (B-series well) at each monitor well station. In addition, the elevation of the top of the PVC well casing (measuring point) was determined for most wells. Where not recorded, this elevation was later determined by measurement from the elevations of the top of the PVC casing in each monitor well.

2.3.7 Baseline Groundwater Quality Sampling

The objective of the groundwater sampling and analytical program was to characterize existing or "background" groundwater chemistry in overburden and bedrock beneath, up-gradient and hydraulically down-gradient of the proposed RDF. Wells were sampled for a wide variety of organic (i.e., EPA 624, EPA 625, EPA 608, PCBs and petroleum hydrocarbons), inorganic (i.e., major ions, metals, mercury, fluoride, nitrate and nitrite, ammonia, BOD, COD and physio-chemical parameters), and radionuclide (i.e., total uranium and radon -222) compounds.

The groundwater sampling process involved several stages:

- well purging prior to sampling

- sampling
- sample documentation
- sample shipment to lab
- QA/QC procedures

For long term landfill compliance monitoring, it is essential that groundwater samples be collected in a manner which is consistent, reproducible, and as accurate as possible. Potential sampling bias could be introduced at any stage in the sampling process, including, purging, sample retrieval, preservation (if applicable) and labeling. Careful attention and documentation of each of these stages is required in order to obtain samples which are representative of the existing groundwater quality.

Each monitor well was sampled under a specific sampling procedure for a pre-determined suite of parameters. A dedicated sampler consisting of 13 mm ID polyethylene tubing with a Delrin foot valve was installed in each permanent monitoring well. This sampler was attached to a peristaltic pump or used manually to develop, purge and retrieve samples. Use of dedicated samplers eliminates the need for sampling equipment decontamination, and reduces cross-contamination bias between wells.

2.3.7.1 Well Purging

Prior to sample retrieval, each bedrock well was typically purged a minimum of three casing volumes. For very slow responding wells in clay till, one casing volume was removed. A casing volume is defined as the volume of water contained in the well casing above the screened interval and the volume of water contained in the sand pack between the well screen and the bentonite seal.

Purging was conducted with the foot valve from the dedicated sampler tube set at a point approximately 1 m above the top of the screen. Field measurements were made during purging for temperature, pH, dissolved oxygen and electrical conductance to determine when the well was adequately purged. Purging was considered to be sufficient when these parameters showed stabilized readings at intervals of two minutes. Stable readings are with tolerances of 1 °C, 0.2 pH units and 10% for conductivity and dissolved oxygen. Table A6.1, Appendix 6 summarizes field parameters for all wells.

2.3.7.2 Sample Retrieval

During sampling, the foot valve was lowered from above the screen to the middle of the screened interval. The pumping rate was typically decreased to 100 ml/min to minimize turbidity and contact with the air. The water samples were collected directly from the end of the tube, using appropriate sample containers supplied by the lab. No air space was allowed during collection of samples. The end of the sampling tube was maintained in a clean condition, and never allowed to touch the ground during sampling.

Radon gas samples were typically collected using a protocol developed by Victoria General Hospital for the Nova Scotia Uranium Task Force work in 1983. Initially, samples were collected in duplicate using 1) scintillation vials containing mineral oil provided by the lab and 2) sterile, clean polyethylene sample containers. Samples were collected from the discharge tube either using a hypodermic syringe or a polyethylene container. Using the syringe, air bubbles were first removed and the sample was injected under the mineral oil to eliminate contact with the atmosphere. Both sets of samples were labeled, and returned to the laboratory within 12 hours of sampling. An initial comparison was made of the two sampling methods. Since there were apparent differences in the two methods, all subsequent sample collection followed the VG protocol (i.e., mineral oil and syringe), so that results would be comparable with regional sample data from the NS Uranium Task Force (1986) results for Harrietsfield.

Samples for metals, and mercury analysis were filtered either using disposable or in-line 0.45 micron filters, and preserved with 1 % nitric acid and potassium dichromate/nitric acid respectively.

2.3.7.3 Sample Containers, Sample Handling and Storage

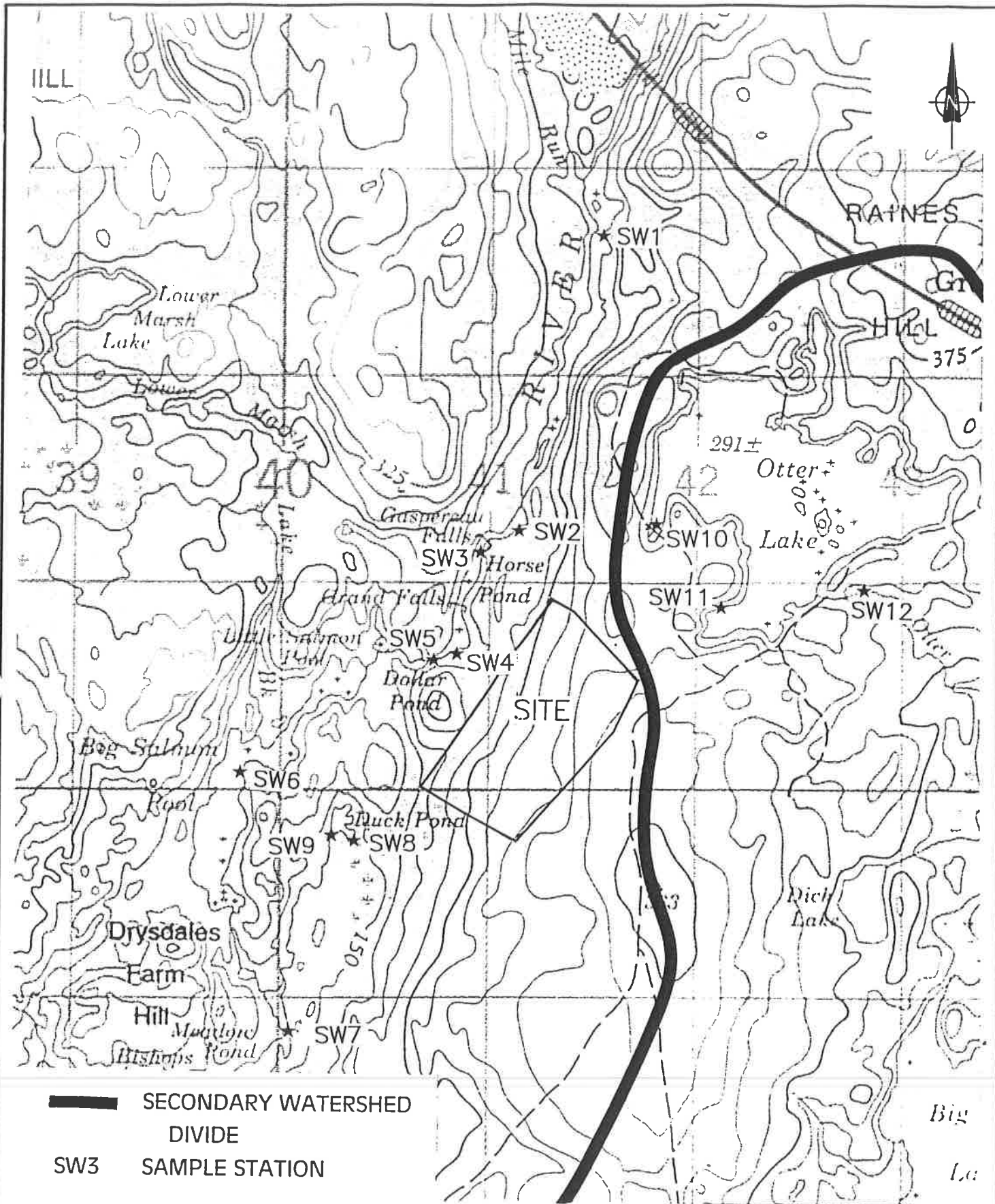
Groundwater samples were collected in specific containers supplied by the analytical labs. All containers were carefully labeled at the time of sampling. All bottles, or components were clean or pre-treated, as appropriate, and stored in protective containers cooled for shipment to the field. Groundwater samples were stored in coolers, and transported to the lab daily.

2.4 Hydrologic Investigations

Hydrologic investigations involved selection of 12 stream water and sediment sampling sites both up-gradient and down-gradient of the RDF. Stream water and sediment samples were collected and analyzed to establish baseline conditions.

2.4.1 Stream Sampling Locations

A reconnaissance stream survey was conducted to select 12 monitoring stations (Figure 2.1). Locations were selected based on potential for impact from the landfill operation. Five sampling stations (SW-1, 3, 5, 6 and 7) were located along Nine Mile River, two stations (SW-8 and SW-9) are situated at the inlet and outlet of a small pond immediately southwest of the RDF, two locations (SW-2 and SW-4) are situated at the confluence of drainage from proposed sedimentation lagoons, and three stations were located along the shore and outlet of Otter Lake, east of the RDF. Of the 12 sampling locations, nine are situated within the Nine Mile River watershed, and three are situated within the Otter Lake watershed.



STREAM SAMPLING LOCATIONS

SCALE 1 : 25 000



FIGURE 2.1

2.4.2 Stream Water Sampling

Stream water sampling was carried out on July 9 to 16, 1996, and is representative of early summer hydrologic conditions. Water samples were collected under a standard sampling protocol. Field measurements were made at each location for temperature, dissolved oxygen and pH. Samples were collected at all stations for analysis of general chemistry, metals, radon gas, BOD, COD, mercury, total phosphorus, and kjeldahl nitrogen using containers and appropriate preservatives supplied by the lab. Three locations on Nine Mile River (SW-1, 3 and 5) were also sampled for a suite of priority pollutants including EPA 624 volatiles, EPA 625 semi-volatiles, petroleum hydrocarbon, and EPA 608 OC- Pesticides/PCBs.

2.4.3 Stream Sediment Sampling

Stream sediment samples were collected using an Eckman dredge at still areas near each sampling station. All samples were placed in 400 ml glass jars. All stations were analysed for total acid-digestible metals and mercury. Three stations (SW-1, 3 and 5) were also analysed for priority pollutants including EPA 624 volatiles, EPA 625 semi-volatiles, petroleum hydrocarbon, and EPA 608 OC- Pesticides/PCBs.

2.5 Analytical Program

2.5.1 Water Chemistry Analysis

Tables 2.2 and 2.3 summarize the groundwater and stream station analytical programs for Site A. All samples were collected, documented and sent to MDS laboratory in Halifax, N.S. for analysis or transshipment. All inorganic chemistry, OP-pesticides, and petroleum hydrocarbons were analysed at MDS lab in Halifax. Analysis for EPA 624 and EPA 625 organic compounds was performed by EPL Laboratory in Mississauga Ontario.

2.5.2 QA/QC Program

Quality control and quality assurance procedures were carried out throughout the sample collection, shipment, and analysis stages to minimize sampling biases.

Field QA/QC Procedures

Field QA/QC procedures included use of dedicated samplers in all wells, field documentation of all sampling procedures, coolers for sample storage and shipment, distilled water rinse for all inter-well equipment, and documentation of all procedures on specific field forms, which are on file at JWEL.

Table 2.2 Analytical Program - Groundwater Samples

Well	Unit	Field Parameters	RCap	Metals	Radon & Uranium	Hg	F	TPH MUST	EPA 624	EPA 625	EPA 608	BOD	COD
MW-1B	Granite	1	1	1	1	1	1						
MW-2B	Granite	1	1	1	1	1	1						
MW-3A	Sand Till	1	1	1	1	1	1		1	1	1	1	1
MW-3B	Granite	1	1	1	1	1	1	1					
MW-3C	Granite	1	1	1	1	1	1						
MW-4A	Sand Till	1	1	1	1	1	1						
MW-4B	Granite	1	1	1	1	1	1	1					
MW-5A	Sand Till	1	1	1	1	1	1	1	1	1	1	1	1
MW-5B	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-5C	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-6A	Sand Till	1	1	1	1	1	1						
MW-6B	Granite	1	1	1	1	1	1						
MW-7A	Sand Till	1	1	1	1	1	1	1	1	1	1	1	1
MW-7B	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-7C	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-8A	Sand Till	1	1	1	1	1	1	1	1	1	1	1	1
MW-8B	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-8C	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-9A	Silty sand Till	1	1	1	1	1	1						
MW-9B	Granite	1	1	1	1	1	1						
MW-10B	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-10C	Granite	1	1	1	1	1	1						
MW-11B	Granite	1	1	1	1	1	1						
MW-12B	Granite	1	1	1	1	1	1						
MW-13B	Granite	1	1	1	1	1	1	1					
MW-13C	Granite	1	1	1	1	1	1	1					
MW-14A	Clay Till	1	1	1	1	1	1						
MW-14B	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-15A	Silt Till	1	1	1		1	1						
MW-15B	Granite	1	1	1	1	1	1						
MW-15C	Granite	1	1	1	1	1	1						
MW-16A	Clay Till	1	1	1	1	1	1						
MW-16B	Granite	1	1	1	1	1	1						
MW-17A	Clay Till	1	1	1	1	1	1						
MW-17B	Granite	1	1	1	1	1	1						
MW-18B	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-18C	Granite	1	1	1	1	1	1						
MW-19A	Sand Till	1					1						
MW-19B	Granite	1	1	1	1	1	1						
MW-20A	Sand Till	1	1	1	1	1	1	1	1	1	1	1	1
MW-20B	Granite	1	1	1	1	1	1	1	1	1	1	1	1
MW-21B	Granite	1	1	1	1	1	1						
MW-22	Silty sand/gravel	1	1	1	1	1	1	1				1	1
MW-23	Sand Till	1	1	1	1	1	1	1				1	1
MW-95-1A	Bedrock	1	1	1	1	1							
MW-95-1B	Sand Till	1	1	1	1								
MW-95-2A	Bedrock	1	1	1	1								
MW-95-2B	Clay Till	1	1	1	1								
MW-95-3A	Bedrock	1	1	1	1	1	1						
MW-95-3B	Clay Till	1	1	1	1								
MW-95-4A	Bedrock	1	1	1	1	1	1						
MW-95-4B	Clay Till	1	1	1	1								
RD-11	Bedrock	1	1	1	1	1	1						
RD-14A	Bedrock	1	1	1	1	1	1						
RD-16	Bedrock	1	1	1	1	1	1						
RD-21	Bedrock	1	1	1	1	1	1						
RD-31	Bedrock	1	1	1	1	1	1						
QA/QC (Field Duplicates)		0	4	4	0	4	4	2	1	1	1	2	2
Total Samples		57	60	60	55	53	55	22	16	16	16	19	19

Analytical Procedures:

TPH by Alberta MUST Protocol includes BTEX, total purgeable hydrocarbons

EPA-624 includes BTEX, solvents, light aliphatics

EPA-625 includes PAH, phenolics, phthalates

EPA 608 includes heavy pesticides, PCB

RCap includes 24 major ions, total metals, nutrients, physical parameters

Metals includes 23 field filtered (dissolved) metals

Radon done by Victoria General Lab duplicate scintillation vial procedure

Table 2.3 Analytical Program - Surface Water and Sediment Samples

Station No.		Location	Field Parameters¹	Surface Water											Stream Sediment						
				RCap	Tot-P TKN	Radon/ Uranium	Hg	Fl	BOD	COD	TSS	BTEX/ TPH	EPA 624	EPA 625	Pest/ PCBs	Metals ICP-25	Hg	PCBs	EPA 624	EPA 625	Pest. 608
SW-1	9 Mile River Upstream	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-2	Outlet from Sed. Pond #1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-3	9 Mile River below Sed Pond 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-4	Outlet from Sed. Pond #2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-5	9 Mile River below Sed Pond 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-6	Big Salmon Pool	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-7	9 Mile River Downstream	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-8	Duck Pond Inflow	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-9	Duck Pond Outflow	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-10	Otter Lake Causeway Inlet	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-11	Otter Lake South Inlet	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SW-12	Otter Lake Outfall	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
QA/QC		0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total		12	13	13	12	13	13	13	13	13	3	3	3	3	9	9	9	4	1	4	1

Notes:

1. Dissolved oxygen, pH, conductivity and temperature

Field Duplicate Sampling

Several duplicate samples were collected by filling two bottles simultaneously with minimization of contact with the air. Each sample container was then tightly capped, labeled, and placed in the cooler-container for transport to the lab.

Lab QA/QC Procedure

The internal lab QA/QC procedures included replicate analysis on each set of samples received, surrogate recovery analysis for each suite of organic samples analysed.

2.6 Data Management

The large volumes of water quality, geotechnical, hydraulic and other information generated through implementation of this investigation were stored in a data base management system (Appendix 7). It is anticipated that future information, particularly water level and water quality data, will be integrated into this data base for trend analysis.

The data base was used to generate the isopach and cross-sections presented in this report. A description of database set-up and contents is presented in Appendix 7.

2.7 Health and Safety Plan

A health and safety plan was completed for the duration of this project. The plan included continuous on-site communication between field crews and the project managers via cellular phone, first aid kits and fire extinguishers at the site security trailer and on each drill rig, an on-site security trailer with generator, lights and heat, and personal protective equipment.

A base camp was established on April 19, 1996 at the clay pit near monitor well MW-15. A site trailer was moved on site to provide shelter for site personnel and overnight security guards, since only off-road vehicles could enter the site.

A site safety lecture involving all site personnel was held on site prior to initiation of drilling operations.

3.0 GEOTECHNICAL CONDITIONS

The geotechnical program focused primarily within the proposed RDF foot-print but also included intrusive work in the drumlin area, proposed sedimentation pond areas and an area east of the RDF. Figure 1.2 shows the location of all sampling points.

The strata encountered in the geotechnical boreholes and test pits are summarized below and described in detail on the Borehole and Test Pit Records (Appendix 1). The overburden thickness and distribution of soil types are described below and shown on Figure 3.1. Tables 3.1 and 3.2 summarize the depth to bedrock, thickness of overburden, and the depth to water for the boreholes and test pits.

Table 3.1 Borehole Stratigraphic Summary

Borehole	Location	Thickness of		Depth to	
		Rootmat and Topsoil (m)	Till (m)	Bedrock (m)	Water Table (m) 22 May 96
B1	Drumlin	0.61	24.69	25.30	-
B2	Drumlin	0.61	>21.82	>22.43	-
B3	Drumlin	0.46	>20.80	>21.26	-
B4	Drumlin	0.46	>22.70	>23.16	-
B5	Drumlin	0.46	>16.25	>16.71	-
RD-1	RDF	0.46	7.54	8.00	3.37
RD-2	RDF	0.61	4.32	4.93	5.21
RD-3	RDF	0.79	0.07	0.86	0.85
RD-4	RDF	0.13	-	0.13	0.82
RD-5	RDF	0.46	0.51	0.97	1.74
RD-6	RDF	0.30	2.42	2.72	0.03
RD-7	RDF	0.30	3.79	4.09	1.21
RD-8	RDF	0.71	3.18	3.89	2.56
RD-9	RDF	0.46	3.53	3.99	2.76
RD-10	RDF	0.46	2.41	2.87	2.56
RD-11	RDF	0.61	0.30	0.91	0.31
RD-12	RDF	0.61	0.25	0.86	1.69
RD-13	RDF	0.46	2.26	2.72	0.14
RD-14	RDF	0.86	10.37	11.23	-2.98
RD-15	RDF	0.61	2.42	3.03	2.87

Table 3.1 Borehole Stratigraphic Summary

Borehole	Location	Thickness of		Depth to	
		Rootmat and Topsoil (m)	Till (m)	Bedrock (m)	Water Table (m) 22 May 96
RD-16	RDF	0.76	0.38	1.14	0.26
RD-17	RDF	0.61	1.68	2.29	0.34
RD-18	RDF	0.30	0.56	0.86	0.40
RD-19	RDF	0.46	0.35	0.81	0.50
RD-20	RDF	0.46	2.61	3.07	0.90
RD-21	RDF	0.56	0.71	1.27	0.60
RD-22	RDF	0.61	1.65	2.26	0.27
RD-23	RDF	0.46	1.29	1.75	0.21
RD-24	RDF	0.46	1.37	1.83	0.65
RD-25	RDF	0.91	0.82	1.73	0.09
RD-26	RDF	0.51	-	0.51	1.72
RD-27	RDF	0.61	1.60	2.21	0.89
RD-28	RDF	0.46	1.88	2.34	0.47
RD-29	RDF	0.61	1.22	1.83	0.70
RD-30	RDF	0.46	0.35	0.81	0.64
RD-31	RDF	0.46	5.38	5.84	0.59

Table 3.2 Test Pit Stratigraphic Summary

Test Pit	Location	Thickness of		Depth to	
		Rootmat and Topsoil (m)	Till (m)	Bedrock (m)	Water Table (m)
TP-B1	Drumlin	0.61	3.96	4.57	0.30
TP-B2	Drumlin	0.46	4.11	4.57	Dry*
TP-RD-1	RDF	0.56	>4.32	>4.88	Dry*
TP-RD-2	RDF	0.71	2.80	3.51	0.61
TP-RD-3	RDF	0.46	0.33	0.79	Dry*
TP-RD-4	RDF	0.64	2.87	3.51	0.64
TP-RD-5	RDF	0.41	>4.77	>5.18	0.41
TP-RD-6	RDF	0.61	0.76	1.37	1.37
TP-RD-7	RDF	0.76	0.76	1.52	1.52

Table 3.2 Test Pit Stratigraphic Summary

Test Pit	Location	Thickness of		Depth to	
		Rootmat and Topsoil (m)	Till (m)	Bedrock (m)	Water Table (m)
TP-RD-8	RDF	0.41	4.01	4.42	Dry*
TP-RD-9	RDF	0.61	2.29	2.90	1.22
TP-RD-10	RDF	0.30	>4.88	>5.18	Dry*
TP-RD-18	RDF	0.30	3.96	4.26	1.82
TP-101	RDF	0.61	2.03	2.64	0.91
TP-102	RDF	0.46	0.15	0.61	0.47
TP-103	RDF	0.20	0.92	1.12	0.46
TP-104	RDF	0.41	0.35	0.76	0.15
TP-105	RDF	0.30	0.61	0.91	1.07
TP-106	RDF	0.38	0.84	1.22	Dry*
TP-107	RDF	0.41	>4.77	>5.18	0.46
TP-108	RDF	0.30	3.81	4.11	0.91
TP-109	RDF	0.53	1.25	1.78	Dry*
TP-110	RDF	0.66	3.30	3.96	0.66
TP-111	RDF	0.30	1.22	1.52	0
TP-112	RDF	0.30	2.44	2.74	2.69
TP-113	RDF	0.61	-	0.61	Dry*
TP-114	RDF	0.25	2.18	2.43	0.91
TP-115	RDF	0.53	0.69	1.22	0.61
TP-116	RDF	0.30	0.51	0.81	Dry*
TP-117	RDF	0.30	4.42	4.72	0.30
TP-118	North Sed. Pond	0.30	-	>1.52	0
TP-119	North Sed. Pond	0.61	1.22	>4.27	0
TP-120	North Sed. Pond	0.30	0.91	4.57	0.61
TP-121	North Sed. Pond	0.30	-	>1.93	0.30
TP-122	North Sed. Pond	0.30	>4.58	>4.88	0.30
TP-123	North Sed. Pond	0.30	>4.58	>4.88	1.22
TP-124	North Sed. Pond	0.61	>3.35	3.96	0.82
TP-125	South Sed. Pond	0.91	1.53	2.44	0.15
TP-126	South Sed. Pond	0.30	-	4.11	0.30

Table 3.2 Test Pit Stratigraphic Summary

Test Pit	Location	Thickness of		Depth to	
		Rootmat and Topsoil (m)	Till (m)	Bedrock (m)	Water Table (m)
TP-127	South Sed. Pond	0.30	>1.23	>4.27	0.30
TP-128	South Sed. Pond	0.30	>1.98	>4.72	1.88
TP-129	South Sed. Pond	0.61	>3.36	>4.88	1.52
TP-130	South Sed. Pond	0.30	>5.79	>6.09	1.22
TP-131	South Sed. Pond	0.30	>5.19	>5.49	0.91
TP-132	East of RDF	0.91	>5.49	>6.40	0.61
TP-133	East of RDF	0.91	>4.88	>5.79	0.61
TP-134	East of RDF	0.30	0.31	0.61	0.61
TP-135	East of RDF	0.61	5.33	5.94	0.30
TP-136	East of RDF	0.30	5.80	6.10	0.61
TP-137	East of RDF	0.91	1.02	1.93	0.30
TP-138	East of RDF	0.91	2.14	3.05	0.76
Note: *no seepage observed					

Generally, the site is overlain by sandy clay till with some cobbles and boulders in the eastern portion and in the drumlin. The western portion of the site is overlain by sandy silt to silty sand till with gravel and varying amounts of cobbles and boulders. Within the foot-print of the proposed RDF, the overburden thickness ranged from nil (at bedrock outcrops) to 10.4 m, with an average thickness of 2.2 m.

3.1 Rootmat and Topsoil

A surficial layer of rootmat and topsoil was encountered in the test pits and boreholes. The thickness of the rootmat and topsoil layer ranged from 0.2 to 0.9 m as shown in Tables 3.1 and 3.2 with an average thickness of 0.5 m. The surface is strewn with boulders – many of them larger than 1 m diameter – throughout most of the site.

3.2 Organic Deposits

A deposit of brown to black peat was found in the area of the proposed sedimentation ponds. The results of nineteen probes in the boggy area of the northern sedimentation pond and nine probes in the southern sedimentation pond area are summarized in Table 3.3. Locations of the twenty-eight probes are shown on Figure 1.2. In the area of the proposed northern sedimentation pond, the depth of peat interpreted from the probes ranged from 0.8 to greater than 4.6 m, with an average depth of 1.9 m. In the proposed

southern sedimentation pond area, the depth of peat interpreted from nine probes in the swamp area ranged from 0.7 to 1.5 m, with an average depth of 1.1 m. Peat was not encountered in Test Pits 125 to 131 which were excavated around the perimeter of the swamp in the area of the proposed southern sedimentation pond. Peat, with a thickness of 0.7 m, was found only in one test pit - TP-118 near the proposed northern sedimentation pond.

Table 3.3 Swamp Probes

North Sedimentation Pond		Southern Sedimentation Pond	
Probe Number	Peat Depth (m)	Probe Number	Peat Depth (m)
P1	1.3	S1	0.9
P2	0.9	S2	0.9
P3	0.9	S3	1.3
P4	1.5	S4	1.5
P5	1.5	S5	0.7
P6	1.4	S6	1.1
P7	2.9	S7	1.2
P8	1.2	S8	1.1
P9	2.4	S9	1.5
P10	0.6		
P11	1.8		
P12	>4.6		
P13	3.1		
P14	2.1		
P15	3.4		
P16	1.5		
P17	2.6		
P18	0.8		
P19	0.8		

3.3 Sand, Sand and Gravel, Cobbles and Boulders

In the area of the southern sedimentation pond a layer of cobbles and boulders with a matrix of brown sand and gravel was encountered underlying the rootmat and topsoil layer in Test Pits 126, 127, 128, and 129.

Thickness of the layer of cobbles and boulders with a sand matrix ranged from 0.8 to 3.8 m. In Test Pits 125 and 128, a layer of grey sand and gravel with varying amounts of cobbles and boulders was encountered underlying the rootmat and topsoil.

In the area of the northern sedimentation pond, a layer of greyish brown sand with cobbles and boulders to sand and gravel with silt and cobbles and boulders was encountered underlying the rootmat and topsoil layer in Test Pits 118, 119, 120, and 121. Thickness of the layer of sand and gravel ranged from 0.6 to 3.1 m.

3.4 Sandy Clay Till

The eastern portion of the site is overlain by a stiff to hard, reddish brown, silty clayey sand to sandy clay till. The till is consistent with a Lawrencetown till. In the area of the RDF, the thickness of the sandy clay till ranged from 1.2 to 10.4 m with an average thickness of 3.4 m. The till contains some cobbles and boulders.

The results of grain size analyses are summarized in Appendix 4a. The grain size curves and soil classifications according to the Unified Soil Classification System for all samples tested are shown in Figures A4.b1 to A4.b42 in Appendix 4b. Plasticity charts for all samples tested are included as Figures A4.c1 to A4.c11 in Appendix 4c. Results from these tests show that the till in the eastern portion of the site varies from silty clayey sand (SC-SM) to sandy clay (CL) with gravel and some cobbles and boulders.

Hydraulic conductivity testing was conducted in the laboratory on remolded samples from the sandy clay till within the RDF and from the sandy clay till east of the RDF. The permeability in the sandy clay till was less than 3×10^{-7} cm/s for the remolded samples tested at natural moisture contents. Hydraulic conductivity tests were also performed at four points on the Standard Proctor curve for TP-110 Sa 4 from the RDF to establish a moisture/density/hydraulic conductivity relationship. The plot of hydraulic conductivity versus moisture content and dry density versus moisture content for Test Pit 110 is included in Appendix 4d. The results of all hydraulic conductivity tests are summarized in Table 3.4.

The fine portions of two sandy clay till samples were tested for clay mineralogy using X-Ray powder diffraction. The minerals identified in the sandy clay till were predominately quartz, muscovite, albite and orthoclase with no evidence of significant clay minerals. The results of X-Ray powder diffraction are summarized in Table 3.5.

Table 3.4 Results of Laboratory Hydraulic Conductivity Testing

Sample	Depth (m)	Location	Type of Till	Moisture Content (%)	Hydraulic Conductivity (cm/s)	Dry Density (lb/ft ³)
TP-B1	0.8	Drumlin	Sandy clay	12 (natural)	1x10 ⁻⁷	123.5
				7	5x10 ⁻⁷	122.1
				9	4x10 ⁻⁸	127.5
				10	3x10 ⁻⁸	127.4
				14	6x10 ⁻⁸	118.3
TP-B1	2.6	Drumlin	Sandy clay	12 (natural)	5x10 ⁻⁸	123.7
				6	1x10 ⁻⁶	124.8
				9	4x10 ⁻⁷	129.0
				10	5x10 ⁻⁸	127.7
				14	6x10 ⁻⁸	117.3
TP-B1	4.3	Drumlin	Sandy clay	11 (natural)	4x10 ⁻⁸	127.0
				6	4x10 ⁻⁷	123.6
				8	2x10 ⁻⁸	127.1
				12	7x10 ⁻⁸	122.8
				14	8x10 ⁻⁸	117.5
TP-B2	1.5	Drumlin	Sandy clay	12 (natural)	8x10 ⁻⁸	123.6
				6	6x10 ⁻⁷	123.8
				8	6x10 ⁻⁸	126.6
				10	2x10 ⁻⁸	127.7
				14	6x10 ⁻⁸	119.2
TP-B2	3.1	Drumlin	Sandy clay	11 (natural)	1x10 ⁻⁸	125.8
				7	1x10 ⁻⁷	119.6
				9	1x10 ⁻⁸	124.9
				13	2x10 ⁻⁸	121.6
				15	3x10 ⁻⁸	115.1
TP-B2	4.6	Drumlin	Sandy clay	11 (natural)	1x10 ⁻⁸	127.1
				7	1x10 ⁻⁷	122.1

Table 3.4 Results of Laboratory Hydraulic Conductivity Testing

Sample	Depth (m)	Location	Type of Till	Moisture Content (%)	Hydraulic Conductivity (cm/s)	Dry Density (lb/ft ³)
				9	1x10 ⁻⁸	127.0
				13	3x10 ⁻⁷	120.8
				15	3x10 ⁻⁸	115.1
BHB1, Sa11-14	15.3-22.1	Drumlin	Sandy clay	12	2x10 ⁻⁸	122.6
BHB5, Sa3-5	3.8-8.7	Drumlin	Sandy clay	13 (natural)	2x10 ⁻⁷	-
TP-110, Sa4	3.8	RDF	Sandy clay	11 (natural)	3x10 ⁻⁷	128.9
				15	5x10 ⁻⁸	120.5
				8	1x10 ⁻⁶	127.9
				7	2x10 ⁻⁶	121.9
TP-117, Sa2	4.0	RDF	Sandy clay	11 (natural)	1x10 ⁻⁸	123.7
TP-119, Sa1	3.4	Perimeter	Silty sand	10 (natural)	3x10 ⁻⁸	130.2
TP-122, Sa1	1.4	Perimeter	Silty sand	12 (natural)	2x10 ⁻⁸	-
TP-133, Sa1	1.5	Perimeter	Sandy clay	14 (natural)	2x10 ⁻⁸	121.9
TP-136, Sa1	2.1	Perimeter	Sandy clay	16 (natural)	2x10 ⁻⁸	117.1

Table 3.5 X-RAY Diffraction Results

Sample	Depth (m)	Type of Till	Location	Minerals Identified
TP-B1, Sa3	4.3	Sandy clay	Drumlin	Muscovite, quartz
TP-B2, Sa3	4.6	Sandy clay	Drumlin	Quartz, albite, orthoclase
BHB5, Sa8	16.5	Sandy clay	Drumlin	Quartz, albite
BHB5, Sa8*	16.5	Sandy clay	Drumlin	Muscovite, clinocllore
TP-RD8, Sa2	1.2	Sandy clay	RDF	Quartz, muscovite, orthoclase
TP-117, Sa2	4.0	Sandy clay	RDF	Quartz, muscovite, albite
Note: *second separation				

3.4.1 Drumlin

In the drumlin borrow source, the clay till was encountered to elevations less than 57 m which is near that of the river. In Borehole B1, where bedrock was encountered, the till had a thickness of 24.7 m. The till

in the drumlin consists of stiff to hard, reddish brown, sandy clay to clayey sand, with gravel and numerous cobbles and boulders. The sandy clay till of the drumlin extends towards the southern sedimentation pond where the sandy clay till underlies the layer of cobbles and boulders with a matrix of sand.

Twenty-six grain size analyses were performed on samples taken during the testpit and borehole investigation in the drumlin. The gradation ranged from a silty sand to a sandy clay with gravel. The average of the grain size analysis gave 13% gravel, 39% sand, and 48% silt and clay sized particles. The gradation ranged from 3- 25% gravel, 31- 47% sand, and 39-57% silt and clay sized particles. Results of hydrometer testing on twenty-five samples gave an average of 12% clay sized particles with a range of 1-19%. The fine portion of the soils had a plasticity index which ranged from non-plastic to 17 with an average of 10 for the thirty-five samples tested. The soil classification ranged from silty sand (ML) to sandy clay with gravel (CL). Moisture contents ranged from 8 to 14% with an average of 11% for the forty-seven samples tested.

Hydraulic conductivity testing was performed in the laboratory for two remolded samples from BHB1 and BHB5 in the drumlin. The hydraulic conductivities were 2×10^{-8} cm/s and 2×10^{-7} cm/s respectively. Hydraulic conductivity tests were also performed at five points on the Standard Proctor curve for six samples from the drumlin to establish a moisture/density/hydraulic conductivity relationship. The results of all hydraulic conductivity tests are summarized in Table 3.4. Plots of hydraulic conductivity versus moisture content and dry density versus moisture content are included in Appendix 4d.

The fine portions of three sandy clay till samples were tested for clay mineralogy using X-Ray powder diffraction. No evidence of significant clay minerals was found in the sandy clay till samples. The predominant minerals in the sandy clay till samples included quartz, albite, muscovite and orthoclase. The results of X-Ray powder diffraction are summarized in Table 3.5.

3.5 Silty Sand Till

The western portion of the site is overlain by compact to very dense brown silty sand till with gravel, and varying amounts of cobbles and boulders. The till is consistent with a granite till. The thickness of the silty sand till in the area of the RDF ranged from zero to greater than 4.6 m in TP-107, with an average of 1.3m. The silty sand till extends west towards the northern sedimentation pond where the till underlies the sand and cobbles and boulders layers.

Laboratory testing is summarized in Appendix 4a. The grain size curves and soil classifications according to the Unified Soil Classification System for all samples tested are shown in Figures A4.b1 to A4.b42 in Appendix 4b. Plasticity charts for all samples tested are included as Figures A4.c1 to A4.c11 in Appendix 4c. Results from these tests show that the till in the western portion of the site may be classified as sandy silt (ML) to silty sand (SM) with varying amounts of cobbles and boulders.

The optimum moisture content for minimum permeability ranged between 8 and 10 percent.



Hydraulic conductivity testing was conducted in the laboratory on two remolded samples from Test Pits 119 and 122. The hydraulic conductivities were 3×10^{-8} cm/s and 2×10^{-8} cm/s respectively. The results are summarized in Table 3.4.

3.6 Bedrock

The site lies across a gradational boundary between the Harrietsfield Monzogranite and the Halifax Peninsula Leucomonzogranite (MacDonald and Horne, 1987). Leucomonzogranite typically exhibits < 5% mafic mineral content, while Monzogranite typically has > 5% mafic mineral content. The Harrietsfield unit is a light- to medium-gray, fine- to coarse-grained, alkali feldspar megacrystic biotite monzogranite. The Halifax Peninsula unit is characteristically light whitish-grey to buff or pinkish in colour, medium- to predominantly coarse-grained, and contains variable amounts of biotite, cordierite, muscovite, and alkali feldspar megacrysts. The most distinguishing features are the coarse grain size and the low biotite content.

Bedrock fracturing varies widely, generally being most fractured in the upper 2 to 3 m of bedrock, becoming less fractured with depth (Figure 3.2). The degree of fracturing can be described by the Rock Quality Designation (RQD) expressed as a percentage where 100% RQD is indicative of solid bedrock with little or no fracturing. The average RQD for most shallow boreholes on the RDF is 48 %.

Evidence of shear zones were detected in Boreholes RD-1, RD-4 and RD-7, consisting of gouge, slickensides, high degree of weathering and alteration. Several instances of zero RQD (or no core recovery) were reported (e.g. monitor wells MW-4, MW-5, MW-6, MW-95-3); these are believed to be associated with drilling intersection of sub-vertical NE and NW trending joint sets or zones of high thermal alteration.

The granite is locally highly altered into feldspar-rich, soft, rock where silica was leached out by hydrothermal alteration. The altered zones are generally low in quartz content compared to natural monzogranite, and resemble de-silicified, epi-syenite. Poor core recoveries were reported in these zones, which also appear to coincide with a north-south trending bedrock depression in the north-east corner of the RDF foot-print, (Figure 3.1 and 3.3) (implying less resistance to glacial erosion). The degree of alteration is noted on the borehole and monitor well records as highly altered where most of the quartz has been removed from the rock, to slightly altered where the alteration is evidenced by some discolouration. Most of the alteration has occurred throughout the zone which is overlain by the clay till.

The main structural features consist of joint sets which trend in a northwest and northeast direction as is common throughout the South Mountain Batholith (Horne et al, 1992). The jointing is visible along Highway 103 to the north of the site and in bedrock ridges within the site. An additional set of sub-horizontal joints were prevalent throughout most of the core obtained and the combination of the three joint

sets give the granite a blocky structure which is also apparent in the shapes of the large boulders throughout the site.

Figure 3.3 shows bedrock surface elevations interpreted from 118 borehole and test pit logs. Bedrock surface elevation ranges from 100 m at the up-gradient northeast corner of the RDF, to 47.5 m at the down-gradient, southwest corner of the RDF. Bedrock surface slope is southwest across the RDF at an average slope of 6.5 percent.

The bedrock depression is believed to be associated with zones of granitic alteration. Poor core returns, low RQD, and reports of "sand" returns in the 1995 and 1996 boreholes were common to these locations. It is hypothesized that the glacial movement from NW to SE scoured weakened bedrock zones leaving the observed depressions filled with Lawrencetown basal till. Intervening areas of more competent granite were left as bedrock ridges.

A series of north-south bedrock ridges, possibly associated with the NE-trending joint set, results in several 3 m to 6 m high bedrock ridges visible at monitor wells MW-3 and between MW-12 and MW-13.

4.0 HYDROGEOLOGY AND HYDROLOGY

4.1 Regional Hydrogeological Setting

4.1.1 Physiography

Site A is situated within the Southern Uplands Physiographic Region of Nova Scotia (Goldthwaite, 1924; Roland, 1981). This region forms the largest remnant of the Atlantic Upland of the Maritime Provinces which extends southeast from the Caledonia Highlands of New Brunswick to the continental shelf southeast of Nova Scotia. This dissected peneplain slopes southeast from a maximum altitude of 225 m at South Mountain, to sea level.

The landscape surrounding Site A is rugged and barren, characterized by numerous low hills and smooth-topped ridges interspaced with swamp and muskeg. Large exposures of granite with sparse ground vegetation are common throughout the area. Most of the relief is controlled by granite bedrock or by clay till drumlins scattered throughout the area.

The soil cover is generally a shallow, sandy, highly permeable sand loam characterized by numerous cobbles, boulders and glacial erratic, primary composed of granite. Bedrock exposures were observed along Highway 103, the access road leading to Otter Lake, and several small areas around the perimeter of the RDF.

4.1.2 Drainage

Regional topographic drainage is considered to be moderate to poor, and is controlled by several large river systems which trend north to south across the area. Numerous shallow (i.e., less than 20 m deep) lakes and wetlands are common to the area. The study area is located within the Nine Mile River watershed. Nine Mile River has a total watershed area of approximately 135 km², and extends approximately 13.5 km from the confluence of the Fraser Lake and Governor Lake, to its discharge point near Shad Bay. Upstream drainage impacts included road salt from Highways 3 and 103, urban runoff from the communities of Timberlea and Lakeside, and discharge from a sewage treatment plant near Timberlea.

The RDF is located between two surface water bodies, Nine Mile River on the west, and Otter Lake on the northeast (Figure 2.1). The watershed divide between Nine Mile River and Otter Lake occurs a few hundred metres east of the RDF foot-print. The RDF is contained within the east side of the Nine Mile River watershed. All site drainage is southwestward towards Nine Mile River.

Nine Mile River

The river immediately west of the RDF is characterized by small cataracts, riffles, pools, and wide shallow flats. The river bottom is characterized by granite bedrock in areas of riffles or cataracts, and mud and silt in shallow pond areas.

Stream flows at a culvert where Nine Mile River flows under Highway 103 north of the RDF were measured on three occasions (Nov. 16/95, Nov 29/95 and Dec. 20/95) as part of the Phase 1 assessment work. Stream flows of 4.51, 2.93, and 2.32 m³/s, respectively, were reported on these dates.

Otter Lake

Otter Lake is a shallow lake (i.e., maximum depth 12 m) covering an area of 34 hectares. Drainage is to the southeast to Prospect Bay, located 11 km to the southeast, via Otter Lake Brook and a series of lakes which include Big Indian, Nichols, McDonald, Fiddle, Pantaloon and Whites Lakes. The Otter Lake watershed receives drainage from Highway 103 and Lakeside. Specific details on Otter Lake are summarized as follows (Ogden 1972):

Elevation:	88.7 m
Area:	93.9 ha (232 acres)
Watershed area:	345 ha (853 acres)
Shoreline Length:	5.72 km
Maximum Depth	11.6 m
Mean depth:	4.17 m
Flushing Time:	1.6 years

Site Drainage Patterns

Site drainage patterns are shown on Figure 1.2. Three tributaries of Nine Mile River flow westward across the RDF, and through wetlands before reaching Nine Mile River. These tributaries collect drainage from numerous seeps and wet areas on the RDF. The majority of the RDF is drained by two streams originating near the gravel pit on the northeast side of the RDF, and between the RDF and the drumlin on the southwest side. These streams flow through proposed sedimentation pond No. 1, to Nine Mile River, and are monitored by SW-2.

The southwest corner of the RDF drains to a wetland in the vicinity of MW-7 and MW-8, and thence southwards through Duck Pond, and into Nine Mile River. This pathway is monitored by SW-8 (Duck Pond Inlet) and SW-9 (Duck Pond Outlet).

Large areas of marsh are present along the west toe of the RDF, and extending northwest through two proposed sedimentation pond areas to Nine Mile River. These marsh areas are characterized by high water table, discharging groundwater conditions, and peat deposits overlying sand and boulders.

4.1.3 Climate

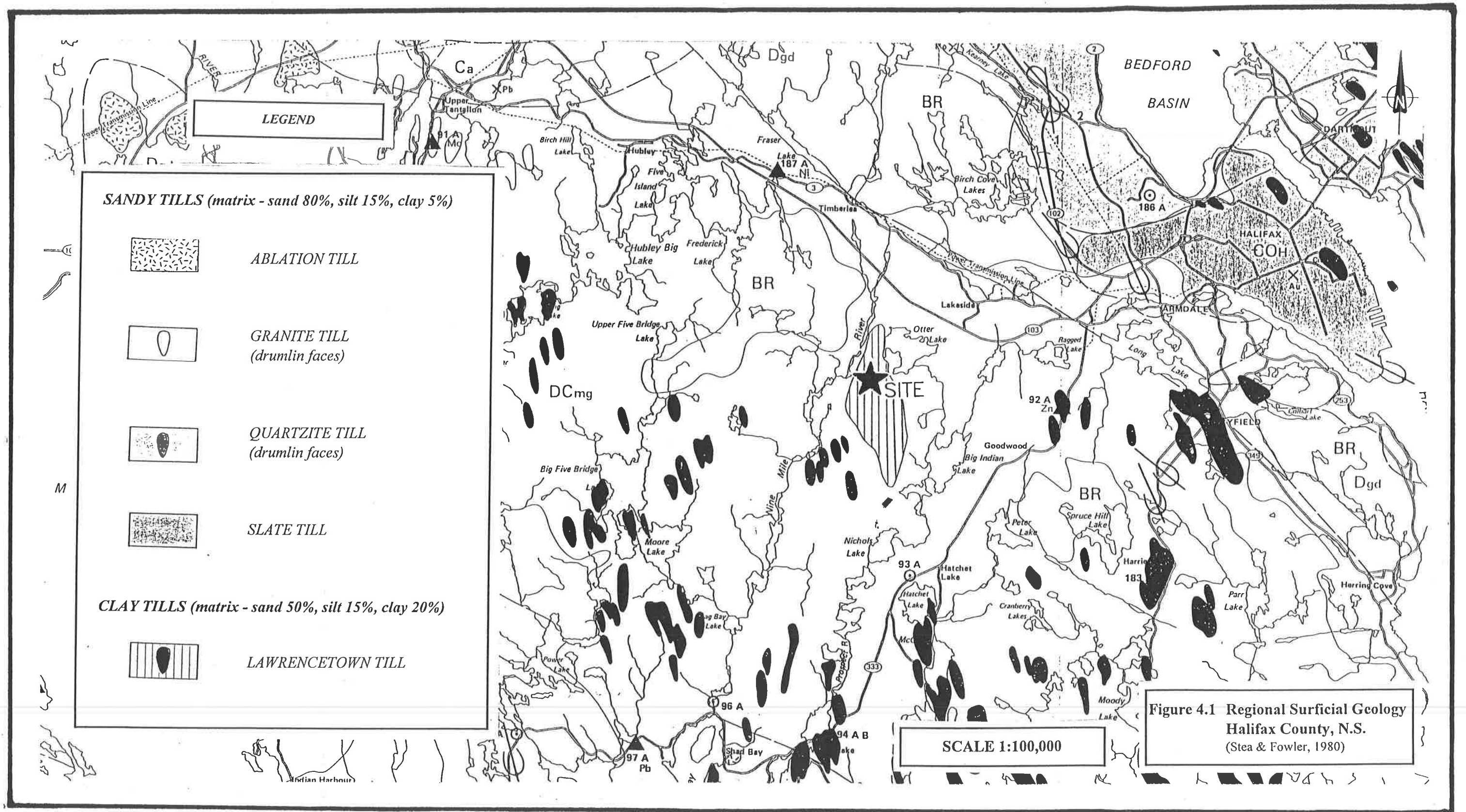
Climatic data were obtained from long term climate normals for Shearwater Airport, located approximately 25 km east of Site A (Appendix 5). Shearwater is the closest long-term climate station and its data is generally representative of Site A. Nova Scotia has a continental weather pattern influenced by proximity to the Atlantic Ocean. This results in relatively high rainfall amounts compared to more inland areas of Canada, more uniform temperature extremes, with average summer temperature in the order of 20 °C, and average winter temperatures in the order of 0 °C. The mean annual precipitation is 1361.4 mm with a standard deviation of 231.1 mm, of which 1157.3 mm (85 %) occurs in the form of rain, and about 200 mm occurs as snow. Maximum 24 hour precipitation events up to 185 mm have occurred in August, and maximum snowfalls of 50-54 cm have occurred in February (AES, 1995). A typical year can have an average of 162 days with measurable precipitation with 121 days with rain, and 41 days with snow.

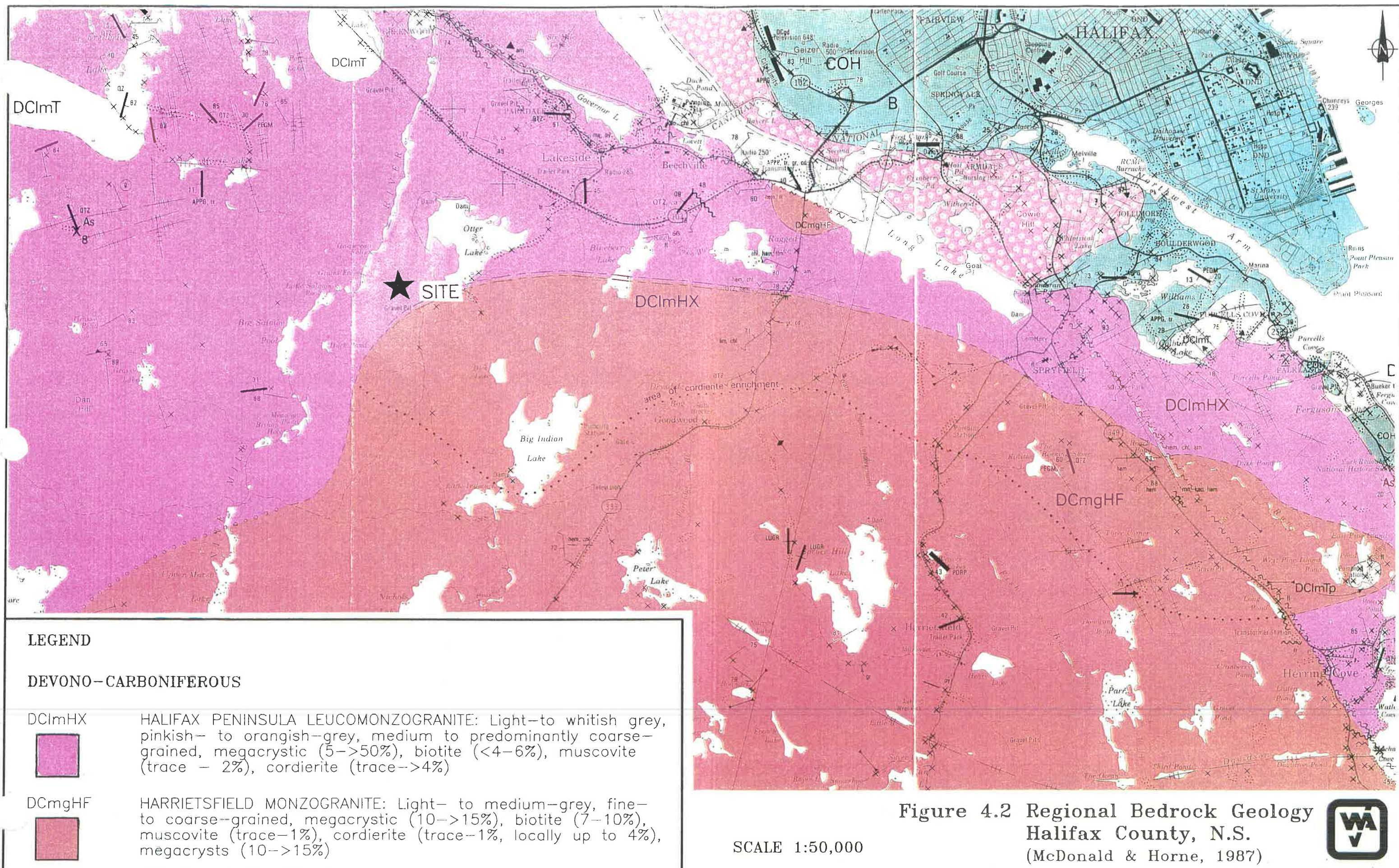
The mean annual daily temperature for this area of Nova Scotia is 6.6 °C with a standard deviation of 0.6 degrees. Extreme temperatures range from -26.1 °C in January and February, to +33.3 °C in July.

4.1.4 Geology

Figure 4.1 shows the surficial geology of the study area (Stea et al, 1981). The area is characterized by thin deposits (typically 0 to 9 m) of sandy gravel till with abundant cobbles and boulders (granite till), comprised of 45 % gravel, 41 % sand and 13 % silt and clay fraction. A sandy clay till unit consistent with the Lawrencetown Till sheet which covers some of southern Nova Scotia (Stea & Fowler 1981), occurs sporadically throughout the area as NW-SE oriented drumlin hills and localized areas of clayey silt basal till; the hill immediately southwest of the RDF is an example of a typical drumlin structure. This material typically contains 15 % gravel, 40 % sand and 45 % clay and silt fraction.

Figure 4.2 illustrates the bedrock geology surrounding Site A. The study area is underlain by Devonian-aged quartz monzogranite, on the southeast extremity of the South Mountain Batholith. The batholith averages 5 km in thickness, and reaches a maximum depth in the order of 17 km near New Ross, N.S. This granitic intrusion is believed to have been emplaced in Devonian Era (371 ± 7 million years ago (Mackenzie and Clarke, 1975), by quiet intrusion into older greywacke and shale metasediments of the Cambro-Ordovician aged Meguma Group. Several types of granite occur within the batholith. The three main types are differentiated based on proportion of silica content granodiorite (60 % silica), monzogranite (74 % silica) and alaskite (76 % silica) from the earliest to the youngest facies. The Site A study area is





30000

The bedrock granitic definition does not impact the site design or expected performance

predominantly underlain by monzogranite. Section 3.6 presents more details on bedrock geology and structure.

4.1.5 Hydrogeology

Groundwater flow patterns in Nova Scotia generally follow the topographic drainage patterns. Groundwater, which is derived from recharging precipitation both locally and in up-land areas, flows laterally through the overburden and bedrock aquifers to discharge points in springs, swamps, streams and lakes. The regional groundwater flow direction is north to south following the regional topography. In Nova Scotia, groundwater flow pathways are short, generally less than a few kilometres (Lin 1975) from point of recharge to points of discharge in streams, lakes and wetlands. Groundwater in overburden deposits and shallow bedrock (e.g., less than 30 m below grade) is generally recharged within the local watershed. Deep groundwater flow may be recharged in highlands areas along South Mountain, and is expected to discharge into the Atlantic Ocean.

Groundwater flow in granite bedrock is primarily through interconnected fractures, joints and faults (i.e., secondary porosity) developed in the upper few hundred metres of bedrock. The degree of fracturing, and groundwater flow potential, decreases with depth in granites. The upper few tens of metres of rock which were exposed to weathering and glacial action are typically highly fractured, and considered to be the pathway for groundwater movement.

secondary

Averaged hydraulic properties of the granite aquifer are best determined from pumping tests performed on domestic and commercial water wells completed within granite. Table 4.1 summarizes hydraulic properties and water supply development potential for granite aquifers in Nova Scotia. Granites in Nova Scotia typically exhibit geometric mean transmissivity, storage coefficient and hydraulic conductivity values of 1.1 m²/day, 5×10^{-4} , and 3.6×10^{-4} cm/s, respectively. Granite in Halifax County exhibits slightly higher average values for these parameters, possibly due to greater degree of fracturing associated with proximity to Meguma bedrock-granite contacts.

In comparison to the granite aquifer, fine-grained till units overlying the granite typically have lower hydraulic conductivities than the granite. No water supply pumping tests are available for these units.

4.1.6 Water Supply Development Potential

Most rural residents and about 50 % of the total population of Nova Scotia rely on groundwater from individual drilled or dug wells for potable water supply. Due to its widespread occurrence, the granite aquifer, although considered a poor water supply source for commercial and industrial applications, remains an important rural water supply resource.

Table 4.1 Summary of Pumping Tests Results - Bedrock Aquifer

	Well Depth (m)	Well Diameter (mm)	Casing Length (m)	Water Level (m)	Test Yield (L/min)	Well Properties			Aquifer Properties		
						T (m²/d)	K (cm/s)	Specific Capacity (m³/d/m)	Safe Yield (L/min)	T (m²/d)	S
Nova Scotia (N = 66)											
Maximum	131.1	203.0	34.1	37.3	931.95	250.0	0.013058	222.0	745.98	250.0	0.00050
Minimum	22.3	127.0	3.1	0.1	4.09	0.1	0.000001	0.1	0.91	1.0	0.00050
Arithmetic Mean	66.0	155.0	10.2	6.2	85.81	7.8	0.000287	19.1	45.90		0.00050
Geometric Mean	61.2	155.0		3.7	44.85	1.7	0.000036	22.9	185.94		
Standard Deviation	24.9	24.4	7.4	7.0	133.90	31.0	0.001592	40.6	103.61		
N	66	66	23	66	300.04	66	66	67	300.04	2	2
Halifax County (N = 37)											
Maximum	131.1	203.0	34.1	37.3	190.94	24.1	0.000337	148.0	261.68		
Minimum	22.3	127.0	3.1	0.5	4.09	0.1	0.000001	0.2	0.78		
Arithmetic Mean	69.1	155.0	10.2	7.7	49.59	2.3	0.000056	10.1	24.08	1.0	0.0
Geometric Mean	63.5	155.0		4.7	33.24	1.1	0.000077	3.9	0.00		
Standard Deviation	20.5	23.8	11.2	9.6	36.26	7.6	0.000083	48.6	82.20		
N	37.0	37.0	23	37	168.21	37	37	37	163.66	1	1

Notes:

1. Source - NSDOE Pumping Test Inventory.
2. T = Transmissivity; K = Hydraulic Conductivity; S = Coefficient of Storage.

Quantity and quality are the key criteria for groundwater resource assessment. Drilled wells in granite can be expected to provide from <5 L/min to over 450 L/min, with a geometric mean of 45 L/min, based on 66 pumping tests conducted on wells completed in granite throughout Nova Scotia (Table 4.1). In comparison, wells throughout Halifax County generally provide 33 L/min (geometric mean). Well yields in granite tend to be a function of well depth, overburden cover, and proximity for major fracture zones, such as occur along the granite-Meguma contact.

The sandy granite till units are typically highly permeable, and may be exploited for rural domestic water supply where sufficient saturated thickness occurs. Dug well yields in excess of 20 L/min are common in sand till. The clay till is poorly permeable, and is suitable only for individual dug well water supply development. This unit typically yields small flows (2 L/min to 5 L/min) to domestic dug wells.

The granite aquifer typically yields good inorganic and organic quality groundwater to drilled wells. Typical water quality problems reported from the Halifax area include iron, manganese, low pH, and to a lesser extent, arsenic, uranium, radon and fluoride, based on NSDOE's Well Water Chemistry Inventory. Water quality from glacial till is generally good, with a tendency to exceed aesthetic guidelines for hardness, iron and manganese in areas of restricted shallow groundwater flow. Dug or screened wells completed in sandy till typically have good quality groundwater which has a tendency to be naturally corrosive, and to be impacted by nearby activities such as road salting or septic effluent discharge. Wells within the clay till overlying the granite typically produce low yields (i.e., less than 5 L/min) of moderately hard and alkaline groundwater, with a tendency to exceed iron and manganese criteria.

4.2 Site Hydrogeology

4.2.1 Water Table Elevations

Table 4.2 summarizes depth to water table and groundwater elevations for Site A. Two complete sets of water levels were collected from all site wells on June 19th and July 24th, while a third data set for many wells was collected on May 22nd. The water levels were consistently high over this site, ranging (on June 19, 1996) from 5.6 m below grade at the most up-gradient well MW-15C, to flowing (+3.0 m) at RD-14A.

Based on information to date, the majority of this site appears to be within a local or regional groundwater discharge zone. Almost all bedrock wells exhibit water table elevations above the top of bedrock (e.g., within the confining till unit), or near grade (mean 1.4 m below grade) where limited overburden exists (see cross-sections Figures 4.3 and 4.4). The locations of these cross sections are shown on Figure 3.3.

The May, June and July water level data presented in Table 4.2 represent late spring to early summer groundwater level data. Typically groundwater levels are highest in the spring and fall, in response to recharge from snow melt and/or infiltration, and lowest in early fall and late winter. The highest site

Table 4.- Summary of Water Level Measurements

Well	Unit	Well Depth (m)	Casing Stick-up (m)	Ground Elevation July 24, 1996	Top Casing Elevation July 24, 1996	Water levels (m below grade)							Groundwater Elevations				
						Sep 20/95 (mbsg)	Feb 7/96 (mbsg)	Feb 16/96 (mbsg)	Feb 26/96 (mbsg)	Mar 14/96 (mbsg)	Apr 23/96 (mbsg)	May 22 (mbsg)	Jun 19 (mbsg)	Jul 24 (mbsg)	May 22 (m)	Jun 19 (m)	Jul 24 (m)
MW-95-1A	B	15.30	0.53	62.17	62.70	0.92	TCE	-	-	-	-0.03	0.15	0.33	0.27	62.02	61.84	61.90
MW-95-1B	T	4.30	0.58	62.43	63.01	1.51	1.01	-	-	-	0.70	0.88	0.82	0.75	61.55	61.61	61.68
MW-95-2A	B	12.60	0.74	108.25	108.99	0.50	0.41	-	-	-	0.12	0.13	0.56	0.50	108.12	107.69	107.75
MW-95-2B	T	6.40	0.72	108.13	108.85	1.33	0.28	-	-	-	0.34	0.34	0.47	0.33	107.79	107.66	107.80
MW-95-3A	B	15.70	0.45	101.20	101.65	1.07	0.0 (ice)	-	-	-	-0.06	-0.12	0.12	0.10	101.32	101.08	101.10
MW-95-3B	T	9.00	-	-	-	-	2.16	-	-	-	Destroyed	-	-	-	-	-	-
MW-95-4A	B	13.90	0.67	92.05	92.72	1.74	0.28(ice)	-	-	-	0.01	0.01	0.58	0.28	92.04	91.47	91.77
MW-95-4B	T	6.40	0.67	92.12	92.79	1.70	0.68	-	-	-	0.30	0.33	0.66	0.50	91.79	91.46	91.62
RD-1A	B	13.05	0.08	100.51	100.59	-	-	3.46	3.31	3.53	3.29	3.37	3.59	3.41	97.14	96.92	97.10
RD-1B	T	4.20	0.12	100.51	100.63	-	-	0.934	0.42	0.59	0.46	0.30	0.62	0.55	100.21	99.89	99.96
RD-2A	B	8.09	0.16	97.18	97.34	-	-	5.34	5.23	5.41	5.18	5.21	5.37	5.29	91.97	91.81	91.89
RD-2B	T	4.47	0.13	97.18	97.31	-	-	3.38	3.85	3.88	3.73	3.76	3.73	3.77	93.42	93.45	93.41
RD-3	B	3.83	0.14	90.07	90.21	-	-	1.31	1.03	1.20	0.63	0.85	1.45	0.99	89.22	88.62	89.08
RD-4	B	9.39	-	87.50	87.50	-	-	0.85	0.82	lost	lost	-	-	0.00	-	87.50	87.50
RD-5	B	7.15	0.21	83.24	83.45	-	-	1.84	1.65	1.79	1.54	1.74	2.14	2.01	81.50	81.10	81.23
RD-6	B	5.89	0.43	69.43	69.86	-	-	0.25	0.11	0.17	0.36	0.03	0.25	0.08	69.40	69.18	69.35
RD-7	B	7.90	0.12	98.19	98.31	-	-	-	-	1.31	0.97	1.21	1.40	1.19	96.98	96.79	97.00
RD-8	B	7.62	0.11	97.83	97.94	-	-	-	2.03	2.67	2.57	2.56	3.03	2.69	95.27	94.80	95.14
RD-9A	B	10.59	0.16	95.96	96.12	-	-	-	2.76	3.04	2.71	2.76	3.16	2.82	93.20	92.80	93.14
RD-9B	T	2.50	0.13	95.96	96.09	-	-	-	0.98	1.46	1.22	1.10	1.06	1.34	94.86	94.90	94.92
RD-10A	B	5.81	0.16	91.57	91.73	-	-	-	2.74	3.16	2.58	2.56	3.43	2.91	89.01	88.14	88.66
RD-10B	T	1.97	0.17	91.57	91.74	-	-	-	1.43	1.16	0.82	0.85	1.38	0.96	90.72	90.19	90.61
RD-11	B	7.31	0.14	83.21	83.35	-	-	-	0.45	0.54	0.35	0.31	0.79	0.57	82.90	82.42	82.64
RD-12	B	5.81	0.17	78.90	79.07	-	-	-	1.68	2.09	1.58	1.69	2.39	1.88	77.21	76.51	77.02
RD-13A	B	5.79	0.31	95.16	95.47	-	-	-	0.16	Frozen	0.05	0.14	0.44	0.08	95.02	94.72	95.08
RD-13B	T	2.50	0.19	95.16	95.35	-	-	-	0.26	0.44	0.22	0.31	0.36	0.27	94.85	94.80	94.89
RD-14A	B	13.72	0.66	103.23	103.89	-	-	-	-	-	-2.98	-2.98	-2.98	-2.98	106.21	106.21	106.21
RD-14B	T	5.96	-	103.23	103.23	-	-	-	-	-	0.53	0.41	-	0.33	102.82	103.23	102.90
RD-15A	B	6.40	0.30	95.54	95.84	-	-	-	-	-	2.87	2.87	3.36	3.48	92.67	92.18	92.06
RD-15B	T	2.69	0.33	95.54	95.87	-	-	-	-	-	2.47	2.16	1.91	2.22	93.38	93.63	93.32
RD-16	B	4.42	0.13	86.51	86.64	-	-	-	-	-	0.23	0.26	1.08	0.59	86.25	85.43	85.92
RD-17	B	4.42	0.20	78.17	78.37	-	-	-	-	-	0.31	0.34	0.65	0.54	77.83	77.52	77.63
RD-18	B	3.71	0.39	67.33	67.72	-	-	-	-	-	0.34	0.40	0.92	0.63	66.93	66.41	66.70
RD-19	B	3.89	0.39	88.21	88.60	-	-	-	-	-	0.45	0.50	2.23	1.30	87.71	85.98	86.91
RD-20	B	6.27	0.43	82.64	83.07	-	-	-	-	-	0.82	0.90	1.31	1.04	81.74	81.33	81.60
RD-21	B	4.01	0.56	75.64	76.20	-	-	-	-	-	0.59	0.59	1.00	0.66	75.05	74.64	74.98
RD-22	B	5.56	0.44	64.41	64.85	-	-	-	-	-	0.22	0.27	0.41	0.31	64.14	64.00	64.10
RD-23	B	5.26	0.37	86.30	86.67	-	-	-	-	-	0.17	0.21	0.30	0.24	86.09	86.00	86.06
RD-24	B	5.11	0.36	83.97	84.33	-	-	-	-	-	0.66	0.65	0.80	0.64	83.32	83.17	83.33
RD-25	B	5.33	0.24	81.46	81.70	-	-	-	-	-	-	0.09	0.39	0.18	81.37	81.07	81.28
RD-26	B	4.04	0.43	77.30	77.73	-	-	-	-	-	1.56	1.72	1.88	1.79	75.58	75.51	75.51
RD-27	B	5.18	0.60	65.70	66.30	-	-	-	-	-	0.58	0.89	1.29	1.52-0.6	64.81	64.41	65.70
RD-28	B	5.51	0.22	83.70	83.92	-	-	-	-	-	-	0.47	0.71	0.52	83.23	82.99	83.18
RD-29	B	5.28	0.45	83.01	83.46	-	-	-	-	-	-	0.70	1.10	0.79	82.31	81.91	82.22
RD-30	B	3.81	0.40	72.97	73.37	-	-	-	-	-	-	0.64	0.87	0.69	72.33	72.10	72.28
RD-31	B	9.04	0.44	61.23	61.67	-	-	-	-	-	-	0.59	0.83	0.75	60.64	60.40	60.48
MW-1B	B	7.31	0.53	76.30	76.83	-	-	-	-	-	-	-	2.16	1.62	-	74.14	74.68
MW-2B	B	9.14	0.61	71.57	72.18	-	-	-	-	-	-	3.39	4.03	3.88	68.18	67.54	67.69
MW-3A	T	3.20	0.65	62.92	63.57	-	-	-	-	-	-	-	0.24	0.21	-	62.68	62.71
MW-3B	B	8.86	0.65	62.98	63.63	-	-	-	-	-	-	-0.18	0.12	-0.01	63.16	62.86	62.99
MW-3C	B	15.39	0.52	62.94	63.46	-	-	-	-	-	-	-0.48	-0.45	-0.46	63.42	63.39	63.40

Table 4.2: Summary of Water Level Measurements

Well	Unit	Well Depth (m)	Casing Stick-up (m)	Ground Elevation July 24, 1996	Top Casing Elevation July 24, 1996	Water levels (m below grade)							Groundwater Elevations		
						Sep 20/95 (mbgs)	Feb 7/96 (mbgs)	Feb 16/96 (mbgs)	Feb 26/96 (mbgs)	Mar 14/96 (mbgs)	Apr 23/96 (mbgs)	May 22 (mbgs)	Jun 19 (mbgs)	Jul 24 (mbgs)	Groundwater Elevations (m)
MW-4A	T	4.37	0.42	63.90	64.32	-	-	-	-	-	-	-	0.37	0.27	63.53
MW-4B	B	12.20	0.31	63.83	64.14	-	-	-	-	-	-	0.22	0.27	0.19	63.56
MW-5A	T	2.44	0.65	65.15	65.80	-	-	-	-	-	-	-	2.19	1.85	62.96
MW-5B	B	7.01	0.73	65.20	65.93	-	-	-	-	-	-	2.04	2.20	1.91	63.00
MW-5C	B	14.94	0.57	65.20	65.77	-	-	-	-	-	-	-	2.20	1.92	63.00
MW-6A	T	6.10	0.56	64.00	64.56	-	-	-	-	-	-	-	3.43	3.22	60.78
MW-6B	B	12.34	0.53	63.83	64.36	-	-	-	-	-	-	3.27	3.58	3.39	60.44
MW-7A	T	3.96	0.79	52.69	53.48	-	-	-	-	-	-	-	0.32	0.27	52.41
MW-7B	B	12.65	0.89	52.79	53.68	-	-	-	-	-	-	0.18	0.08	0.04	52.71
MW-7C	B	21.33	0.32	53.05	53.37	-	-	-	-	-	-	0.27	0.40	0.31	52.75
MW-8A	T	2.44	0.52	49.66	50.18	-	-	-	-	-	-	-	0.22	0.18	52.65
MW-8B	B	6.45	-	49.70	49.70	-	-	-	-	-	-	0.18	-	0.62	49.44
MW-8C	B	12.34	0.56	49.63	50.19	-	-	-	-	-	-	-	-0.56	-0.56	49.08
MW-9A	T	3.05	0.54	64.37	64.91	-	-	-	-	-	-	-	0.76	0.63	50.19
MW-9B	B	6.86	0.50	64.08	64.58	-	-	-	-	-	-	0.13	1.31	0.16	63.61
MW-10B	B	7.16	0.52	77.82	78.34	-	-	-	-	-	-	-	1.05	0.89	62.77
MW-10C	B	15.24	0.47	77.89	78.36	-	-	-	-	-	-	1.13	1.35	1.21	76.77
MW-11B	B	9.60	0.39	94.82	95.21	-	-	-	-	-	-	-	0.91	0.74	76.54
MW-12B	B	8.99	0.34	97.59	97.93	-	-	-	-	-	-	-	1.36	0.29	93.91
MW-13B	B	6.10	0.31	95.27	95.58	-	-	-	-	-	-	0.03	0.14	0.05	96.23
MW-13C	B	12.19	0.49	95.32	95.81	-	-	-	-	-	-	0.17	0.34	0.25	95.13
MW-14A	T	5.33	0.37	107.42	107.79	-	-	-	-	-	-	-	0.80	0.56	95.15
MW-14B	B	19.66	0.28	107.42	107.70	-	-	-	-	-	-	-	1.30	1.26	106.62
MW-15A	T	4.16	0.30	108.58	108.88	-	-	-	-	-	-	4.12	2.66	3.05	106.12
MW-15B	B	11.51	0.46	108.51	108.97	-	-	-	-	-	-	5.40	5.67	5.87	105.92
MW-15C	B	17.70	0.48	108.57	109.05	-	-	-	-	-	-	5.58	5.72	5.91	105.53
MW-16A	T	4.72	0.54	100.39	100.93	-	-	-	-	-	-	-	2.43	2.15	102.84
MW-16B	B	10.67	0.51	100.40	100.91	-	-	-	-	-	-	-	2.64	2.49	102.85
MW-17A	B	3.66	0.54	97.47	98.01	-	-	-	-	-	-	-	1.97	1.14	97.96
MW-17B	B	8.08	0.55	97.45	98.00	-	-	-	-	-	-	-	2.14	1.70	97.76
MW-18B	B	9.45	0.77	95.80	96.57	-	-	-	-	-	-	-	0.70	0.37	95.50
MW-18C	B	17.80	0.59	96.00	96.59	-	-	-	-	-	-	1.05	1.37	0.83	95.31
MW-19A	T	3.16	0.59	82.10	82.69	-	-	-	-	-	-	-	1.84	0.83	95.10
MW-19B	B	9.14	0.67	82.10	82.77	-	-	-	-	-	-	-	0.61	1.99	94.63
MW-20A	T	3.05	0.56	67.97	68.53	-	-	-	-	-	-	-	1.89	1.76	80.26
MW-20B	B	9.50	0.49	68.05	68.54	-	-	-	-	-	-	-	1.72	1.65	81.49
MW-21	B	3.45	0.82	64.02	64.84	-	-	-	-	-	-	1.58	2.08	1.86	66.08
MW-22	T	2.74	0.27	62.90	63.17	-	-	-	-	1.91	-	-	0.24	0.13	66.33
MW-23	T	3.81	0.49	62.63	63.12	-	-	-	-	-	-	-	0.60	0.49	62.44
															62.03
															62.14

Notes:

1. Ground elevations based on site survey.

2. Top of casing elevations at multiple piezometer nest refined by elevation survey of TOC and Grade on July 24/96.

B = Bedrock

T = Till

groundwater levels can be expected in March - April or October - November. Data from a limited number of wells on April 22nd typically provide the highest site water levels recorded for the existing period of record, while data for May and June show a decreasing water level trend. Rise in groundwater levels on July 24th, when compared to June 19th levels, may reflect significant rainfall in the latter part of June. While the June 19th data is representative of the site, it probably does not represent the highest seasonal groundwater levels at the site. Additional seasonal water level data monitoring is needed to assess the relevance of the 1.4 m below grade value for June 19th.

4.2.2 Groundwater Flow Directions

Figures 4.5 and 4.6 show the interpreted overburden water table surface and bedrock piezometric surface, respectively, using data collected on June 19, 1996. Figure 4.5 is principally based on water level data from wells that are considered to be unconfined, while data presented in Figure 4.6 is based on data from wells considered to be semi-confined or confined. Stratigraphy and bedrock structure were both used in qualitatively assessing which wells were unconfined and confined. These flow distributions should be representative of average annual water level conditions when water levels are expected to be close to seasonal mean.

The dominant direction of groundwater flow is west and southwest towards Nine Mile River. All of the proposed RDF is situated on the western side of the watershed divide between Nine Mile River and Big Indian River, based on existing water level data.

4.2.3 Horizontal Hydraulic Gradient

Water table horizontal hydraulic gradients were calculated for three section lines across the RDF foot-print, parallel to groundwater flow direction. Water level data from June 19, 1996 measurements was used. The gradients range from 5.5 % to 8.2 % to 6.3 % for south, mid-point and north sections respectively (average 6.7 %).

Water table horizontal hydraulic gradients between the toe of the proposed landfill and Nine Mile River and/or Duck Pond were calculated for two sections, one originating along the northwest side of the RDF foot-print and the other along the southwest side. These two areas are considered to be the critical release pathways for shallow flow, with a large glacial drumlin between them diverting flow around itself. The calculated gradients are 2.9 % from the southwest RDF toe to the nearest body of water, Duck Pond, and 5.2 % from the northwest RDF toe to the Nine Mile River (average 4 %).

Bedrock potentiometric surface horizontal hydraulic gradients were also calculated for three sections across the RDF. These gradients ranged from 6 % to 7.7 % to 7.8 % for south, mid-point and north sections, respectively (average 7.2 %) and are similar to the water table horizontal gradient. A gradient was also

calculated for a section just outside of the northwestern RDF toe, where enough data was present. This bedrock potentiometric surface horizontal gradient is 3.8 %. Data for the southwestern area outside of the RDF toe was not available.

4.2.4 Vertical Hydraulic Gradients

Vertical hydraulic gradients were calculated based on well pair water level elevations and distances between well screen measuring points. These vertical hydraulic gradients were calculated for 31 locations with multiple monitoring wells based on water level data collected on June 19, 1996 and July 24, 1996. Table 4.3 summarizes the calculated vertical hydraulic gradients for these dates. The values discussed below are for the June 19, 1996 data.

Upward vertical gradients ranged from 0.15 to 40.9 % at some locations where one monitor well of a pair was completed in granite bedrock and an adjacent monitor well completed in the overlying glacial till (MW-95-1, MW-95-2, MW-95-4, RD-14, 15, MW-3, MW-4, MW-5, MW-7, MW-19 and MW-20). In situations where both monitor wells in the pair were completed at different depths in the granite bedrock, upward vertical gradients ranged from 0.2 to 7.9 % (MW-15, and MW-3).

Downward vertical gradients ranged from 3.0 to 58.9 % at other locations where one monitor well of a pair was completed in granite bedrock and an adjacent monitor well completed in the overlying glacial till (RD-1, RD-2, RD-9, RD-10, RD-13, RD-15, MW-6, MW-7, MW-9, MW-10, MW-13, MW-14, MW-15, and MW-16). In situations where both monitor wells in the pair were completed at different depths in the granite bedrock, downward vertical gradients ranged from 0.01 to 5.4 % (MW-5, MW-7, MW-10, MW-13, MW-17 and MW-18).

Zones of both groundwater recharge and discharge are present at the site, as indicated by the well-pair vertical hydraulic gradients discussed above. In general, the topographically downgradient areas of the site (western toe of the RDF) are groundwater discharge areas and the upgradient areas of the site (eastern RDF) are groundwater recharge areas. A few exceptions to these generalizations occur such as at downgradient location MW-6 which is a local recharge area and at upgradient location RD-14 which is a discharge area.

RD-14 is an anomalous upgradient well that has a strong vertical upward hydraulic gradient resulting in flowing artesian conditions (potentiometric surface about 2.9 metres above ground surface). This effect is believed to be caused by confined bedrock underlying an 11m thick deposit of clay till. The source of this hydraulic pressure is believed to be either the watershed divide located about 1100 m to the southeast, or over-pressurized groundwater trapped within sands reported at the base of the clay unit. Due to persistence of flowing borehole conditions over several months, the former hypothesis is more likely.

4.2.5 Hydraulic Conductivity Variation

Hydraulic conductivity is used to assess the permeability of water bearing units. In unconsolidated deposits, hydraulic conductivity is a function of matrix grain size and open pore spaces. In crystalline bedrock, hydraulic conductivity is a function of secondary permeability caused by fractures and joints. Tables 4.4 and 4.5 summarize hydraulic conductivity testing results from slug and packer tests, respectively. There are three main geological units at this site: sandy till, clay till and granite bedrock. The following discussions describe the hydraulic conductivity, porosity and groundwater velocities of these units.

4.2.5.1 Surficial Materials

Monitoring wells were installed in both the silty sand and gravel unit, as well as the sandy clay/clayey silt till. The upper silty sand and gravel unit located along the western perimeter of the RDF, exhibits a relatively high hydraulic conductivity ranging from 2×10^{-4} to 2×10^{-2} cm/s. This unit has a hydraulic conductivity geometric mean of 1.8×10^{-3} cm/s based on ten slug tests (Table 4.4). The sandy clay and clayey silt till units which cover the eastern half of the RDF and may underlie the sand units to the west, exhibit a significantly lower hydraulic conductivity ranging from 1×10^{-6} to 9×10^{-5} cm/s, with a geometric mean of 8.9×10^{-6} cm/s (Table 4.4), based on ten slug tests. On average, the sandy gravel till is about ten times more permeable than the underlying bedrock, and the sandy clay till unit is about fifty times less permeable than the underlying granite bedrock unit.

Correlation calculations were made to assess the relationship between hydraulic conductivity and depth. The clayey tills exhibit no correlation between hydraulic conductivity and depth below grade (correlation coefficient of - 0.07). The sandy tills exhibit a small increase in hydraulic conductivity with depth (correlation coefficient of +0.42), possibly reflecting greater proportion of granite cobbles and boulders approaching bedrock surface.

4.2.5.2 Bedrock

The shallow granite bedrock from 3 to 20 m below bedrock surface exhibits a four order of magnitude variation in hydraulic conductivity, that ranges from 3×10^{-2} cm/s near the bedrock surface at RD-16 and MW-21B (Table 4.4), to less than 1×10^{-7} cm/s below a depth of 20 m in deep boreholes MW-13C and MW-18C (Table 4.5). The geometric means from 88 slug tests and 47 packer tests were 4.9×10^{-4} cm/s and 3.1×10^{-4} cm/s, respectively.

The in-situ mean hydraulic conductivities for bedrock, determined from slug and packer testing, are about one order of magnitude higher than the regional hydraulic conductivity geometric mean of 7.7×10^{-5} cm/s for 37 domestic well pumping tests in Halifax County (Tables 4.4 and 4.1). This is likely due to the greater degree of fracturing of the upper few metres of bedrock. As indicated previously, the regional data are

Table 4.3 Summary of Vertical Hydraulic Gradients

Location	Unit	Well Depth (mbsg)	ELEVATION		Sand Packed Interval		Measuring Midpoint		Water Levels 1996				Vertical Hydraulic Gradient		
			Ground Surface (m)	To (mbsg)	From (mbsg)	To (mbsg)	Mid- Sandpack (m)	Delta L (m)	Delta H (m)		JUN 19	Flow Direction	Delta H/Delta L		
									JUL 24	JUN 19					
NW-95-1A	Granite	15.30	62.17	12.90	15.30	14.10	61.84	61.90	-0.2300	-0.0210	Up	-0.0201	Up		
NW-95-1B	Till	4.30	62.43	2.00	4.30	3.15	61.61	61.68	0.0500	0.0078	Down	0.0078	Down		
NW-95-2A	Granite	12.60	108.25	9.70	12.60	11.15	107.69	107.75	-0.0300	-0.0047	Up	-0.0047	Up		
NW-95-2B	Till	6.40	108.13	3.10	6.40	4.75	107.66	107.80	-0.0300	-0.0047	Up	-0.0047	Up		
NW-95-3A	Granite	15.70	101.20	14.20	15.70	14.95	101.08	101.10	-0.0300	-0.0047	Up	-0.0047	Up		
NW-95-3B	Till	9.00	-	6.30	9.00	7.65	-	-	-	-	-	-	-		
NW-95-4A	Granite	13.80	92.05	8.50	13.80	11.15	91.47	91.77	-0.0130	-0.0015	Up	-0.0174	Up		
NW-95-4B	Till	3.10	92.12	1.60	3.10	2.35	91.46	91.62	-0.0130	-0.0015	Up	-0.0174	Up		
RD-1A	Granite	13.05	100.51	9.80	13.00	11.40	98.92	97.10	2.8600	0.3726	Down	0.3588	Down		
RD-1B	Till	4.20	100.51	2.59	4.27	3.43	99.89	99.96	2.8600	0.3726	Down	0.3588	Down		
RD-2A	Granite	8.09	97.18	6.25	8.09	7.17	91.81	91.89	1.6400	0.4444	Down	0.4119	Down		
RD-2B	Till	4.47	97.18	2.49	4.47	3.48	93.45	93.41	1.6400	0.4444	Down	0.4119	Down		
RD-3	Granite	3.83	90.07	1.98	3.83	2.91	88.62	89.08	1.6400	0.4444	Down	0.4119	Down		
RD-4	Granite	9.39	87.50	0.45	9.39	4.92	87.50	87.50	1.6400	0.4444	Down	0.4119	Down		
RD-5	Granite	7.15	83.24	5.10	7.10	6.10	81.10	81.23	1.6400	0.4444	Down	0.4119	Down		
RD-6	Granite	5.89	69.43	4.04	5.70	4.87	69.18	69.35	1.6400	0.4444	Down	0.4119	Down		
RD-7	Granite	7.60	98.19	5.38	7.60	6.49	96.79	97.00	1.6400	0.4444	Down	0.4119	Down		
RD-8	Granite	7.90	97.83	5.54	7.90	6.72	94.80	95.14	1.6400	0.4444	Down	0.4119	Down		
RD-9A	Granite	10.59	95.96	8.40	10.60	9.50	92.80	93.14	1.6400	0.4444	Down	0.4119	Down		
RD-9B	Till	2.50	95.96	0.90	3.07	1.99	94.90	94.62	2.1000	0.2794	Down	0.1969	Down		
RD-10A	Granite	5.81	91.57	3.83	5.81	4.82	88.14	88.66	2.0500	0.5891	Down	0.5603	Down		
RD-10B	Till	1.97	91.57	0.71	1.97	1.34	90.19	90.61	2.0500	0.5891	Down	0.5603	Down		
RD-11	Granite	7.31	83.21	4.06	7.31	5.69	82.42	82.64	2.0500	0.5891	Down	0.5603	Down		
RD-12	Granite	5.81	78.90	2.82	5.81	4.32	76.51	77.02	2.0500	0.5891	Down	0.5603	Down		
RD-13A	Granite	5.79	95.16	3.10	5.63	4.37	94.72	95.08	2.0500	0.5891	Down	0.5603	Down		
RD-13B	Till	2.50	95.16	0.81	2.49	1.65	94.80	94.89	2.0500	0.5891	Down	0.5603	Down		
RD-14A	Granite	13.72	103.23	10.66	13.72	12.19	106.21	106.21	0.0800	0.0295	Down	-0.0700	Up		
RD-14B	Till	5.96	103.23	3.86	5.96	4.91	103.23	102.90	-2.9800	-0.4093	Up	-0.4547	Up		
RD-15A	Granite	6.40	95.54	3.66	6.40	5.03	92.18	92.06	1.4500	0.4441	Down	0.3859	Down		
RD-15B	Till	2.69	95.54	0.84	2.69	1.77	93.63	93.32	1.4500	0.4441	Down	0.3859	Down		
RD-16	Granite	4.22	86.51	2.41	4.42	3.42	85.43	85.92	1.4500	0.4441	Down	0.3859	Down		
RD-17	Granite	4.42	78.17	1.37	4.42	2.90	77.52	77.63	1.4500	0.4441	Down	0.3859	Down		
RD-18	Granite	3.71	67.33	0.91	3.71	2.31	66.41	66.70	1.4500	0.4441	Down	0.3859	Down		
RD-19	Granite	3.89	88.21	1.83	3.89	2.86	85.98	86.91	1.4500	0.4441	Down	0.3859	Down		
RD-20	Granite	6.27	82.64	4.19	6.29	5.24	81.33	81.60	1.4500	0.4441	Down	0.3859	Down		
RD-21	Granite	4.01	75.64	1.22	4.01	2.62	74.64	74.98	1.4500	0.4441	Down	0.3859	Down		
RD-22	Granite	5.56	64.41	3.53	5.56	4.55	64.00	64.10	1.4500	0.4441	Down	0.3859	Down		
RD-23	Granite	5.26	86.30	2.97	5.26	4.12	86.00	86.06	1.4500	0.4441	Down	0.3859	Down		
RD-24	Granite	5.11	83.97	3.28	5.11	4.20	83.17	83.33	1.4500	0.4441	Down	0.3859	Down		
RD-25	Granite	5.33	81.46	3.58	5.33	4.46	81.07	81.28	1.4500	0.4441	Down	0.3859	Down		
RD-26	Granite	4.04	77.30	1.52	4.04	2.78	75.42	75.51	1.4500	0.4441	Down	0.3859	Down		
RD-27	Granite	5.18	65.70	1.83	5.18	3.51	64.41	65.70	1.4500	0.4441	Down	0.3859	Down		
RD-28	Granite	5.51	83.70	3.25	5.51	4.38	82.99	83.18	1.4500	0.4441	Down	0.3859	Down		
RD-29	Granite	5.28	83.01	3.10	5.28	4.19	78.91	79.22	1.4500	0.4441	Down	0.3859	Down		
RD-30	Granite	3.81	72.97	1.83	3.81	2.82	72.10	72.28	1.4500	0.4441	Down	0.3859	Down		
RD-31	Granite	9.04	61.23	6.53	9.04	7.79	60.40	60.48	1.4500	0.4441	Down	0.3859	Down		

Table 4.3 Summary of Vertical Hydraulic Gradients

Location	Unit	Well Depth (mbs)	ELEVATION		Sand Packed Interval		Measuring Midpoint		Water Levels 1996				Vertical Hydraulic Gradient			
			Ground Surface (m)	To (mbs)	From (mbs)	Interval (mbs)	Mid-Sandpack (m)	Delta L (m)	1996		Delta H/Delta L		Flow Direction			
									JUN 19	JUL 24	JUN 19	JUL 24		Flow Direction	JUN 19	JUL 24
NW-1B	Granite	7.31	76.30	6.96	3.96	6.96	5.46		74.14	74.68						
NW-2B	Granite	9.14	71.57	6.10	9.14	7.62			67.54	67.69						
NW-3A	Sand Till	3.20	62.92	0.91	3.20	2.06			62.68	62.71						
NW-3B	Granite	8.86	62.98	5.38	8.86	7.12		5.07	62.86	62.99						
NW-3C	Granite	15.39	62.94	12.34	15.39	13.87		6.75	63.39	63.40	-0.1800	-0.0355	Up	-0.0553	Up	
NW-4A	Sand Till	4.57	63.90	3.05	4.57	3.81			63.53	63.63	-0.5330	-0.0790	Up	-0.0612	Up	
NW-4B	Granite	12.20	63.83	9.14	12.20	10.67		6.86	63.56	63.64	-0.0270	-0.0039	Up	-0.0010	Up	
NW-5A	Sand Till	2.44	65.15	0.91	2.44	1.68			62.96	63.30						
NW-5B	Granite	7.01	65.20	3.66	7.01	5.34		3.66	63.00	63.29	-0.0440	-0.0120	Up	0.0016	Down	
NW-5C	Granite	14.94	65.20	11.89	14.94	13.42		8.08	63.00	63.28	0.0010	0.0001	Down	0.0014	Down	
NW-6A	Sand Till	6.10	64.00	4.57	6.10	5.34			60.57	60.78						
NW-6B	Granite	12.34	63.83	9.14	12.34	10.74		5.41	60.25	60.44	0.3230	0.0598	Down	0.0635	Down	
NW-7A	Sand Till	3.96	52.69	2.44	3.96	3.20			52.37	52.41						
NW-7B	Granite	12.65	52.79	9.45	12.20	10.83		7.62	52.71	52.75	-0.3480	-0.0456	Up	-0.0443	Up	
NW-7C	Granite	21.33	53.05	17.22	20.73	18.98		8.15	52.65	52.74	0.0630	0.0077	Down	0.0016	Down	
NW-8A	Sand Till	2.44	49.66	1.22	2.44	1.83			49.44	49.48						
NW-8B	Granite	6.45	49.70	3.05	6.45	4.75		2.92		49.08						
NW-8C	Granite	12.34	49.63	9.30	12.34	10.82		6.07	50.19	49.63						
NW-9A	Silty sand Till	3.05	64.37	1.22	3.05	2.14			63.61	63.74						
NW-9B	Granite	6.86	64.08	3.05	6.25	4.65		2.52	62.77	63.92	0.8360	0.3324	Down	-0.0732	Up	
NW-10B	Granite	7.16	77.82	4.11	7.16	5.64			76.77	76.93						
NW-10C	Granite	15.24	77.89	11.79	15.24	13.52		7.88	76.54	76.68	0.2280	0.0289	Down	0.0315	Down	
NW-11B	Granite	9.60	94.82	4.42	9.60	7.01			93.91	94.08						
NW-12B	Granite	8.99	97.59	4.32	8.99	6.66			96.23	97.30						
NW-13B	Granite	6.10	95.27	3.05	6.10	4.58			95.13	95.22						
NW-13C	Granite	12.19	95.32	9.14	13.41	11.28		6.70	94.98	95.07	0.1510	0.0225	Down	0.0225	Down	
NW-14A	Clay Till	5.33	107.42	2.13	5.33	3.73			106.62	106.86						
NW-14B	Granite	19.66	107.42	16.46	19.66	18.06		14.33	106.12	106.16	0.5000	0.0349	Down	0.0488	Down	
NW-15A	Silt Till	4.16	108.58	2.13	4.17	3.15			105.92	105.53						
NW-15B	Granite	11.51	108.51	8.68	11.50	10.09		6.94	102.84	102.64	3.0890	0.4451	Down	0.4177	Down	
NW-15C	Granite	17.70	108.57	14.30	17.98	16.14		6.05	102.85	102.66	-0.0140	-0.0023	Up	-0.0040	Up	
NW-16A	Clay Till	4.72	100.39	3.20	4.72	3.96			97.96	98.24						
NW-16B	Granite	10.67	100.40	7.62	10.67	9.15		5.19	97.76	97.91	0.2030	0.0392	Down	0.0642	Down	
NW-17A	Granite	3.66	97.47	2.13	3.66	2.90			95.50	96.33						
NW-17B	Granite	8.08	97.45	5.18	8.08	6.63		3.74	95.31	95.75	0.1870	0.0501	Down	0.1545	Down	
NW-18B	Granite	9.45	95.80	6.40	9.45	7.93			95.10	95.43						
NW-18C	Granite	17.80	96.00	14.73	18.70	16.72		8.79	94.63	95.17	0.4720	0.0537	Down	0.0298	Down	
NW-19A	Till	3.16	82.10	1.66	3.16	2.41			80.26	80.11						
NW-19B	Granite	9.14	82.10	6.37	9.37	7.87		5.46	81.49	80.21	-1.2300	-0.2253	Up	-0.0183	Up	
NW-20A	Till	3.05	67.97	1.53	3.05	2.29			66.08	66.21						
NW-20B	Granite	9.50	68.05	6.45	9.50	7.98		5.69	66.33	66.40	-0.2460	-0.0433	Up	-0.0327	Up	
NW-21	Granite	3.45	64.02	1.09	3.45	2.27			61.94	62.16						
NW-22	Silty sand/grav	2.74	62.90	0.61	2.74	1.68			62.66	62.77						
NW-23	Sand Till	3.81	62.63	2.29	3.81	3.05			62.03	62.14						

Table 4.4 Summary of Hydraulic Testing Results - Slug Testing

Well	Date	Unit	Test Type	Sand Pack Interval		Median Interval (m)	K (cm/s)	Aquifer Type	Test Method
				From (mbgs)	To (mbgs)				
MW-95-1A	Sep 28/95	B	S	12.9	15.3	2.4	8.50E-03	U	FHS
MW-95-2A	Sep 28/95	B	S	9.7	12.6	2.9	5.60E-03	U	FHS
MW-95-3A	Sep 28/95	B	S	13.2	15.6	2.4	2.10E-03	U	FHS
MW-95-4A	Sep 28/95	B	S	8.5	13.8	5.3	1.30E-03	U	FHS
RD-1A	Feb 27/96	B	S	9.8	13.0	3.2	2.62E-05	C	FHS
RD-2A	Feb 27/96	B	S	6.3	8.1	1.8	2.60E-05	U	FHS
RD-3	Feb 27/96	B	S	1.9	3.8	2.0	8.00E-04	U	FHS
RD-4	Feb 27/96	B	S	0.9	9.4	8.5	3.30E-04	U	FHS
RD-5	Feb 27/96	B	S	5.2	7.2	2.0	3.60E-04	U	FHS
RD-6	Feb 27/96	B	S	4.0	5.7	1.7	9.00E-04	U	R&F
RD-7	May 6/96	B	S	5.4	7.6	2.2	2.60E-05	C	FHS
RD-8	Feb 27/96	B	S	5.5	7.9	2.4	1.10E-04	U	FHS
RD-9	Feb 27/96	B	S	8.4	10.6	2.2	5.00E-04	U	FHS
RD-10A	Feb 27/96	B	S	3.8	5.8	2.0	5.60E-04	U	FHS
RD-11A	Feb 27/96	B	S	4.1	7.3	3.3	8.00E-04	U	FHS
RD-12A	Feb 27/96	B	S	2.8	5.8	3.0	3.10E-03	U	FHS
RD-13A	Feb 27/96	B	B	3.1	5.6	2.5	2.30E-04	C	RHB
RD-14A	May 7/96	B	B	10.7	13.7	3.1	2.20E-03	C	RHB
RD-15A	May 7/96	B	S	3.7	6.4	2.7	5.00E-04	U	FHS
RD-16	May 2/96	B	S	2.4	4.4	2.0	3.00E-02	U	FHS
RD-19	May 2/96	B	S	1.8	3.9	2.1	1.20E-03	U	FHS
RD-20	May 2/96	B	B	4.2	6.3	2.1	5.60E-05	U	RHB
RD-21	May 2/96	B	B	1.2	4.0	2.8	2.30E-03	U	RHB
RD-22	May 2/96	B	B	3.5	5.6	2.0	1.10E-03	U	RHB
RD-23	May 2/96	B	B	3.0	5.3	2.3	1.20E-04	U	RHB
RD-24	May 2/96	B	B	3.3	5.1	1.8	5.10E-05	U	RHB
RD-25	May 2/96	B	B	3.6	5.3	1.8	1.70E-03	U	RHB
RD-26	May 2/96	B	S	1.5	4.0	2.5	4.00E-04	U	FHS
RD-27	May 2/96	B	S	1.8	5.2	3.4	2.10E-04	U	FHS
RD-28	May 2/96	B	B	3.3	5.5	2.3	3.00E-03	U	RHB
RD-29	May 7/96	B	B	3.1	5.3	2.2	2.00E-05	U	RHB
RD-30	May 2/96	B	S	1.8	3.8	2.0	2.10E-04	U	FHS
RD-31	May 2/96	B	S	6.5	9.0	2.5	1.20E-04	C	FHS
MW-1B	May 7/96	B	S	4.0	7.0	5.5	1.70E-04	U	FHS
MW-2B	May 7/96	B	S	6.1	9.1	7.6	2.20E-03	U	FHS
MW-3B	May 7/96	B	S	5.4	8.9	7.1	1.40E-04	U	FHS
MW-3C	May 7/96	B	B	12.1	15.2	13.7	1.90E-06	C	RHB
MW-4B	May 10/96	B	S	9.3	12.4	10.8	3.30E-03	U	FHS
MW-5B	May 10/96	B	S	3.4	7.0	5.2	6.80E-03	U	RHB
MW-5C	Jun 20/96	B	S	11.9	14.9	13.4	3.30E-04	U	FHS
MW-6B	May 10/96	B	S	9.1	12.3	10.7	5.20E-03	U	FHS
MW-7B	May 10/96	B	S	9.5	12.2	10.8	3.90E-03	U	FHS
MW-7C	May 10/96	B	S	17.2	20.7	19.0	1.58E-04	U	FHS
MW-8B	May 10/96	B	S	3.1	6.5	4.8	4.80E-04	U	FHS
MW-8C	Jun 21/96	B	S	9.3	12.3	10.8	8.90E-04	C	FHS
MW-9B	May 10/96	B	S	3.1	6.3	4.7	1.12E-03	U	FHS
MW-10B	Jun 21/96	B	S	4.1	7.2	5.6	4.50E-05	U	FHS
MW-10C	May 17/96	B	S	11.8	15.3	13.5	5.00E-04	U	FHS/RHB
MW-11B	Jun 21/96	B	S	4.4	9.6	7.0	9.00E-05	U	FHS
MW-12B	Jun 21/96	B	S	4.3	9.0	6.7	5.30E-04	U	FHS

Table 4.4 Summary of Hydraulic Testing Results - Slug Testing

Well	Date	Unit	Test Type	Sand Pack Interval		Median Interval (m)	K (cm/s)	Aquifer Type	Test Method
				From (mbgs)	To (mbgs)				
MW-13B	May 24/96	B	S	3.0	6.1	4.6	7.60E-04	U	FHS/RHB
MW-13C	May 24/96	B	S	9.1	13.4	11.3	7.20E-04	U	FHS/RHB
MW-14B	Jun 28/96	B	S	16.5	19.7	18.1	2.04E-04	C	FHS
MW-15B	Feb 27/96	B	S	8.7	11.5	10.1	2.50E-04	C	FHS
MW-15C	May 10/96	B	S	15.0	18.0	16.5	4.00E-03	C	FHS
MW-16B	Jun 20/96	B	S	7.6	10.7	9.1	4.30E-04	C	FHS
MW-17B	Jun 20/96	B	S	5.2	8.1	6.6	4.30E-04	U	FHS
MW-18B	Jun 20/96	B	S	6.4	9.5	7.9	2.60E-04	U	FHS
MW-18C	Jun 20/96	B	S	14.7	18.7	16.7	3.30E-04	U	FHS
MW-19B	Jun 20/96	B	S	6.4	9.4	7.9	1.86E-04	U	FHS
MW-20B	Jun 20/96	B	S	6.5	9.5	8.0	1.10E-03	U	FHS
MW-21B	May 7/96	B	S	1.1	3.5	2.3	3.30E-02	U	FHS
RD-1B	Feb 27/96	CT	B	2.5	4.5	2.0	1.72E-06	U	RHB
RD-2B	Feb 16/96	CT	B	2.7	4.2	1.5	4.50E-06	U	RHB
RD-9B	May 6/96	CT	S	0.6	2.5	1.9	4.00E-06	U	FHS
RD-14B	May 7/96	CT	S	3.9	6.0	4.9	1.00E-06	U	FHS
RD-15A	May 7/96	CT	B	0.8	2.7	1.9	3.40E-05	U	RHB
MW-14A	Jun 28/96	CT	S	2.1	5.8	4.0	7.90E-05	U	FHS
MW-16A	Jun 20/96	CT	S	3.2	4.7	4.0	6.70E-06	U	FHS
MW-17A	Jun 20/96	CT	S	2.1	3.7	2.9	1.15E-06	U	FHS
MW-95-2B	Sep 28/95	CT	S	2.5	4.5	3.5	5.80E-05	U	FHS
MW-95-4B	Sep 28/95	CT	S	1.2	3.2	2.2	8.80E-05	U	FHS
MW-4A	Jun 20/96	ST	S	3.1	4.6	3.8	3.00E-03	U	FHS/RHB
MW-3A	Jun 20/96	ST	S	0.9	3.2	2.1	2.50E-03	U	FHS
MW-6A	Jun 21/96	ST	S	4.6	6.1	5.3	6.10E-04	U	FHS
MW-7A	Jun 21/96	ST	S	2.4	4.1	3.3	2.50E-04	U	FHS
MW-8A	Jun 21/96	ST	S	1.2	2.4	1.8	4.30E-04	U	FHS
MW-9A	Jun 21/96	ST	S	1.2	3.1	2.1	2.20E-03	U	FHS
MW-19A	Jun 20/96	ST	S	1.7	3.2	4.5	2.00E-02	U	FHS
MW-23	Jun 20/96	ST	S	2.3	3.8	3.1	4.20E-03	U	FHS
MW-22	Jun 20/96	ST	S	0.6	2.7	1.7	3.50E-04	U	FHS
MW-95-1B	Sep 28/95	ST	S	2.7	4.2	3.5	1.10E-02	U	FHS

Notes:

Unit: B = Granite bedrock, CT = Clayey Till, ST = Sandy Till

Test Type: S = Slug; B = Bail down

Test Method: FHS = Falling Head Slug, RHB = Rising Head

FHS/RHB = Mean Rising/Falling, BBT = Borehole Bail Test

Table 4.5 Summary of Hydraulic Testing Results - Packer Testing

Location	Date	Test Interval			Hydraulic Conductivity K (cm/sec)	Geometric Mean K of Test Zone (cm/sec)
		Length (m)	Zone (m)	Median Depth (mbgs)		
MW-2B	23-Apr-96	1.52	1.52 - 3.05	2.29	3.00E-03	** 1.04E-04
		1.52	4.27 - 5.79	5.03	5.68E-05	
		1.52	7.32 - 8.84	8.08	6.60E-06	
MW-3C	22-Apr-96	1.52	4.57 - 6.10	5.33	1.48E-04	5.88E-04
		1.52	9.30 - 10.82	10.06	2.34E-03	
MW-6B	28-Apr-96	1.52	7.62 - 9.14	8.38	9.88E-04	* 5.70E-04
		1.52	9.14 - 10.67	9.91	5.98E-04	
		1.52	10.67 - 12.19	11.43	3.90E-04	
		1.52	10.67 - 12.19	11.43	4.59E-04	
MW-7C	30-Apr-96	3.20	9.14 - 12.19	10.67	2.67E-03	2.42E-04
		3.20	10.67 - 13.72	12.19	2.29E-04	
		3.20	10.67 - 13.72	12.19	2.25E-04	
		3.20	11.58 - 14.63	13.11	9.36E-05	
		3.20	14.63 - 17.67	16.15	7.43E-04	
		3.20	17.67 - 20.73	19.2	7.62E-05	
		3.20	17.67 - 20.73	19.2	6.69E-05	
MW-10C	15-May-96	3.20	3.05 - 5.94	4.34	4.73E-05	6.30E-05
		3.20	6.10 - 8.99	7.39	4.35E-05	
		3.20	11.89 - 15.09	13.49	1.22E-04	
MW-13C	18-May-96	3.20	2.74 - 44.04	23.39	1.49E-03	* Entire Hole 2.71E-04
		3.20	2.74 - 5.94	4.34	8.89E-04	
		3.20	4.27 - 7.47	5.87	0.00E+00	
		3.20	7.32 - 10.52	8.92	3.35E-04	
		3.20	10.36 - 13.56	11.96	6.66E-05	
		3.20	13.41 - 16.61	15.01	0.00E+00	
		3.20	16.46 - 44.04	30.25	0.00E+00	
		3.20	16.46 - 19.66	18.06	0.00E+00	
		3.20	22.56 - 25.76	24.16	0.00E+00	
		3.20	28.65 - 44.04	36.35	0.00E+00	
		3.20	28.65 - 31.85	30.25	0.00E+00	
		3.20	34.75 - 37.95	36.35	0.00E+00	
		3.20	37.78 - 41.00	39.39	0.00E+00	
		3.20	40.84 - 44.04	42.44	0.00E+00	
MW-15C	20-Apr-96	1.52	8.53 - 10.06	9.3	6.34E-04	7.07E-04
		1.52	10.06 - 11.58	10.82	4.74E-03	
		1.52	11.58 - 13.11	12.34	2.75E-05	
		1.52	13.11 - 14.63	13.87	7.21E-04	
		1.52	14.63 - 16.15	15.39	8.03E-04	
		1.52	16.15 - 17.68	16.92	2.61E-03	
MW-18C	22-May-96	3.20	3.35 - 6.55	4.95	1.49E-04	* Entire Hole 1.78E-04
		3.20	9.45 - 37.03	23.24	7.36E-04	
		3.20	9.45 - 12.65	11.05	1.64E-04	
		3.20	15.54 - 37.03	26.29	3.64E-04	
		3.20	15.54 - 18.75	17.15	2.32E-04	
		3.20	27.74 - 37.03	32.39	0.00E+00	
		3.20	27.74 - 30.94	29.34	0.00E+00	
		3.20	33.83 - 37.03	35.43	0.00E+00	

Notes:

1. mbgs = metres below ground
2. Hydraulic conductivity calculated based on the following formula:

$$K \text{ (cm/s)} = (Q/2 \cdot \pi \cdot L \cdot H) \cdot (\ln L/r) \cdot 100 \text{ when } L > 10 r \text{ (Nielsen, 1991)}$$
3. ** Test result for MW 2B (23-Apr-96; 5.03 m median depth) may be biased due to slightly leaking equipment
4. * Test zone is entire hole to top of test interval.
5. See detailed packer testing results, Appendix 3a.

derived from domestic wells typically 60 metres in depth, and the test results represent averaged bedrock values over a much larger aquifer volume than assessed during slug packer testing.

Spatially, hydraulic conductivity tends to be highest in the westerly edges of the site closest to the river. The vertical variation in bedrock hydraulic conductivity with depth was determined through packer tests on three deep wells (i.e., MW-7C, MW-13C and MW-18C) which were drilled to depths of 22 to 45 m, to be coincident with the elevation of Nine Mile River. All wells showed a decrease in bedrock hydraulic conductivity with depth below bedrock surface. The 39 m and 45 m deep boreholes (i.e., MW-18C and MW-13C) exhibited "no take" during packer testing below 20 m depth, which suggests a hydraulic conductivity of less than 10^{-7} cm/s below a 20 m depth.

Figure 4.7 illustrates the relationship between hydraulic conductivity, rock quality designation (RQD) and fracture frequency with increasing depth in MW-13C. Figure 4.8 illustrates the relationship between hydraulic conductivity and depth for all wells. Hydraulic conductivity appears to randomly vary within the upper 10 to 20 m of the bedrock surface. This supports a conceptual hydrogeological bedrock model that treats the upper bedrock as a homogeneously fractured unit underlying the entire site.

4.2.6 Porosity Estimates

Based on evaluations of slug test data, groundwater literature values, and assuming confined conditions, shallow (3 to 20 metres) bedrock porosity in the order of 0.005 (0.5%) was estimated. This porosity value has been subsequently used in velocity calculations. Porosity values for the surficial materials were assumed, as follows: sand till 0.2 to 0.3 (mean 0.25) and clay till 0.1 to 0.25 (mean 0.2). Within the saturated zone, coefficient of storage values can be used to approximate porosity values. Table 4.1 data summarizes NSDOE coefficient of storage (i.e., S) data for typically 60 m deep wells within granite aquifers of Nova Scotia and indicates a mean value of 0.0005. This 0.0005 result, when compared to the calculated 0.005 value for Site A, suggests that granite porosity beneath Site A is greatest in the near surface bedrock and decreases with depth.

4.2.7 Groundwater Velocity

Average linear groundwater velocities were calculated for Site A as follows:

$$v = K (dh/dl)/n, \text{ where}$$

v - groundwater velocity in metres per day (m/day)

K - hydraulic conductivity in m/day

dh/dl - hydraulic gradient (dimensionless number)

n - porosity (dimensionless number)

Figure 4.7 Vertical Distribution of Bedrock RQD, K, and Fracture Frequency for MW-13C

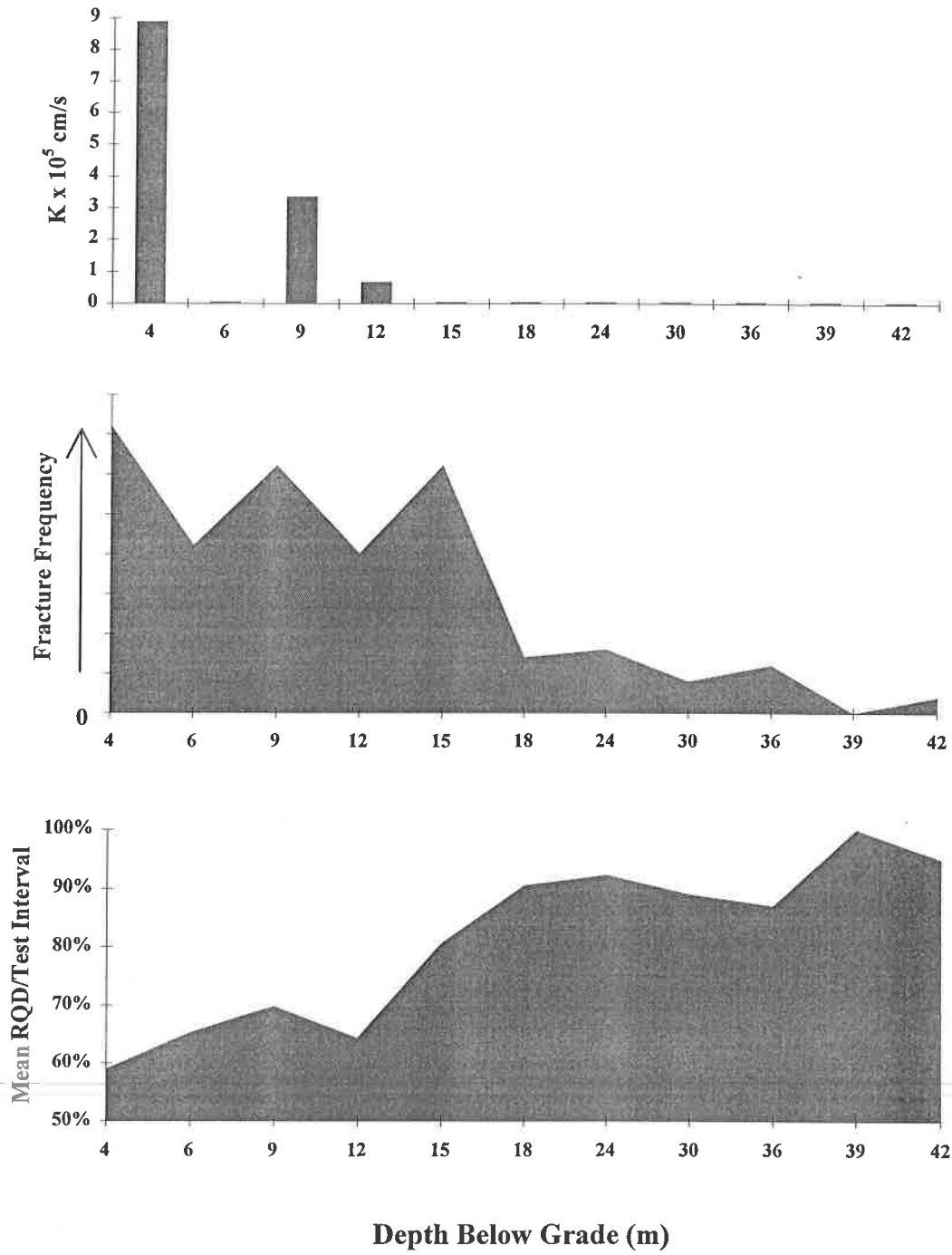
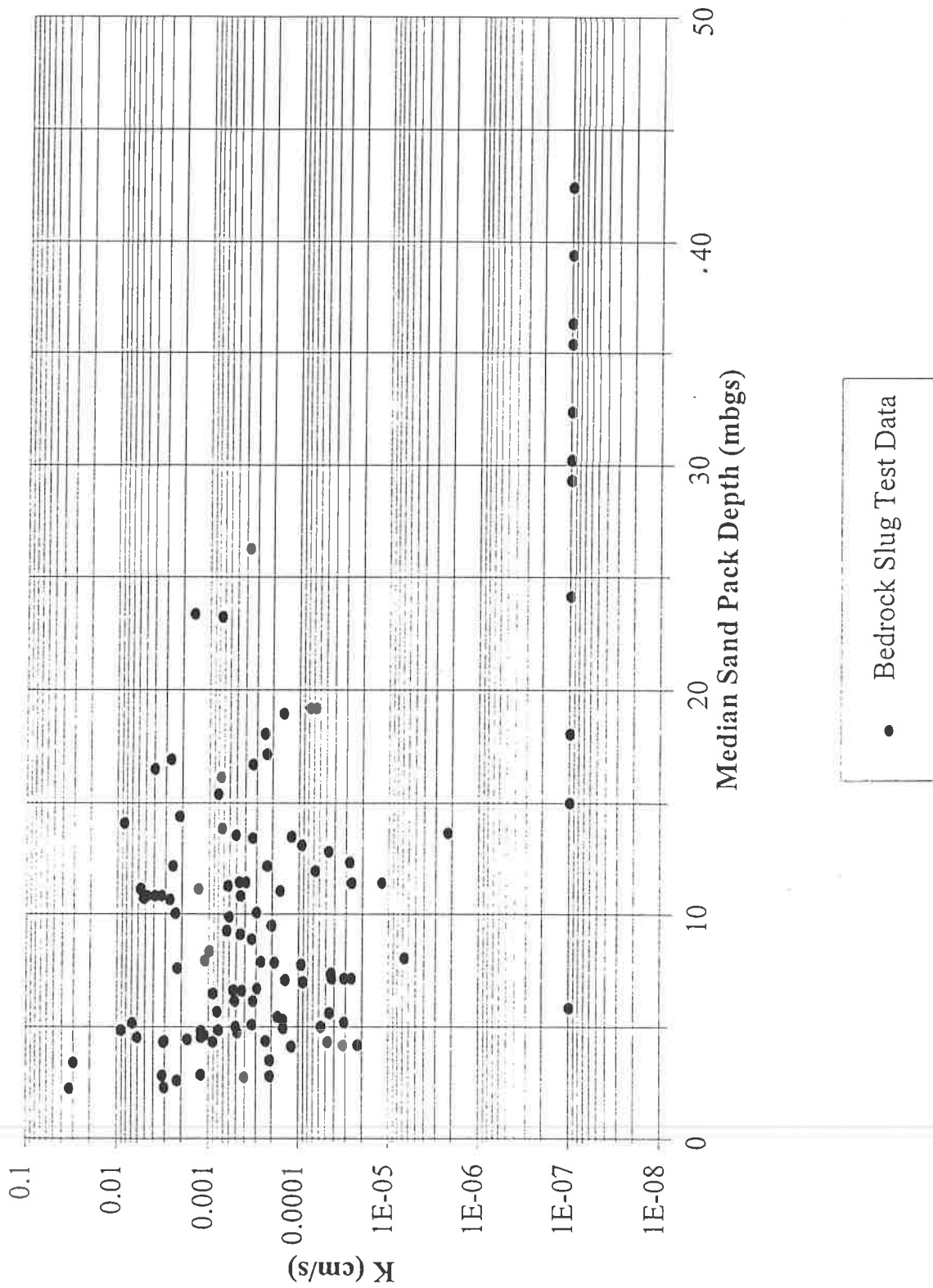


Figure 4.8 Variation in Bedrock Hydraulic Conductivity



Average linear groundwater velocities for surficial and bedrock units both within the proposed RDF and down-gradient of the RDF to Nine Mile River were calculated. Potential groundwater contamination originating within the RDF will first have to migrate across all or some of the RDF foot-print (i.e., depends upon when a release occurs during operational history) then down-gradient into the River. Hydraulic conductivity values are based on Table 4.4, and hydraulic gradients are based on an approximate 500 m separation across the RDF foot-print and a 300 m separation between the RDF toe and Nine Mile River. Porosity values used in groundwater velocity calculations are summarized as follows: granite - 0.005, sand till - 0.25 and clay till - 0.2.

Across the proposed RDF foot-print, estimated average linear velocities of 6.1, 0.4 and 0.0026 m/day were calculated for bedrock, sand till and clay till, respectively. Down-gradient of the RDF toe to Nine Mile River, average linear velocities of 3.2, 0.26 and 0.0016 m/day were calculated for bedrock, sand till and clay till, respectively.

Across the RDF, these groundwater velocities translate into conservative potential contaminant travel times of 82, 1,250 and 190,000 days for the granite, sand till and clay till units, respectively. Similarly, from the RDF toe to Nine Mile River, travel times of 94, 1,150 and 188,000 days are estimated for the granite, sand till and clay till units, respectively.

Clearly migration of potentially contaminated groundwater from the toe of the RDF, within fractured bedrock, represents the greatest potential to impact Nine Mile River. Migration of potential contaminants through sand till (i.e., 1150 days) offers less potential to impact Nine Mile River. As earlier demonstrated, the RDF toe region is a groundwater discharge area. However, the degree of groundwater flow vector portioning between bedrock and sand till units is not known at this time.

In some down-gradient areas, there also exists potential for discharge of groundwater into surface wetland areas between the RDF and Nine Mile River. Groundwater contaminants discharged from shallow fractured granite units or sand till units into such surface water features could result in contaminants reaching Nine Mile River much more quickly than average linear groundwater velocities would suggest. This has potential implications in two management areas - monitoring and contingency planning.

Given the potential for rapid migration of potential contaminants within the fractured bedrock, frequent groundwater monitoring of at least down-gradient wells will be required. This suggests at least quarterly (i.e., 90 day) groundwater monitoring will be required for those wells installed within the shallow granite unit. For some critically placed wells within the shallow fractured granite, monthly monitoring may be appropriate to maximize the time available to address remediation of groundwater contamination originating from the RDF. Semi-annual or annual monitoring of wells within the sand till and clay till units, respectively, should provide adequate protection against potential groundwater contamination originating from the proposed RDF.

Rapid groundwater migration to Nine Mile River, either within fractured granite or via discharge to intermediate wetlands, requires development of specific contingency planning to address this issue. Although details of remedial response (e.g., treatment options) will depend upon the contaminants of concern, general procedures and actions should be established prior to operation. Such planning may also require prior installation of an appropriate groundwater interceptor system that will capture leachate potentially migrating from the RDF.

4.2.8 Groundwater-Surface Water Interaction

As previously indicated, Site A is situated on the west side of the watershed divide that lies between Nine Mile River on the west and Otter Lake Brook on the southeast (Figure 2.1). The dominant direction of groundwater flow across the proposed landfill area is west and southwest to Nine Mile River, which drains southward to Shad Bay 10 km to the southwest. Nine Mile River is the receiving water for shallow groundwater and interflow originating in the vicinity of the proposed RDF. Interflow represents precipitation that infiltrates below the soil or root zone, but discharges either to ground surface or surface water bodies before it can reach the water table.

Figure 4.5 (i.e., water table surface) when compared to the Site A topography (Figure 1.2) clearly indicates that the water table surface is close to ground surface in several areas of Site A. These areas include the southwestern and northwestern portions of Site A. Based on topography, local groundwater recharge is expected to occur on the hills forming the watershed divide immediately south and southeast of the RDF. Based on the observed-groundwater flow directions and upward vertical hydraulic gradients west of the RDF, groundwater will probably discharge from the bedrock either into Nine Mile River and/or its associated wetlands located about 300 m down-gradient of the RDF.

5.0 BASELINE CHEMISTRY

All analytical data are summarized in the database in Appendix 7.

5.1 Soil Chemistry

Two samples of sandy clay till from the RDF and two samples of sandy clay till from the drumlin were analyzed for organic content, carbonate content, soil pH, trace metals, and cation exchange capacity (CEC). One sample of silty sand till from the RDF was analyzed for organic content, carbonate content, soil pH, and trace metals. The results are summarized in Table 5.1. All concentrations are well within both the CCME Commercial/Industrial and Residential/Parkland criteria.

Table 5.1 Soil Analytical Results for pH, Metals, TOC, TIC and CEC

	Units	TP-B1 Sa3	TP-B2 Sa3	TP-RD-8 Sa2	TP-101 Sa1	TP-117 Sa2
Type of Till		Sandy clay	Sandy clay	Sandy clay	Silty sand	Sandy clay
Location		Drumlin	Drumlin	RDF	RDF	RDF
Soil pH		6.6	6.4	6.3	6.0	7.9
Aluminum	mg/Kg	11000	11000	12000	15000	11000
Antimony	mg/Kg	3.0	<2	<2	<2	<2
Arsenic	mg/Kg	5.4	5.7	6.1	6.2	6.1
Barium	mg/Kg	100	120	120	83.	120
Beryllium	mg/Kg	<5	<5	<5	<5	<5
Boron	mg/Kg	<5	<5	<5	<5	<5
Cadmium	mg/Kg	<0.3	<0.3	<0.3	<0.3	<0.3
Chromium	mg/Kg	18	15.	18.	15.	17.
Cobalt	mg/Kg	9.0	8.7	8.7	6.9	9.7
Copper	mg/Kg	15.	16.	16.	14.	17.
Iron	mg/Kg	19000	20000	22000	18000	20000
Lead	mg/Kg	11.	10.	12.	9.8	12.
Manganese	mg/Kg	590	580	460	430	630
Molybdenum	mg/Kg	<2	<2	<2	<2	<2
Nickel	mg/Kg	19.	18.	20.	15.	21.
Selenium	mg/Kg	<2	<2	<2	<2	<2

Table 5.1 Soil Analytical Results for pH, Metals, TOC, TIC and CEC

	Units	TP-B1 Sa3	TP-B2 Sa3	TP-RD-8 Sa2	TP-101 Sa1	TP-117 Sa2
Strontium	mg/Kg	10.	9.0	9.0	5.0	15.
Thallium	mg/Kg	0.1	0.1	0.1	0.2	0.2
Tin	mg/Kg	<2	<2	<2	<2	<2
Uranium	mg/Kg	1.0	1.3	2.2	2.7	1.2
Vanadium	mg/Kg	17.	17.	18.	16.	16.
Zinc	mg/Kg	49.	50.	53.	41.	56.
TOC	grams/Kg	7.3	6.3	7.8	8.6	7.7
TIC	grams/Kg	16.8	17.0	20.0	16.2	24.1
CEC	meq/Kg	108.	254.	59.0	-	72.0

Uranium testing was carried out on the -230 mesh fraction of three sandy clay till samples from the RDF, six (plus one duplicate) sandy clay samples from the drumlin and one sandy clay till sample from the perimeter of the RDF using neutron activation. The uranium results are summarized in Table 5.2 and are lower than the arithmetic mean of 4.5 mg/kg reported by Stea and Fowler (1980) for glacial till in the Halifax area.

Table 5.2 Soil Analytical Results for Uranium

Sample	Depth (m)	Type of Till	Location	U (ppm)
B1, Sa2	1.5	Sandy clay	Drumlin	3.2
B1, Sa2 (duplicate)	1.5	Sandy clay	Drumlin	3.1
B2, Sa11	15.8	Sandy clay	Drumlin	4.0
B3, Sa3	3.4	Sandy clay	Drumlin	3.0
B3, Sa6	7.6	Sandy clay	Drumlin	3.1
B3, Sa8	11.3	Sandy clay	Drumlin	2.8
B3, Sa11	16.5	Sandy clay	Drumlin	4.2
AP3, Sa2	1.5	Sandy clay	Perimeter	3.1
AP8, Sa1	1.2	Sandy clay	RDF	3.3
AP10, Sa3	2.7	Sandy clay	RDF	2.7
MW3, Sa3	1.5	Sandy clay	RDF	4.1

5.2 Groundwater Chemistry

Groundwater chemistry data from the 44 perimeter monitoring wells, seven 1995-series wells, and 5 selected wells within the RDF are presented in Appendix 7. Table 5.3 summarizes the chemistry data range, mean and standard deviation of wells completed in sand till, clay till and granite bedrock, respectively. An interpretation of baseline chemistry is presented below.

5.2.1 Overburden

The surficial aquifer is subdivided into two main lithological types: (1) clayey silt till (Lawrencetown Till), and (2) a more permeable sandy till with cobbles and boulders (Granite Till). Figure 5.1 is a Piper plot illustrating the distribution of major ion chemistry for the baseline monitor wells completed in overburden. Cations are dominated by sodium (sandy till) and calcium (clay till). Anions are dominated by bicarbonate (clay till) and sodium or sulfate (sand till).

Clay Till

The clay till covering the northeastern portions of the site are represented by 7 monitor wells (MW-95-2B, 3B, 4B; MW-14A, 15A, 16A, 17A). The clay till overburden groundwater is classified as a hard (mean hardness 108 mg/L), and alkaline (mean alkalinity 112 mg/L, pH 7.5), calcium bicarbonate water type, with higher dissolved solids (mean TDS 163 mg/L) concentrations than the sandy till or bedrock units (Table 5.3). All parameters except iron (mean 1.02 mg/L) and manganese (mean 0.18 mg/L) fall within the Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1993).

Sand Till

The sand and silty sand till covering the western portions of the site are represented by 11 monitor wells. The sand till overburden groundwater is classified as a soft (mean hardness 12.7 mg/L), and naturally corrosive (mean alkalinity 9.4 mg/L, pH 6.15, Langelier calcite saturation index -4.33), sodium chloride to sodium sulfate water type, with low concentrations of dissolved ions (mean TDS 42 mg/L). All parameters except iron (mean 1.31 mg/L) and manganese (mean 0.32 mg/L) fall within the Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1993).

5.2.2 Bedrock Aquifer

Figure 5.2 is a Piper plot illustrating the distribution of major ion chemistry for granite bedrock wells. Cations are dominated by calcium and sodium, and anions are controlled by bicarbonate and sulfate.

Table 5.3 Baseline Groundwater Quality - Statistical Summary

Parameter	Units	GCDWQ	Method Detection Limit	Sandy Till					Clay Till					Granite Bedrock				
				Max	Min	Avg.	STD	N	Max	Min	Avg.	STD	N	Max	Min	Avg.	STD	N
Sodium	mg/L	200.0	1.0	12.00	4.10	5.77	1.94	15	55.20	6.30	23.39	18.65	7	180.00	3.50	13.80	26.55	42
Potassium	mg/L	-	0.1	1.40	0.20	0.60	0.32	15	3.00	1.00	2.00	0.60	7	8.60	0.10	1.07	1.64	42
Calcium	mg/L	-	1.0	11.00	0.90	3.75	2.72	15	72.50	3.70	34.53	22.25	7	36.00	0.70	11.77	9.88	42
Magnesium	mg/L	-	0.1	2.10	0.40	0.81	0.47	15	9.00	0.90	5.23	2.68	7	21.20	0.10	2.38	3.26	42
Alkalinity	mg/L	-	1.0	26.00	2.00	9.40	6.84	15	178.00	35.00	112.14	52.40	7	158.00	<1.0	41.62	37.89	42
Sulphate	mg/L	500.0	2.0	23.00	<2	7.87	5.34	15	84.00	9.00	32.00	25.99	7	275.00	<2.0	16.64	41.12	42
Chloride	mg/L	250.0	1.0	14.70	3.90	5.65	2.63	15	16.70	5.00	8.36	3.73	7	56.60	3.10	7.47	7.93	42
Reactive Silica	mg/L	-	0.5	21.50	7.20	10.80	3.73	15	19.00	10.90	14.33	3.39	7	52.20	4.00	16.37	7.69	42
Ortho-Phosphate	mg/L	-	0.01	0.22	<0.1	0.03	0.05	15	1.90	<0.01	0.30	0.65	7	4.50	<0.01	0.19	0.68	42
Nitrate + Nitrite	mg/L	10.00	0.05	0.59	<0.05	0.21	0.20	15	0.89	0.07	0.35	0.26	7	5.46	<0.05	0.30	0.82	42
Ammonia	mg/L	-	0.05	0.42	<0.05	0.10	0.10	15	0.38	<0.05	0.12	0.12	7	1.08	<0.05	0.09	0.16	42
Colour	TCU	15.0	3.0	560.00	15.00	199.73	174.43	15	>1000	2.00	210.86	339.77	7	>1000	<5.0	215.26	291.41	42
Turbidity	JTU	5.0	0.3	489.00	2.60	91.42	148.63	15	183.00	2.02	64.37	54.73	7	668.00	0.30	68.46	117.81	42
Specific Cond	uS	-	-	103.00	38.80	54.75	16.27	15	487.00	102.00	322.71	125.30	7	825.00	27.90	129.02	124.27	42
pH	Units	6.5 - 8.5	-	8.00	5.70	6.15	0.59	15	8.00	6.80	7.53	0.42	7	7.70	5.10	6.59	0.59	42
TOC	mg/L	-	-	18.90	<0.50	3.53	5.87	15	6.10	0.90	2.49	1.65	7	7.20	<0.5	1.37	1.38	42
Hardness	mg/L	-	-	36.10	3.80	12.67	8.53	15	212.00	12.90	107.60	65.67	7	154.00	2.20	39.23	34.51	42
Bicarbonate	mg/L	-	1.0	26.00	2.00	8.46	6.86	13	162.00	35.00	86.25	53.39	4	158.00	<1.0	41.04	38.21	41
Carbonate	mg/L	-	0.1	0.20	<0.1	0.01	0.05	15	1.20	<1.0	0.96	0.15	7	<0.1	<0.1	<0.1	0.00	42
TDS	mg/L	500	-	73.00	30.00	42.08	12.76	13	263.00	74.00	162.75	67.13	4	740.00	17.00	95.83	107.88	42
Theoretical Cond	uS/cm	-	-	108.00	35.00	61.23	21.51	13	472.00	106.00	278.25	129.85	4	1260.00	26.00	151.12	187.80	41
Cation Sum	Sum	-	-	1.06	0.34	0.53	0.19	15	4.80	0.92	3.22	1.24	7	11.20	0.21	1.42	1.68	42
Anion Sum	Sum	-	-	0.90	0.25	0.52	0.19	15	4.59	1.10	3.16	1.17	7	10.90	0.21	1.41	1.63	42
Ion Balance	-	-	-	17.80	0.16	7.37	5.09	15	9.19	0.77	3.59	2.96	7	12.00	0.04	4.19	3.67	42
Langelier Index	Units	-	-	-1.90	-5.70	-4.33	1.03	15	0.03	-2.72	-0.94	1.08	7	-0.88	-6.69	-2.97	1.53	42
Saturation pH	Units	-	-	11.50	9.48	10.46	0.57	15	9.72	7.77	8.47	0.69	7	11.80	8.21	9.55	0.97	42
METALS																		
Aluminum	ug/L	-	10.0	2600.00	100.00	584.00	620.54	15	3900.00	29.00	1197.00	1263.89	7	2800.00	11.00	467.10	572.03	42
Antimony	ug/L	-	2.0	<20.00	<2.00	-	-	15	2.00	<2.00	-	-	7	2.00	<2	-	-	42
Arsenic	ug/L	25.0	2.0	5.00	<2.00	3.60	4.50	15	6.00	<2.00	2.86	1.36	7	30.00	<2.00	4.79	5.76	42
Barium	ug/L	-	5.0	110.00	<5.00	32.27	34.87	15	130.00	14.00	57.86	37.44	7	330.00	<5.00	51.67	82.72	42
Beryllium	ug/L	-	5.0	<50	<5	-	-	15	<5.00	<5.00	<5.00	0.00	7	<50.00	<5.00	-	-	42
Bismuth	ug/L	-	2.0	<2.0	<2.0	<2.0	0.00	12	<2.0	<2.0	<2.0	0.00	3	<20.0	<2.0	-	-	20
Boron	ug/L	5000.0	2.0	50.00	5.00	9.93	11.11	15	70.00	<5.00	22.00	21.78	7	120.00	<2.0	16.79	21.53	42
Cadmium	ug/L	5.0	0.3	3.00	0.30	0.51	0.67	15	0.70	<0.5	0.41	0.15	7	0.70	<0.3	0.39	0.42	42
Chromium	ug/L	50.0	2.0	49.00	2.00	12.67	18.54	15	38.00	<2.00	7.86	12.33	7	80.00	<2.0	5.02	12.20	42
Cobalt	ug/L	-	1.0	22.00	1.00	6.13	5.52	15	20.00	<1.00	4.00	6.57	7	8.00	<1.0	1.74	1.83	42
Copper	ug/L	1000.0	2.0	23.00	2.00	9.80	7.15	15	140.00	<2.00	28.29	46.57	7	47.00	<2.00	7.31	10.41	42
Iron	ug/L	300.0	10.0	4600.00	50.00	1306.73	1566.52	15	4100.00	<10.00	1021.43	1339.32	7	4500.00	<10.0	461.52	765.83	42
Lead	ug/L	10.0	0.1	6.00	0.10	-	-	15	7.00	0.20	2.30	2.20	7	4.10	<0.10	0.91	0.84	42
Manganese	ug/L	50.0	10.0	1600.00	10.00	315.80	385.52	15	370.00	17.00	178.86	123.63	7	640.00	6.00	109.00	128.91	42
Molybdenum	ug/L	-	2.0	3.00	<2.00	2.13	0.34	15	130.00	<2.0	22.00	44.17	7	120.00	<2.0	15.07	25.33	42

Table 5.3 Baseline Groundwater Quality - Statistical Summary

Parameter	Units	GCDWQ	Method Detection Limit	Sandy Till					Clay Till					Granite Bedrock				
				Max	Min	Avg.	STD	N	Max	Min	Avg.	STD	N	Max	Min	Avg.	STD	N
Nickel	ug/L	-	2.0	96.00	<2.00	14.00	22.81	15	6.00	<2.00	3.29	1.75	7	10.00	<2.0	3.33	3.23	42
Selenium	ug/L	10.0	2.0	<20.00	<2.00			15	2.00	<2.00			7	2.00	<2.0	2.43	2.74	42
Silver	ug/L	-	0.5	0.80	<0.50	0.52	0.07	15	<0.5	<0.5			7	1.40	<0.1	0.65	0.70	42
Strontium	ug/L	-	5.0	29.00	5.00	17.73	10.85	15	180.00	29.00	108.00	52.01	7	160.00	<5.00	48.45	32.08	42
Thallium	ug/L	-	0.1	0.10	<0.1	0.16	0.22	15	0.10	<0.10			7	0.10	<0.1	0.12	0.14	42
Tin	ug/L	-	2.0	<20.00	<2.00	3.20	4.49	15	<2.00	<2.00	<2.00	0.00	7	2.00	<2			42
Titanium	ug/L	-	2.0	130.00	<2.00	15.58	34.84	12	52.00	5.00	30.33	19.36	3	27.00	<2	8.45	7.48	20
Uranium	ug/L	100.0	0.1	3.80	<0.10	1.01	0.92	15	39.00	<0.10	10.00	13.06	7	200.00	0.20	17.32	33.09	42
Vanadium	ug/L	-	2.0	6.00	<2.00	2.33	1.01	15	4.00	<2.00	2.57	0.73	7	3.00	<2	2.48	2.75	42
Zinc	ug/L	5000.0	2.0	190.00	3.00	51.80	47.38	15	130.00	9.00	45.57	36.93	7	820.00	3.00	118.95	169.36	42
Mercury	ug/L	1.0	0.05	0.56	<0.05	0.09	0.14	13	0.07	<0.05	0.06	0.01	4	0.26	<0.05	0.07	0.04	39
Phosphorous	mg/L	-	0.1	0.10	<0.10	0.10	0.00	12	10.70	<0.10	3.63	5.00	3	107.00	<0.10	5.58	23.27	20
Fluoride	mg/L	1.5	0.1	0.20	<0.10	0.12	0.03	13	0.34	0.14	0.21	0.08	4	1.21	<0.10	0.39	0.34	36
BOD	mg/L	-	2	<2.00	<2.00			6					0	4.00	<2	2.15	0.53	13
COD	mg/L	-	5.0	109.00	14.00	36.83	34.09	6					0	20.00	<5	9.15	4.02	13
Radon VG	bq/L	-	4	793	46	266	256	11	104	3	33	35	6	3633	32	1211	912	38

Notes:

* Testing by MDS Laboratories

1. GCDWQ - Guidelines for Canadian Drinking Water Quality, Health & Welfare Canada, 1993.

Figure 5.1

Distribution of Major Ion Chemistry Overburden Wells

LEGEND

1	MW95-1B	08\96
2	MW95-1B	08\96
3	MW95-2B	08\96
4	MW95-3B	08\96
5	MW95-4B	08\96
6	MW96-1B	08\96
7	MW96-3A	08\96
8	MW96-4A	08\96
9	MW96-5A	08\96
10	MW96-6A	08\96
11	MW96-7A	08\96
12	MW96-8A	08\96
13	MW96-9A	08\96
14	MW96-14A	08\96
15	MW96-15A	08\96
16	MW96-16A	08\96
17	MW96-17A	08\96
18	MW96-20A	08\96
19	MW96-22A	08\96
20	MW96-23A	08\96

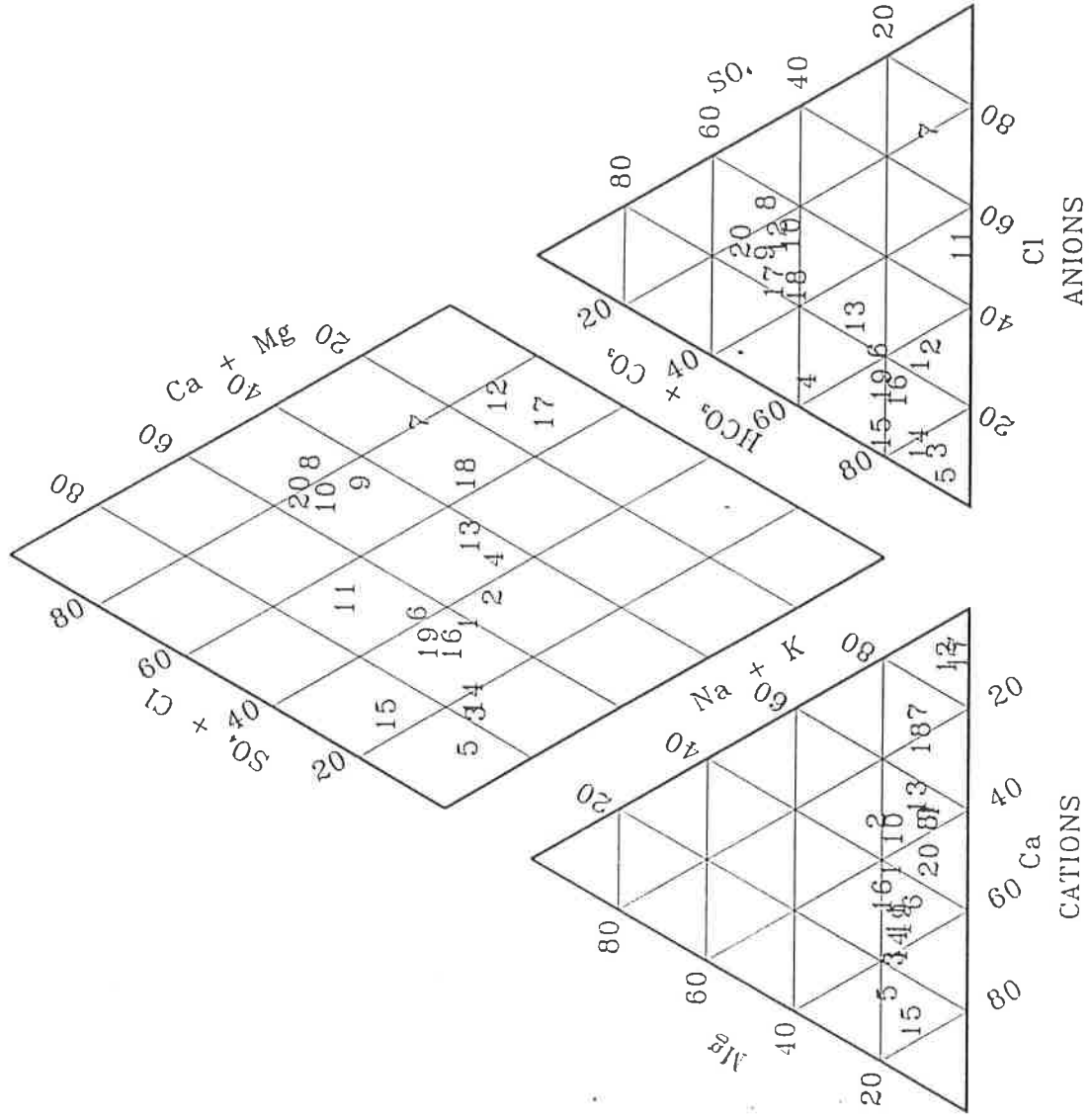
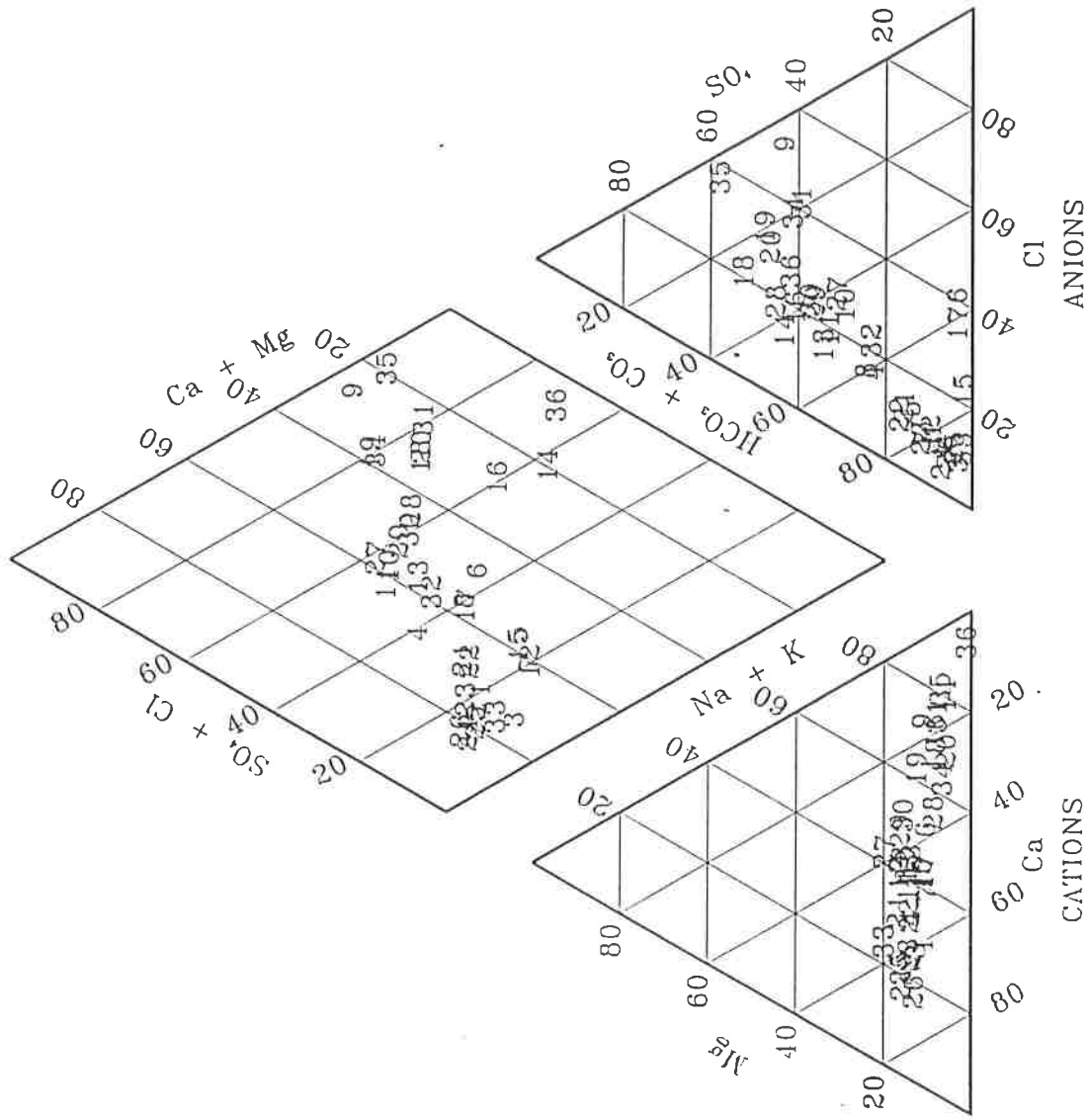


Figure 5.2

Distribution of Major Ion Chemistry Bedrock Wells

LEGEND

1	95-1A	07/96
2	95-2A	07/96
3	95-3A	07/96
4	95-4A	07/96
5	96-2B	07/96
6	96-3B	07/96
7	96-3C	07/96
8	96-4B	07/96
9	96-5B	07/96
10	96-5C	07/96
11	96-6B	07/96
12	96-7B	07/96
13	96-7C	07/96
14	96-8B	07/96
15	96-8C	07/96
16	96-9B	07/96
17	96-10B	07/96
18	96-10C	07/96
19	96-11B	07/96
20	96-12B	07/96
21	96-13B	07/96
22	96-13C	07/96
23	96-14B	07/96
24	96-15B	07/96
25	96-15C	07/96
26	96-16B	07/96
27	96-17B	07/96
28	96-18B	07/96
29	96-18C	07/96
30	96-20B	07/96
31	96-21B	07/96
32	RDF-11	07/96
33	RDF-14A	07/96
34	RDF-16	07/96
35	RDF-21	07/96
36	RDF-31	07/96



The bedrock ground water is classified as a soft (mean hardness 39.2 mg/L), slightly alkaline (mean alkalinity 41.6 mg/L), calcium-bicarbonate water of good chemical quality. All parameters except iron (mean 0.46 mg/L), manganese (mean 0.11 mg/L), and single occurrences of arsenic (0.03 mg/L at MW-10C), uranium (0.20 mg/L at MW-3C) and chromium (0.08 mg/L at MW-8B) fall within respective drinking water guidelines.

Fluoride was analysed due to the presence of high natural fluoride in wells north of this site. Fluoride is a useful indicator of landfill leachate, originating from foods and fertilizers. Background fluoride concentrations ranged from <0.1 mg/L to 1.21 mg/L, averaging 0.39 mg/L in granite. Mean fluoride concentration in clay till and sand till was 0.21 and 0.12 mg/L respectively. Although fluoride is within the 1.5 mg/L drinking water guideline, elevated concentrations (0.8-1.21 mg/L) are present along the southwest boundary at MW-7 and MW-8, as well at up-gradient well MW-13. Fluoride concentration increases with depth, and is associated with granite bedrock.

Mercury concentrations ranged from <0.05 to 0.56 µg/L, averaging at most, 0.09 µg/L. No samples exceeded the drinking water limit.

The distribution of bedrock chemistry confirms local recharge of bedrock through the overlying till. Monitor wells MW-14B, 15B, 16B, MW-95-2 located along the upgradient side of the RDF where clay till cover is present exhibit higher concentrations of hardness, alkalinity and TDS than downgradient wells overlain by sandy materials.

5.2.3 Organic Chemistry Distribution

Organic chemistry analysis was performed on 15 monitoring wells situated at the most probable contaminant release pathways from the RDF. Sampling locations for a full analysis of organic chemistry (petroleum hydrocarbons, EPA624, EPA625, pesticides, BOD, COD) included MW-3B, MW-5A, B, C; MW-7A, B, C; MW-8A, B, C; MW-10B, MW-14B, MW-18B and MW-20A, B. Additional wells were analysed for petroleum hydrocarbons.

5.2.3.1 Petroleum Hydrocarbons

Results for petroleum hydrocarbon analysis are summarized on Table 5.4. Minor evidence of groundwater impact was noted in four of the 20 well locations sampled. The remaining locations exhibited no evidence of petroleum hydrocarbon compounds. Maximum total petroleum hydrocarbon concentrations were 0.26 mg/L, and were limited to surficial deposits or shallow bedrock. No TPH was reported in deeper wells at locations MW-7 and MW-13 where shallow impacts were noted.

Table 5.4 Summary of Petroleum Hydrocarbon Analysis in Groundwater

WELL	DATE SAMPLED	Benzene (mg/L)	Toluene (mg/L)	Ethyl Benzene (mg/L)	Total Xylene (mg/L)	Total BTEX (mg/L)	PETROLEUM HYDROCARBON				Resemblance
							C6-C10 (mg/L)	C11-C20 (mg/L)	C21-C32 (mg/L)	Total Hydrocarbons (mg/L)	
Units											
MDL		(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.01)	(0.05)	(0.10)	(0.10)	
CDWG (1995)		0.005	0.024	0.0024	0.3	-	-	-	-	-	
GFVAL (1995)											
Groundwater		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
MW-3B	07-02-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-4B	07-04-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-5A	06-27-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-5B	06-27-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-5C	06-27-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-7A	06-27-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-7B	06-27-96	nd	nd	nd	nd	nd	nd	nd	0.13	0.13	Lube oil fraction
MW-7C	06-27-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-8A	07-03-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-8B	07-03-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-8C	07-03-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-8C (D)	07-03-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-10B	07-03-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-13B	07-04-96	nd	nd	nd	nd	nd	nd	0.263	nd	0.263	Possible weathered fuel oil
MW-13C	07-04-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-14B	07-04-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-18B	07-04-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-20A	06-28-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-20B	06-28-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-20B (D)	06-28-96	nd	nd	nd	nd	nd	nd	nd	nd	nd	
MW-22	07-04-96	nd	0.001	nd	nd	nd	nd	nd	nd	nd	
MW-23	07-04-96	nd	nd	nd	nd	nd	0.01	nd	nd	0.01	Traces gasoline fraction

Notes:

1. (D) = Field Duplicate Analysis.
2. Alberta MUST Analytical Procedure.
3. Analysis by MDS Laboratory Ltd., Halifax, N.S.

Traces of TPH resembling lube oil (0.13 mg/L in the C22-C32 range) were noted at MW-7A near the proposed west sedimentation lagoons, and a trace (0.01 mg/L) of TPH resembling weathered gasoline was noted at MW-23A near the proposed north sedimentation lagoon. It is likely that these minor occurrences of petroleum hydrocarbon are related to past activities in the area; drums and debris were reported in the wetland areas.

Evidence of weathered gasoline (0.26 mg/L in the C11-C20 range) was noted at MW-13B. An "oily sheen" was reported on drill logs; however no petroleum compounds or other organics were indicated in the deeper well MW-13C. It is likely that this minor occurrence is associated with an abandoned homestead immediately up-gradient of MW-13.

5.2.3.2 Volatile Organic Compounds

Appendix 7 presents results for volatile organic compounds (VOC) analysed by the USEPA-624 procedure. These compounds included BTEX, chlorinated solvents, and others. Trace amounts of chloroethane were detected in MW-8A and a concentration less than twice the method detection limit of chloroform was detected in MW-5A.

5.2.3.3 Base-Neutral Extractable Compounds

Appendix 7 presents results for base-neutral extractable (BNAs) and semi-volatile compounds analysed by the USEPA-625 procedure. These compounds include polyaromatic hydrocarbons (PAH), phenols, and phthalate esters. Trace amounts of bis(2-ethylhexyl) phthalate were detected in MW-5A, MW-8A and MW-18B. Concentrations of chrysene greater than three times the detection limit were detected in MW-14B and MW-18B. Concentrations of di-n-butyl-phthalate ranging from trace amounts to slightly greater than the method detection limit were detected in all well samples with the exception of MW-14B and MW-18B.

5.2.3.4 Pesticides and PCBs

Appendix 7 presents the results for a suite of organo-chloride pesticides analysed under the USEPA 608 procedures. These compounds include persistent heavy pesticide compounds and total PCBs included in the USEPA priority pollutants scan. Neither pesticides nor PCBs were detected in the 16 samples collected.

5.2.3.5 BOD and COD

Concentrations of BOD and COD were monitored at 6 sandy till wells and 13 bedrock wells surrounding the RDF to determine if these parameters would be useful for compliance monitoring purposes.

Concentrations of BOD in groundwater ranged from <2.0 to 4.0 mg/L, and were generally less than detection (Table 5.3).

COD in sand till ranged from 14.0 mg/L to 109 mg/L (mean 36.8 mg/L), and generally correlates with the degree of wetland around a well. COD in granite bedrock wells exhibited a much lower concentration ranging from <5.0 to 20.0 mg/L, mean 9.2 mg/L. COD is generally higher in overburden adjacent to swamps, and decreases with depth in bedrock wells (granite bedrock concentration is generally < 15 mg/L).

BOD and COD may be useful leachate indicators, however the utility of COD in overburden wells may be limited due to presence of natural high COD imparted by wetlands.

5.2.3.6 Radon and Uranium Distribution

Granites in northeastern North America typically exhibit concentrations of uranium and uranium decay daughter products such as radon-222 in groundwater. Concentrations of uranium and radon vary, depending on depth, degree of aquifer isolation from the atmosphere, and other factors.

Table 5.5 summarizes uranium and radon concentrations in groundwater for granite, sand till and clay till units at Site A. Uranium concentration ranged from < 0.1 to 200 µg/L, averaging a high of 18.1 µg/L in the granite bedrock unit. One sample from MW-3C exceeded the 100 µg/L drinking water guideline; all other samples were below 65 µg/L. Groundwater uranium concentration is highest in granite bedrock, and higher in clay till (mean 11.2 µg/L) than in sand till (mean 1.0 µg/L). These results compare well with Uranium Task Force sampling from Harrietsfield, and are generally lower than results for Harrietsfield-Williamstown, Brookside and New Ross (Table 5.6).

Radon gas concentrations are greatest in granite bedrock (mean 1274.7 bq/L), and significantly lower in sand till (mean 228 bq/L) and clay till (mean 32.8 bq/L) (Table 5.6). The range of values is similar to ranges reported for Harrietsfield and Brookside (NS Dept. Of Health, 1986), however, the mean is approximately 50 % higher than for Harrietsfield, and slightly higher than the 1070 bq/L mean reported at New Ross, approximately 50 km to the northwest of Site A.

Regional concentrations of background uranium and radon gas appear to increase in a northwesterly direction from Harrietsfield, through Brookside Road, to Site A to New Ross. This follows the trends in bedrock uranium concentration inferred from radiometric mapping (MacDonald and Horne, 1987). It is also possible that higher mean radon and uranium concentration may reflect the confined nature of the sampling points (e.g., less dilution than at domestic well sampling sites). The Site A wells represent bedrock zones about 3 to 4 m long, while the Harrietsfield and Brookside sampling represents domestic water wells with borehole lengths in excess of 50 m.

Table 5.5 Summary of Uranium and Radon Monitoring in Groundwater and Surface Water

Monitor Well	Unit	Median Depth (m)	Sample Round	Sample Date	Sample Time	Rn-222 (bq/L)	Uranium (µg/L)
MW-95-1A	B	14.55	3	Jul 4/96	922	487	12
MW-95-2A	B	11.85	1	Feb 07/96	1500	32	0.5
MW-95-3A	B	14.95	3	Jul 4/96	1330	148	3.8
MW-95-4A	B	13.05	3	Jul 4/96		1560	0.7
MW-1B	B		3	Jul 3/96	1300	674	2.2
MW-2B	B	8.38	2			1248	17
MW-3B	B	8.01	2	May 23/96	1614	1750	12
MW-3C	B	14.63	2			3633	200
MW-4B	B	11.44	2			1695	13
MW-5B	B	6.25	2			228	0.4
MW-5C	B	14.18	3	Jun 26/96	1530	340	7
MW-6B	B	11.58	2	May 23/96	1500	749	6.8
MW-7B	B	11.44	2			2610	51
MW-7C	B	19.97	2			3557	51
MW-8B	B	5.72	2			1703	62
MW-8C	B	11.58	3	Jul 02/96	1600	2530	53
MW-9B	B	5.49	2			434	3.7
MW-10B	B	6.40	3	Jul 02/96	1745	3160	28
MW-10C	B	14.48	2	May 23/96	1013	2810	17
MW-11B	B	8.08	3	Jul 4/96	1110	733	0.6
MW-12B	B	7.47	3	Jul 4/96	1135	533	1.2
MW-13B	B	5.34	2	May 23/96	1213	943	5.6
MW-13C	B	11.43	2	May 23/96	1225	1118	25
MW-14B	B	18.90	3	Jul 3/96	1200	932	2
MW-15B	B	10.75	2			2016	4.2
MW-15C	B	16.95	2			1509	2
MW-16B	B	9.91	3	Jul 3/96	1630	997	9.4
MW-17B	B	7.32	3	Jul 3/96	1605	1220	2.1
MW-18B	B	8.69	3	Jul 3/96	1445	2330	1.5
MW-18C	B	17.04	3	Jul 3/96	1500	1320	2.7
MW-19B	B	8.62	3	Jul 3/96	1334	1270	62
MW-20B	B	8.74	3	Jun 27/96	1230	986	25
MW-21B	B	2.70	2	May 23/96	1653	185	0.2
RD-11	B	6.55	2	Jul 4/96	1520	353	0.5
RD-14A	B	12.96	2	Jul 4/96	1455	1640	0.8
RD-16	B	3.66	2	Jul 4/96	1440	478	0.2
RD-21B	B	3.25	2	Jul 4/96	1415	331	0.9
RD-31	B	8.28	2	Jul 4/96	1040	195	1.1
Max.						3633	200
Min.						32	0.2
Avg.						1274.7	18.1
N						38	38
MW-95-1B	ST	3.55	1	Feb 07/96	1600	46	0.7
MW-3A	ST	2.44	3	Jun 27/96	1050	148	2
MW-4A	ST	4.19	3	Jul 4/96	846	244	1.2
MW-5A	ST	2.06	3	Jun 26/96	1532	122	0.2
MW-6A	ST	5.72	3	Jul 4/96	940	87	<0.1
MW-7A	ST	3.58	3	Jun 26/96	1700	144	3.8
MW-8A	ST	2.06	3	Jul 02/96	1535	372	0.9

Table 5.5 Summary of Uranium and Radon Monitoring in Groundwater and Surface Water

Monitor Well	Unit	Median Depth (m)	Sample Round	Sample Date	Sample Time	Rn-222 (bq/L)	Uranium (µg/L)
MW-9A	ST	2.65	3	Jul 4/96	1015	362	0.5
MW-20A	ST	2.67	3	Jun 27/96	1300	766	0.3
MW-22	ST	1.98	3	Jul 3/96	910	72	0.2
MW-23	ST	3.43	3	Jul 3/96	1016	143	0.8
Max.						766	3.8
Min.						46	<0.1
Avg.						227.8	1.0
N						11	11
MW-95-2B	CT	5.65	1	Feb 07/96	1500	5	18
MW-95-3B	CT	8.25	1	Feb 07/96	1400	3	39
MW-95-4B	CT	2.35	1	Feb 07/96	1300	9	1.6
MW-14A	CT	4.57	3	Jul 3/96	1140	42	3
MW-16A	CT	4.34	3	Jul 3/96	1625	34	<0.1
MW-17A	CT	3.28	3	Jul 4/96	1310	104	5.3
Max.						104	39
Min.						3	<0.1
Avg.						32.8	11.2
N						6	6
STREAM WATER							
SW-1			3	Jul 10/96	922	<4	0.2
SW-2			3	Jul 10/96	1100	<4	0.3
SW-3			3	Jul 10/96	1230	<4	0.2
SW-4			3	Jul 10/96	1513	8	0.6
SW-5			3	Jul 10/96	1430	<4	0.3
SW-6			3	Jul 11/96	1515	<4	0.3
SW-7			3	Jul 11/96	1330	<4	0.3
SW-8			3	Jul 11/96	950	<4	0.4
SW-9			3	Jul 11/96	1110	<4	0.5
SW-10			3	Jul 15/96	1345	<4	0.1
SW-11			3	Jul 15/96	1415	<4	0.1
SW-12			3	Jul 15/96	1450	<4	0.1
Max.						8	0.6
Min.						<4	0.1
Avg.						4.3	0.3
N						12	12

Notes:

Unit: B = Granite Bedrock, ST = Sandy Till, CT = Clay Till

Table 5.6 Comparison of Uranium and Radon Groundwater Sampling Results for Site A With N.S. Uranium Task Force Sampling at Harrietsfield, Brookside and New Ross

Parameter	Site - A			Harrietsfield			Brookside			New Ross		
	Mean	Range	N	Mean	Range	N	Mean	Range	N	Mean	Range	N
Uranium (µg/L)												
Bedrock	18.1	0.2-200	38	31	<5 - 280	260	38	<5 - 110	26	44	<5 - 700	100
Sand Till	1.0	<0.1 - 3.8	11	-	-	-	-	-	-	-	-	-
Clay Till	11.2	<0.1 - 39	6	-	-	-	-	-	-	-	-	-
Undifferentiated Till	-	-	-	<5	<5 - 8	45	<5	<5 - 10	7	<5	<5 - 180	158
Radon (bq/L)												
Bedrock	1274.7	32 - 3633	38	837	57 - 3586	252	843	34 - 2420	26	1070	29-7130	85
Sand Till	228	46 - 766	11	63	<4 - 241	46	-	-	-	-	-	-
Clay Till	32.8	3 - 104	6	-	-	-	-	-	-	-	-	-
Undifferentiated Till	-	-	-	63	<4 - 241	45	20	8 - 36	7	158	<4-3000	131

Source: NS Dept. of Health Uranium Task Force Report. Feb 28, 1986. Appendix A.

The radon results for bedrock correlate well with the uranium distribution (Correlation coefficient = 0.59). The correlation between radon and uranium is less evident in overburden (+0.10 in sand till and -0.7 clay till); radon is rapidly lost to the atmosphere in sand till, and has poor mobility through clay till.

The highest concentrations of radon, uranium and fluoride occur at the extreme down-gradient southwest corner (MW-8 and MW-9), and at down gradient well MW-3. Higher radon and uranium also occurs in the three deep well locations MW-13, MW-18 and MW-7. No correlations are observed between the inferred fracture zones and these parameters.

5.2.3.7 Seasonal Water Quality Variations

No assessment of seasonal water quality variation can be made at this time.

Concentrations of naturally-occurring dissolved species in groundwater are expected to vary within a defined range due to seasonal recharge and discharge conditions. The present set of water chemistry is representative of mid-summer or average seasonal conditions. These data may be compared with future sample sets collected in June or July.

Quarterly sampling of selected wells is required in order to evaluate any seasonal water level and water quality variances.

5.3 Stream Sampling

This section summarizes results of water and sediment sampling and analysis for 12 stream water monitoring stations, five established along Nine Mile River (SW-1, 3, 5, 6, 7), two along drainage from the two sedimentation pond areas (SW-2, SW-4), two at Duck Pond (SW-8, SW-9) and three at Otter Lake (SW-10, 11 and 12) (Figure 2.1).

5.3.1 Inorganic Surface Water Chemistry

Inorganic chemistry for stream water quality is presented on Table 5.7. Table 5.8 summarizes the range and mean of this inorganic chemistry.

The stream water chemistry is classified as a dilute (mean TDS 29.9 mg/L), and naturally corrosive (mean alkalinity 1.62 mg/L, mean pH 5.37), sodium chloride to sodium sulfate water type. Total suspended solids loads ranged from <1.0 to 7.3 mg/L, averaging 3.2 mg/L. All parameters except pH, aluminum, iron, and occasional zinc, copper and silver fall within acceptable guidelines for protection of fresh water aquatic life (CCME 1995). Aluminum exceeds the 5 to 100 µg/L criteria at most locations. Iron exceeds the 300 µg/L criteria in most locations, and is likely a consequence of naturally-occurring organic-iron complexes in

Table 5.7 Summary of Stream Inorganic Water Chemistry

Location	Units	GFWal	SW-1 9MR 07-11-96	SW-3 9MR 07-11-96	SW-5 9MR 07-11-96	SW-6 9MR 07-15-96	SW-7 9MR 07-15-96	SW-2 SITE 07-11-96	SW-4 SITE 07-11-96	SW-8 DP-in 07-15-96	SW-9 DP-out 07-15-96	SW-10 OL 07-15-96	SW-11 OL 07-15-96	SW-12 OL 07-15-96	SW-12 OL 07-15-96
Sodium	mg/L	-	14.2	11.9	11.4	11.0	11.1	3.6	3.9	4.0	4.3	3.2	3.1	2.9	3.1
Potassium	mg/L	-	1.3	1.0	1.0	0.7	0.7	0.1	0.4	0.2	0.2	0.2	0.3	0.3	0.3
Calcium	mg/L	-	4.4	3.8	3.5	2.9	2.6	0.4	0.4	0.8	0.8	0.6	0.6	0.6	0.7
Magnesium	mg/L	-	0.6	0.5	0.5	0.3	0.3	0.2	0.4	0.4	0.5	0.3	0.3	0.3	0.4
Alkalinity	mg/L	-	5.0	3.0	3.0	<1	1.0	<1	<1	<1	<1	<1	<1	<1	<1
Sulphate	mg/L	500.0	13.0	12.0	12.0	6.0	6.0	8.0	10.0	8.0	7.0	4.0	6.0	4.0	3.0
Chloride	mg/L	250.0	18.3	16.7	16.0	15.0	13.7	4.6	4.4	4.3	4.0	3.7	3.7	3.8	3.9
Reactive Silica	mg/L	-	1.3	1.2	1.3	1.0	1.3	4.6	7.2	5.0	4.5	<0.5	<0.5	<0.5	<0.5
Ortho-Phosphate	mg/L	-	0.01	0.01	0.01	0.05	0.02	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01
Total Phosphorus	mg/L	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.12	0.13	0.15	0.12	<0.1	<0.1
Nitrite	mg/L	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrate	mg/L	1.37 - 2.2	0.97	0.70	0.66	0.38	0.30	0.06	<0.05	0.42	<0.05	<0.05	<0.05	<0.05	<0.05
Ammonia	mg/L	-	0.06	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
TKN	mg/L	-	0.5	0.5	0.5	0.5	0.5	0.6	0.4	0.7	0.5	0.3	0.2	0.3	0.3
Colour	TCU	-	40	38	40	65	58	130	66	160	170	15	<5	8	5
Turbidity	JTU	-	0.9	0.9	0.9	0.7	1.0	0.3	2.0	0.3	0.8	0.3	0.6	0.8	0.8
Specific Conductivity	uS	-	112.0	98.1	90.4	77.7	72.5	49.2	33.1	59.8	44.2	24.5	22.9	23.2	23.2
pH	Units	4.5 - 9.6	6.3	6.1	6.1	5.9	5.8	4.3	5.0	4.2	4.4	5.2	5.3	5.6	5.6
Diss. Organic Carbon	mg/L	-	6.4	7.1	7.3	9.1	10.3	21.7	13.7	31.8	32.7	4.3	2.5	2.3	2.3
Hardness	mg/L	-	13.5	11.5	10.8	8.5	7.7	1.8	2.6	3.6	4.1	2.7	2.7	2.7	3.4
Bicarbonate	mg/L	-	5	3	3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate	mg/L	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
TDS	mg/L	-	60	52	50	39	38	22	28	25	22	13	15	13	12
Total Suspended Solids	mg/L	-	1.6	2.4	2.4	6.8	4.8	<1	2.0	7.3	1.2	3.6	2.4	3.2	2.4
Cation Sum	Sum	-	0.92	0.78	0.74	0.67	0.66	0.25	0.25	0.32	0.32	0.21	0.21	0.19	0.22
Anion Sum	Sum	-	0.96	0.83	0.81	0.59	0.55	0.32	0.36	0.34	0.28	0.21	0.25	0.21	0.20
Ion Balance	%	-	1.65	3.24	4.28	5.98	8.89	12.50	18.20	2.90	5.79	0.54	10.20	4.75	4.97
Langlier Index @ 20° C	Units	-	-3.79	-4.27	-4.30	-5.44	-5.59	-7.49	-6.42	-7.92	-7.41	-6.61	-6.51	-6.21	-6.21
Saturation pH	Units	-	10.1	10.1	10.4	11.3	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
METALS															
Aluminum	ug/L	5-100	230	220	220	300	270	690	680	86	960	160	190	120	120
Antimony	ug/L	-	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Arsenic	ug/L	50	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Barium	ug/L	-	15	12	12	10	9	9	7	7	8	<5	5	5	6
Beryllium	ug/L	100	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bismuth	ug/L	-	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Boron	ug/L	500	11	8	9	7	7	6	7	8	10	5	5	5	5
Cadmium	ug/L	0.2 - 18	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Chromium	ug/L	2 - 20	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cobalt	ug/L	50	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1
Copper	ug/L	2 - 4	<2	<2	<2	2	<2	3	<2	<2	<2	2	3	<2	5
Iron	ug/L	300	360	330	330	400	340	390	460	680	790	220	130	280	270

Table 5.7 Summary of Stream Inorganic Water Chemistry

Location Date	Units	GFWAL ¹	SW-1 9MR 07-11-96	SW-3 9MR 07-11-96	SW-3 9MR 07-11-96	SW-6 9MR 07-15-96	SW-7 9MR 07-15-96	SW-2 SITE 07-11-96	SW-4 SITE 07-11-96	SW-8 DP-in 07-15-96	SW-9 DP-out 07-15-96	SW-10 OL 07-15-96	SW-11 OL 07-15-96	SW-12 OL 07-15-96	SW-12 OL 07-15-96
Lead	ug/L	1 - 7	0.9	0.7	0.6	1.7	1	1.1	0.6	1.3	1.4	0.6	0.8	0.3	0.3
Manganese	ug/L	200	42	34	32	37	34	43	99	37	41	71	67	70	76
Molybdenum	ug/L	10	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Nickel	ug/L	25 - 150	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Selenium	ug/L	1	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Silver	ug/L	0.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3	1.4	<0.5
Strontium	ug/L	-	15	13	13	11	10	7	7	6	7	<5	<5	<5	<5
Thallium	ug/L	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tin	ug/L	-	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Titanium	ug/L	-	<2	<2	<2	3	2	2	9	5	4	<2	2	<2	<2
Uranium	ug/L	10	0.2	0.2	0.3	0.3	0.3	0.3	0.6	0.4	0.5	0.1	0.1	0.1	0.1
Vanadium	ug/L	-	<2	<2	<2	<2	<2	<2	<2	<2	2	<2	<2	<2	<2
Zinc	ug/L	30	6	6	5	15	5	9	<2	29	15	15	32	14	14
Mercury	ug/L	0.1	0.08	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	0.09	<0.05	<0.05	<0.05	<0.05
Fluoride	mg/L	-	0.11	0.1	0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BOD	mg/L	-	<2	<2	<2	<2	<2	<2	<2	2	<2	<2	<2	<2	<2
COD	mg/L	-	21	22	24	26	30	66	36	78	70	12	8	8	7
Radon	bq/L	-	<4	<4	<4	<4	<4	<4	8	<4	<4	<4	<4	<4	<4

Notes:

* Testing by MDS Laboratory, Halifax, N.S.

1. GFWAL - Guidelines for Fresh Water Aquatic Life (CCME 1995).

2. 9MR - Nine Mile River; SITE - Site A Drainage; DP - Duck Pond inlet/outlet; OL - Otter Lake.

Table 5.8 Stream Water Statistical Summary

Parameter	Units	GFWAL ¹	Main Branch Nine Mile River				Draining Site Wetlands				Otter Lake				All Locations				
			MAX	MIN	MEAN	N	MAX	MIN	MEAN	N	MAX	MIN	MEAN	N	MAX	MIN	MEAN	STD	N
Sodium	mg/L	-	14.2	11	11.92	5	4.3	3.6	3.95	4	3.2	2.9	3.08	4	14.2	2.9	6.75	4.17	13
Potassium	mg/L	-	1.3	0.7	1.14	5	0.4	0.1	0.23	4	0.3	0.2	0.28	4	1.3	0.1	0.52	0.37	13
Calcium	mg/L	-	4.4	2.6	3.44	5	0.8	0.4	0.60	4	0.7	0.6	0.63	4	4.4	0.4	1.70	1.44	13
Magnesium	mg/L	-	0.6	0.3	0.44	5	0.5	0.2	0.38	4	0.4	0.3	0.33	4	0.6	0.2	0.38	0.11	13
Alkalinity	mg/L	-	5	<1	2.60	5	<1	<1	0.00	4	<1	<1	<1	4	5	<1	1.62	1.21	13
Sulphate	mg/L	500.0	13	6	9.80	5	10	7	8.25	4	6	3	4.25	4	13	3	7.62	3.15	13
Chloride	mg/L	250.0	18.3	13.7	15.94	5	4.6	4	4.33	4	3.9	3.7	3.78	4	18.3	3.7	8.62	5.87	13
Reactive Silica	mg/L	-	1.3	1	1.22	5	7.2	4.5	5.33	4	<0.5	<0.5	<0.5	4	7.2	<0.5	2.26	2.15	13
Ortho-Phosphate	mg/L	-	0.05	0.01	0.02	5	0.01	0.01	0.01	4	<0.01	<0.01	<0.01	4	0.05	<0.01	0.01	0.01	13
Total Phosphorus	mg/L	-	<0.1	<0.1	<0.1	5	0.13	<0.1	0.06	4	0.15	<0.1	0.07	4	0.15	<0.1	0.11	0.02	13
Nitrite	mg/L	-	<0.01	<0.01	<0.01	5	<0.01	<0.01	<0.01	4	<0.01	<0.01	<0.01	4	<0.01	<0.01	<0.01	0.00	13
Nitrate	mg/L	1.37 - 2.2	0.97	0.3	0.60	5	0.42	<0.3	0.12	4	<0.05	<0.05	<0.05	4	0.97	<0.05	0.29	0.30	13
Ammonia	mg/L	-	0.06	<0.05	0.52	5	<0.05	<0.05	<0.05	4	<0.05	<0.05	<0.05	4	0.06	<0.05	0.05	0.00	13
TKN	mg/L	-	0.5	0.5	0.50	5	0.7	0.4	0.55	4	0.3	0.2	0.28	4	0.7	0.2	0.45	0.13	13
Colour	TCU	-	65	38	48.20	5	170	66	131.50	4	15	<5	7.00	4	170	<5	61.54	54.84	13
Turbidity	JTU	-	1	0.7	0.88	5	2	0.3	0.85	4	0.8	0.3	0.63	4	2	0.3	0.79	0.42	13
Specific Conductivity	uS	-	112	72.5	90.14	5	59.8	33.1	46.58	4	24.5	22.9	23.45	4	112	22.9	56.22	30.13	13
pH	Units	4.5 - 9.6	6.3	5.8	6.04	5	5	4.2	4.48	4	5.6	5.2	5.43	4	6.3	4.2	5.37	0.69	13
Diss. Organic Carbon	mg/L	-	10.3	6.4	40.20	5	32.7	13.7	24.98	4	4.3	2.3	2.85	4	32.7	2.3	11.65	10.16	13
Hardness	mg/L	-	13.5	7.7	10.4	5	4.1	1.8	3.03	4	3.4	2.7	2.88	4	13.5	1.8	5.82	3.89	13
Bicarbonate	mg/L	-	5	<1	2.6	5	<1	<1	<1	4	<1	<1	<1	4	5	<1	1.62	1.21	13
Carbonate	mg/L	-	<1	<1	<1	5	<1	<1	<1	4	<1	<1	<1	4	<1	<1	<1	0.00	13
TDS	mg/L	-	60	38	47.8	5	28	22	24.25	4	15	12	13.25	4	60	12	29.92	15.72	13
Total Suspended Solids	mg/L	-	6.8	1.6	3.6	5	7.3	<1	2.63	4	3.6	2.4	2.90	4	7.3	<1	3.16	1.92	13
Cation Sum	Sum	-	0.92	0.66	0.754	5	0.32	0.25	0.29	4	0.22	0.19	0.21	4	0.92	0.19	0.44	0.26	13
Anion Sum	Sum	-	0.96	0.55	0.748	5	0.36	0.28	0.33	4	0.25	0.2	0.22	4	0.96	0.2	0.45	0.26	13
Ion Balance	%	-	8.89	1.65	4.808	5	18.2	2.9	9.85	4	10.2	0.54	5.12	4	18.2	0.54	6.45	4.69	13
Langelier Index @ 20°C	Units	-	-3.79	-5.59	-4.678	5	-6.42	-7.92	-7.31	4	-6.21	-6.61	-6.39	4	-3.79	-7.92	-6.01	1.24	13
Saturation pH	Units	-	11.4	10.1	10.66	5	11.4	11.4	11.40	4	11.4	11.4	11.40	4	11.4	10.1	11.12	0.51	13
METALS																			
Aluminum	ug/L	5-100	300	220	248	5	960	86	604.00	4	190	120	147.50	4	960	86	326.62	260.74	13
Antimony	ug/L	-	<2	<2	<2	5	<2	<2	<2	4	<2	<2	<2	4	<2	<2	<2	0.00	13
Arsenic	ug/L	50	<2	<2	<2	5	<2	<2	<2	4	<2	<2	<2	4	<2	<2	<2	0.00	13
Barium	ug/L	-	15	9	11.6	5	9	7	7.75	4	6	<5	4.00	4	15	<5	8.46	3.00	13
Beryllium	ug/L	100	<5	<5	<5	5	<5	<5	<5	4	<5	<5	<5	4	<5	<5	<5	0.00	13
Bismuth	ug/L	-	<2	<2	<2	5	<2	<2	<2	4	<2	<2	<2	4	<2	<2	<2	0.00	13
Boron	ug/L	500	11	7	8.4	5	10	6	7.75	4	5	5	5.00	4	11	5	7.15	1.92	13
Cadmium	ug/L	0.2 - 18	<0.3	<0.3	<0.3	5	<0.3	<0.3	<0.3	4	<0.3	<0.3	<0.3	4	<0.3	<0.3	<0.3	0.00	13
Chromium	ug/L	2 - 20	<2	<2	<2	5	<2	<2	<2	4	<2	<2	<2	4	<2	<2	<2	0.00	13
Cobalt	ug/L	50	<1	<1	<1	5	1	<1	0.25	4	<1	<1	<1	4	1	<1	1.00	0.00	13
Copper	ug/L	2 - 4	2	<2	2	5	3	<2	0.75	4	5	<2	2.50	4	5	<2	2.38	0.84	13
Iron	ug/L	300	400	300	352	5	790	390	580.00	4	280	130	225.00	4	790	130	383.08	171.44	13
Lead	ug/L	1 - 7	1.7	0.6	0.98	5	1.4	0.6	1.10	4	0.8	0.3	0.55	4	1.7	0.3	0.88	0.39	13
Manganese	ug/L	200	42	32	35.8	5	99	37	55.00	4	76	67	71.00	4	99	32	52.54	20.55	13
Molybdenum	ug/L	10	<2	<2	<2	5	<2	<2	<2	4	<2	<2	<2	4	<2	<2	<2	0.00	13
Nickel	ug/L	25 - 150	<2	<2	<2	5	<2	<2	<2	4	<2	<2	<2	4	<2	<2	<2	0.00	13
Selenium	ug/L	1	<2	<2	<2	5	<2	<2	<2	4	<2	<2	<2	4	<2	<2	<2	0.00	13
Silver	ug/L	0.1	<0.5	<0.5	<0.5	5	<0.5	<0.5	<0.5	4	3	<0.5	1.10	4	3	<0.5	0.76	0.69	13
Strontium	ug/L	-	15	10	12.4	5	7	6	6.75	4	<5	<5	<5	4	15	<5	8.38	3.43	13
Thallium	ug/L	-	<0.1	<0.1	<0.1	5	<0.1	<0.1	<0.1	4	<0.1	<0.1	<0.1	4	<0.1	<0.1	<0.1	0.00	13
Tin	ug/L	-	<2	<2	<2	5	<2	<2	<2	4	<2	<2	<2	4	<2	<2	<2	0.00	13
Titanium	ug/L	-	3	<2	2.2	5	9	2	5.00	4	2	<2	0.50	4	9	<2	3.00	1.96	13
Uranium	ug/L	10	0.3	0.2	0.26	5	0.6	0.3	0.45	4	0.1	0.1	0.10	4	0.6	0.1	0.27	0.15	13
Vanadium	ug/L	-	<2	<2	<2	4	2	<2	0.50	4	<2	<2	<2	4	2	<2	2.00	0.00	12
Zinc	ug/L	30	15	5	7.4	5	29	<5	13.25	4	32	14	18.75	4	32	<2	12.85	8.74	13
Mercury	ug/L	0.1	0.08	<0.05	0.056	5	0.12	<0.05	0.05	4	<0.05	<0.05	<0.05	4	0.12	<0.05	0.06	0.02	13
Fluoride	mg/L	-	0.11	0.1	0.102	5	<0.1	<0.1	0.00	4	<0.1	<0.1	<0.1	4	0.11	<0.1	0.10	0.00	13
BOD	mg/L	-	<2	<2	<2	5	2	<2	0.50	4	<2	<2	<2	4	2	<2	2.00	0.00	13
COD	mg/L	-	30	21	24.6	5	78	36	62.50	4	12	7	8.75	4	78	7	31.38	23.58	13
Radon	bq/L	-	<4	<4	<4	5	8	<4	2.00	4	<4	<4	<4	4	8	<4	4.31	1.07	13

* Testing by MDS Laboratory, Halifax, N.S.

1. GFWAL - Guidelines for Fresh Water Aquatic Life (CCME 1995)

stream waters draining Nova Scotia's granite terrain. One occurrence of mercury ($0.12 \mu\text{g/L}$ at SW-8 near Duck Pond), and copper ($5 \mu\text{g/L}$ at SW-12 exiting Otter Lake) exceed respective guidelines. A duplicate analysis of SW-12 ($<2 \mu\text{g/L}$) suggests the high copper result may be lab related in this case.

Figure 5.3 illustrates the distribution of major ion chemistry for the surface water samples. Cations fall within a small range and are dominated by sodium. Anions range from chloride in Nine Mile River and Otter Lake samples, to sulfate in the site drainage.

Samples from main branch Nine Mile River (SW-1, SW-3, SW-5, SW-6, SW-7 from upstream to downstream) exhibit different chemistry than the samples draining the site wetlands (SW-2, SW-4, SW-8, SW-9) and Otter Lake (SW-10, SW-11, SW-12). The stream waters exhibit higher pH (mean 6.04), alkalinity, TDS and lower dissolved organic carbon (DOC) than the site wetlands, with a strong sodium-chloride signature. In addition, some urban impacts (elevated nitrate (0.97 to 0.3 mg/L)) and detectable ammonia (0.05 to 0.06 mg/L) possibly from up-stream sewage treatment plants, and sodium and chloride (about twice site drainage) possibly from road salting is observed in the main branch Nine Mile River samples. Concentrations of TDS and urban impact indicator parameters decrease from upstream (SW-1) to downstream (SW-7) locations.

The site drainage samples and samples from Duck Pond exhibit a sodium sulfate dominance, similar to that seen for the Site A shallow groundwater samples. This confirms groundwater discharge conditions in these areas.

5.3.2 Organic Water Chemistry

Organic chemistry including petroleum hydrocarbons, EPA624 and EPA625 priority pollutants, pesticides, and PCBs were analysed on three surface water samples from Nine Mile River (SW-1, SW-3 and SW-5). No petroleum hydrocarbons, EPA624 priority pollutants, pesticides or PCBs were detected in any of the samples (Appendix 7).

Trace amounts of bis(2-ethylhexyl) phthalate were detected in SW-3 while trace amounts of di-n-butyl phthalate were detected in all three surface water samples.

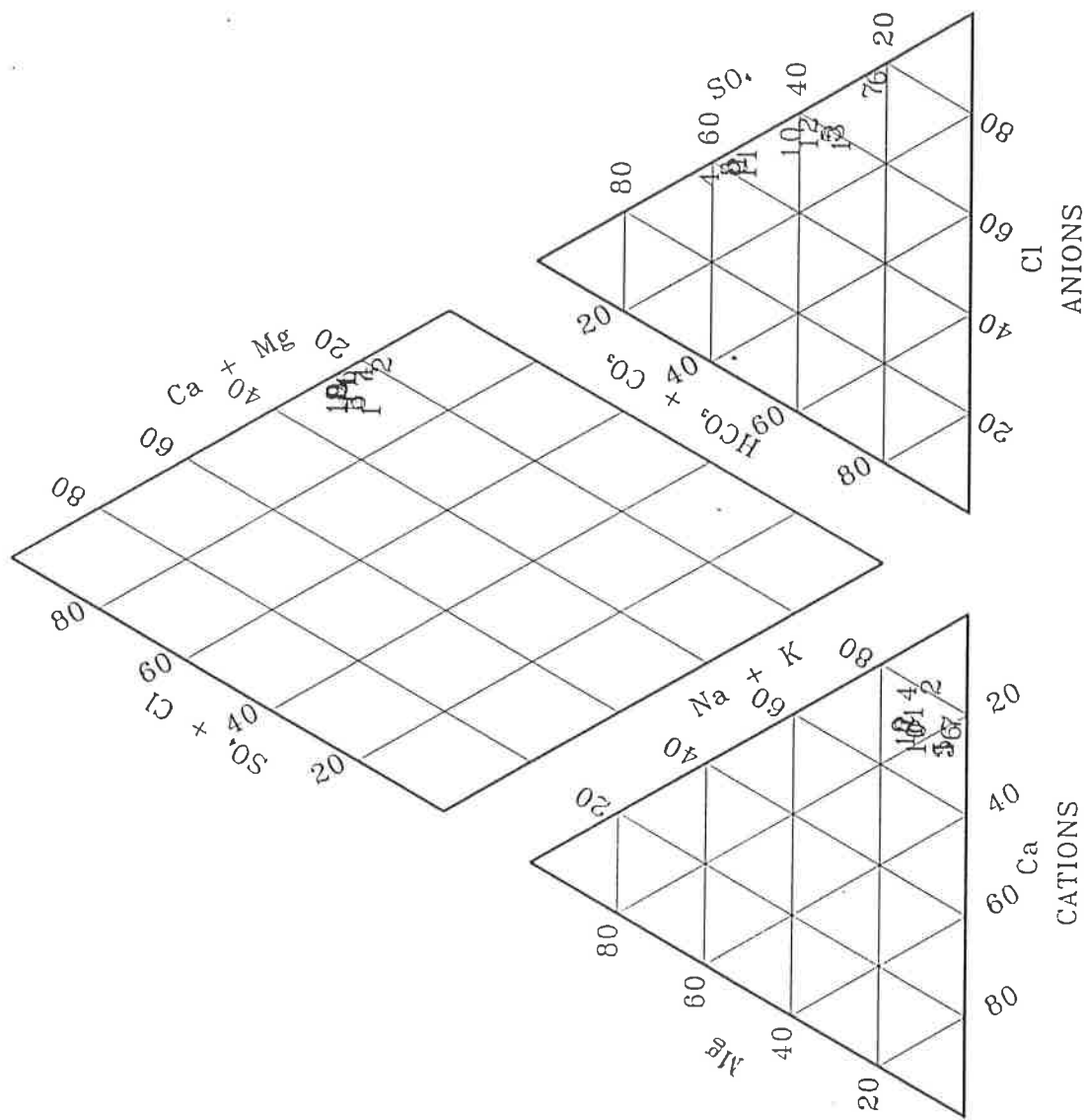
BOD and COD were analysed in all stream water samples (Table 5.7). BOD concentrations were generally at or below the 2.0 mg/L detection limit. COD concentrations ranged from 7 to 78 mg/L , and averaged 31.4 mg/L , being somewhat higher in waters draining wetland areas (mean 62.5 mg/L) than the main stream (mean 24.6 mg/L) or Otter Lake waters (mean 8 mg/L). Results reflect the degree of natural organic loading, and may serve as a baseline for future compliance monitoring. Nutrients (phosphorus, nitrogen) were analysed at all locations. Nitrogen is dominated by nitrate.

Figure 5.3

Distribution of Major Ion Chemistry Surface Water

LEGEND

- | | | |
|----|-------|----|
| 1 | SW-1 | R |
| 2 | SW-2 | S |
| 3 | SW-3 | R |
| 4 | SW-4 | S |
| 5 | SW-5 | R |
| 6 | SW-6 | R |
| 7 | SW-7 | R |
| 8 | SW-8 | DP |
| 9 | SW-9 | DP |
| 10 | SW-10 | OL |
| 11 | SW-11 | OL |
| 12 | SW-12 | OL |



5.3.3 Uranium and Radon

Uranium in stream water ranged from 0.1 to 0.6 µg/L (mean 0.3 µg/L). In comparison to groundwater, radon concentration in the stream waters is very low. All stream locations except SW-4 (8 bq/L) exhibited no detectable radon gas. SW-4 is located on the discharge stream exiting the wetlands immediately west of the RDF and Lagoon #2. It is likely that the detectable radon in stream water at this location is associated with discharging groundwater springs in the immediate area. Elevated radon was noted in wells in this location (Table 5.5).

5.3.4 Stream Sediment Chemistry

Table 5.9 summarizes the results of total acid digestion metals analysis for the stream sediment stations (Figure 2.1). Results are compared with Ontario MOEE Sediment Quality Guidelines Lowest Effects Level (August, 1993).

Arsenic concentrations in stream sediment range from <2 mg/kg to 7.5 mg/kg, slightly exceeding the sediment quality guidelines at one location. Cadmium concentrations range from <0.3 mg/kg to 0.7 mg/kg, marginally exceeding the guidelines at one location. Lead concentrations range from 6.9 mg/kg to 44 mg/kg, less than 1.5 times the respective criteria. One of the ten samples collected slightly exceeds the criteria for manganese.

Mercury concentrations range from 0.01 mg/kg to 0.38 mg/kg, almost twice the guidelines.

PCB concentrations were monitored at each stream station. Due to very low natural solubility, PCBs are expected to be transported as adsorbed loads with suspended solids, and would most likely be found adsorbed on sediment down-gradient of a source. Results indicate no detectable PCBs on any of the stream sediments.

No petroleum hydrocarbons or EPA624 priority pollutants were detected in the three locations sampled (Appendix 7). One stream sediment sample was analyzed for EPA625 priority pollutants. Trace amounts to low concentrations of 1,4 dichlorobenzene, benzidine, bis(2-ethylhexyl) phthalate, di-n-butyl phthalate, diethyl phthalate and phenol were detected in the sample (Appendix 7).

Table 5.9 Summary of Stream Sediment Metals Analysis

Station Date	Units	Guideline ¹	SW-1 07-11-96	SW-2 07-11-96	SW-4 07-11-96	SW-4B 07-11-96	SW-7 07-15-96	SW-7R 07-15-96	SW-8 07-16-96	SW-9 07-16-96	SW-12 07-16-96	SW-12B 07-16-96
Aluminum	mg/kg		3400	7700	14000	15000	6400	5700	6200	7600	6800	6700
Antimony	mg/kg		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Arsenic	mg/kg	6	<2	3.2	7.5	6	2	<2	4.1	4.2	3.5	4.4
Barium	mg/kg		13	51	61	69	65	57	28	27	15	15
Beryllium	mg/kg		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Boron	mg/kg		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cadmium	mg/kg	0.6	<0.3	0.4	0.5	0.7	0.5	0.5	<0.3	<0.3	<0.3	<0.3
Chromium	mg/kg	26	4	4	8	9	5	4	3	3	5	5
Cobalt	mg/kg		1.9	1.7	4.3	4	2	1.8	1.1	1	2.5	2.7
Copper	mg/kg	16	<2	9	7	8	11	10	5	8	2	2
Iron	mg/kg	2%	6000	5400	10000	6900	5200	5100	4600	4200	12000	12000
Lead	mg/kg	31	6.9	39	36	34	34	32	36	44	7	7.2
Manganese	mg/kg	460	83	66	280	190	92	85	27	26	340	470
Molybdenum	mg/kg		<2	<2	<2	<2	<2	<2	<2	3	<2	<2
Nickel	mg/kg	16	3	6	6	7	9	8	3	4	4	4
Selenium	mg/kg		<2	<2	<2	3	<2	<2	<2	3	<2	<2
Strontium	mg/kg		<5	15	13	17	21	21	8	7	<5	<5
Thallium	mg/kg		<0.1	0.1	0.2	0.2	0.1	<0.1	0.1	0.1	0.1	0.1
Tin	mg/kg		<2	2	<2	<2	2	4	2	2	2	2
Uranium	mg/kg		1	6.8	22	24	5.9	5.3	7	30	2.3	2.8
Vanadium	mg/kg		6	9	14	15	12	11	10	8	11	12
Zinc	mg/kg	120	23	25	41	47	44	40	13	16	32	32
Mercury	mg/kg	0.2	0.01	0.21	0.21	0.17	0.15	0.14	0.28	0.38	0.01	0.01

Notes:

* SW3, SW5, SW6, SW10, SW11 - no suitable samples could be retrieved for analysis

1. Ontario MOEE Sediment Quality Guidelines - Lowest Effect Level (August 1993)

2. Metals results are "total available metals" based upon USEPA Method 3050A digestion procedure.

6.0 PRELIMINARY CONTAMINANT FATE AND MOBILITY ASSESSMENT

This section describes the probable plume migration pathways which would occur if there was a leak in the landfill liner and identifies the natural attenuation mechanisms applicable at this site.

6.1 Probable Plume Migration Pathways

The critical release pathway for contaminated seepages which may be released from this engineered RDF is the upper few metres of fractured granite bedrock underlying the RDF liner system, and/or the more permeable sandy surficial deposits immediately west of the RDF.

Based on groundwater flow directions, the main vector of groundwater transport from the RDF is west and southwest via bedrock depressions situated north and south of the drumlin hill. The clay materials comprising this hill will likely intercept westward movement of groundwater, and divert flow towards the wetlands to the north or south of the drumlin.

During the early years of land filling, all seepage movement should be west to wetlands and streams in the vicinity of MW-20, MW-3 and MW-21 and Sedimentation Pond No. 1. The up-ward vertical hydraulic gradients in this area should limit plume migration to the upper bedrock or overburden units.

The primary receptor to potential release of leachate from this RDF is the Nine Mile River and intervening associated wetlands. The organic matter associated with wetlands will provide some attenuation as plumes discharge to the surface water environment.

Nine Mile River has significant flows and some degree of alkalinity and a pH in the order of 6.1. If leachate enters Nine Mile River it is expected to discharge at relatively slow rates along a wide front, and will likely pass through associated wetlands prior to reaching the river. Contaminant attenuation at Nine Mile River will involve processes such as dilution, dispersion, and various redox reactions as the relatively anoxic groundwater plumes enter a highly oxidizing surface water environment.

A typical subsurface contaminant release and migration scenario at this locality would be as follows: Contaminated seepage, if released from the RDF liner system, would be expected to migrate downward into the fractured granite bedrock, and then flow horizontally westward along the upper few metres of weathered and fractured bedrock. Based on the apparent up-ward net groundwater flow directions west of the RDF, seepage would most likely discharge to the wetlands west of the RDF prior to reaching Nine Mile River, and then migrate to Nine Mile River in the overburden or as direct overland flow.

MUST INCLUDE A LEAK-IN
PARAGRAPH - double liner
- extremely low likelihood
of escape & monitoring in leachate

extraction pump, leak detector pump. However, if any release should unlikely occur...



6.2 Leachate Attenuation Capacity

The following sections deal with the natural ability of the overburden and bedrock underlying and down-gradient of the RDF to contain and attenuate potentially contaminated seepages. In general, the sandy clay till materials offer the best natural potential to attenuate contaminated seepages by processes such as dispersion, adsorption, and cation exchange based on chemical analysis performed on five representative samples of sandy clay and silty sand at Site A (Table 5.1).

6.2.1 Cation Exchange Capacity

Cation exchange capacity is the ability of a material to electrochemically bind ions such as metals to clay minerals. In general, the higher the CEC value, the greater the potential for metals to be adsorbed to soils. Cation exchange can be a reversible process, and in leachate plume situations may serve only to delay transport of these compounds. CEC ranged from 59 to 254 meq/kg (mean 123 meq/kg) for the sandy clay till.

6.2.2 Carbonate Content and Soil pH

Total carbonate content is a useful indicator of the ability of a material to buffer acidic drainage, and to limit mobility of some metals. Inorganic carbon ranges from 16,200 mg/kg for silty sand to 24,100 mg/kg for sandy clay till, averaging 18,800 mg/kg (Table 5.1) in clay and silt till. Soil pH ranged from 6.0 in silty sand to 7.9 in sandy clay, averaging 6.64.

6.2.3 Organic Carbon Content

Organic content of a material is a useful indicator of the ability of a material to adsorb organic compounds and metal ions in leachate. In general, the higher the organic content, the greater the capacity to adsorb organic matter. Organic carbon averaged 5,540 mg/kg (Table 5.1) in clay and silt till.

6.2.4 Clay Content

Clay content may influence soil workability, hydraulic conductivity, groundwater velocity and contaminant mobility. Clay type is generally related to CEC, and provides a greater potential than granular media for natural attenuation of metals, organics, and other typical leachate compounds.

X-ray diffraction analysis of sandy clay till (Table 3.5) indicates that the majority of the clay was muscovite, with albite and orthoclase also present. These clays are common to Nova Scotia, and have a low to moderate cation exchange potential.

7.0 CONCLUSIONS

7.1 Geology

Three hydrogeological units were identified on the RDF - sandy clay till, sandy till, and granite bedrock. Each unit offers different capacity to transmit, and to naturally contain and attenuate potential leachate seepages.

- The best capacity to contain and attenuate leachate is provided by the sandy clay till which overlies the eastern and up-gradient portions of the RDF (Figure 8.1). The combination of thick overburden (1.2 to 10.4 m with an average thickness of 3.4 m), high soil pH (mean 6.6), alkaline groundwater associated with these materials, relatively high inorganic carbon content (2 %), measurable organic carbon content (mean 0.55 %), and low in-situ (10^{-6} cm/s) and moulded (10^{-6} to 10^{-8} cm/s) hydraulic conductivity suggests the fine-grained materials on Site A should provide a reasonable degree of natural attenuation for leachate, *and as such provide a further level of protection in addition to the engineered liner at the site.*
- The silty sand and sand and gravel till units overlie the central and down-gradient portions of the RDF. The sandy till is relatively thin, ranging from nil over the central portions of the RDF, increasing to 4.6 m along the toe areas near the drumlin and wetlands and, averaging 1.3 m over the RDF. Due to its moderately high hydraulic conductivity (range 2×10^{-4} to 2×10^{-2} cm/s mean 2×10^{-3} cm/s), and lower proportions of clay minerals and cation exchange capacity, this material offers minimal natural containment and treatment capacity, limited to dilution and dispersion along the flow path.
- The shallow fractured granite bedrock unit also offers minimal natural attenuation capacity. Granites exhibit a wide range of K (range $<1 \times 10^{-6}$ to 3×10^{-2} , geometric mean 4.9×10^{-4} cm/s) and typically contain minimal clay or carbonate mineralization, and groundwater can migrate relatively unchanged through the rock mass.

7.2 Geotechnical

- Overburden thickness beneath the RDF ranged from nil (at bedrock outcrops) to 10.4 m, with an average thickness of 2.2 m. Approximately 22% of the site exhibited < 1 m of overburden thickness. These areas, and identified areas of bedrock exposure must be considered in the subgrade preparation and liner construction.
- Depth to static water table beneath the RDF ranged from ground surface to 5.6 m below grade, averaging 1.4 m. Attention to shallow groundwater seepage will be required in landfill subgrade and liner construction.

HAVE STABILITY ANALYSES BEEN DONE TO DEMONSTRATE
1.3 FOS @ 5% or greater slopes.

- Existing ground surface grades on the RDF ranged from no slope to as high as 16%. It is recommended that a textured FML be used throughout the site where the base slope exceeds 5% to obtain a factor of safety of at least 1.3 and the GCL be substituted with a soil bentonite liner.
- On-site sources of borrow material were identified at two locations - a major drumlin in excess of 27 m thick immediately west of the RDF, and thick clay till deposits along the northeast portion of the site (e.g.; gravel pit). These clayey sands and sandy clays have laboratory measured remoulded permeabilities typically less than 1×10^{-7} cm/s at their natural moisture contents.

7.3 Groundwater Flow Directions and Theoretical Travel Times

- The proposed RDF is situated on the west side of a watershed divide between Otter Lake and Nine Mile River.
- All runoff and seepages from the proposed RDF should move west and southwest towards Nine Mile River and the intervening wetlands.
- The dominant direction of groundwater flow is west and southwest towards Nine Mile River at an average hydraulic gradient of 4 percent, and average linear groundwater velocity of 3.2 m/day (bedrock) and 0.26 m/day (sandy till) respectively.
- Under the above hydraulic conditions, and assuming no natural attenuation along the flow path, leachate plumes could migrate from the west toe of the RDF to Nine Mile River within 94 days via the bedrock pathway, and 1,150 days via the sand till pathway.

7.4 Groundwater Flow Pathways

- The critical release pathway from this engineered RDF is the upper few metres of fractured granite bedrock underlying the RDF liner system, and/or the more permeable sandy surficial deposits immediately west of the RDF.
- Based on bedrock topography, groundwater flow directions, and presence of the clay till drumlin west of the RDF, the primary off-site release pathways are through wetlands to Nine Mile River from the northwest areas of the RDF during early site activities, and southwest via Duck Pond from the southern portions during later activity.
- Based on vertical distribution of hydraulic conductivity, and the upward directions of groundwater flow down-gradient of the RDF, bedrock below 20 m depth is not considered to be an important contaminant release pathway.

7.5 Groundwater Baseline Chemistry

Baseline groundwater quality meets all applicable guidelines except for concentrations of iron and manganese and isolated occurrences of arsenic, uranium, and chromium in excess of drinking water guidelines. Traces of TPH resembling weathered fuel oil were noted near an abandoned homestead (MW-13B). Traces of TPH resembling weathered gasoline and lube oil were detected in the wetlands near the proposed sedimentation lagoons; all concentrations were below 0.5 mg/L TPH.

Two volatile organic compounds (VOCs) were detected at trace concentrations and three base-neutral extractable compounds (BNAs) were detected at concentrations ranging from trace to just over three times the detection limit.

Uranium concentrations in groundwater at the site were similar to results of Uranium Task Force sampling in Harrietsfield, Brookside and New Ross. Concentrations are higher in the granite bedrock compared to the clay till and sand till.

Radon groundwater concentrations are greatest in the granite bedrock and significantly lower in the sand till and clay till. The range of values is similar to those reported for Harrietsfield, Brookside and New Ross, although the mean is approximately 50% higher than for Harrietsfield.

7.6 Stream Baseline Chemistry

Stream water quality is consistent with Nova Scotia rivers. All parameters except pH, aluminum, iron; occasional zinc, copper and silver and one occurrence of mercury fall within acceptable guidelines for protection of fresh water aquatic life (CCME 1995). No petroleum hydrocarbons, VOCs, pesticides or PCBs were detected in any of the stream samples collected, however, trace amounts of several BNAs were detected in the three samples analyzed.

Arsenic, cadmium, lead, manganese and mercury concentrations in stream sediment samples collected at Site A exceed the Ontario MOEE Sediment Quality Guidelines Lowest Effects Level. Concentrations of mercury exceed the guidelines the most, with one sample at almost twice the guideline.

Petroleum hydrocarbons, PCBs and VOCs were not detected in any stream sediment samples. Trace amounts of six BNAs were detected in the one stream sediment sample analyzed.

Uranium in stream water on site is very low in comparison to groundwater. Radon gas was detected in only one stream water sample. The source at this location is likely associated with discharging groundwater springs in the immediate area.

8.0 GEOTECHNICAL RECOMMENDATIONS

8.1 General

Components of the Residuals Disposal Facility include the following:

- Roads
- Buildings and Building Compound
- Residuals Disposal Cell
- Disposal Cell Liner
- Sedimentation Ponds
- Fire Pond
- Leachate Holding Tank

The following discussion presents recommendations and design parameters for design and construction of the foundations and earthworks for each of the components noted above, based on the geotechnical investigations.

8.2 Site Roads

The landfill will have a two-lane perimeter gravel access road. Other gravel roads will be built to access the leachate tank and sedimentation buildings. Roads will be constructed near existing grades and ditching will be provided. Subgrade conditions for the roads will vary among clay tills, silty sand tills and bedrock.

The perimeter road will probably be subjected to its most demanding loadings during construction of the project. It is recommended that, for construction, the subgrade be covered with a minimum subbase of 300 mm of rock fill (200 mm minus material) and a base of 150 mm of Class C to allow for construction traffic. This may require adjustment in some areas depending on where the concentration of hauling occurs and weather conditions. The final gravel requirements can be determined after assessing the condition of the subgrade and base during early phases of construction. For present purposes we anticipate the need for about 150 mm of Class "C" or Class "B" gravel for final surfacing. Roadways to be used for transporting waste to the disposal cell should have a minimum of 450 mm of rock fill as a base course and 300 mm of Class "C" or Class "B" gravel for the surface course.

8.3 Buildings and Building Compound

It is understood that the following buildings will be required for the site:

- Scale house, 10 m x 8 m
- Administration building, 25 m x 8 m
- Maintenance building, 10 m x 24 m

All buildings will be slab on grade construction with concrete frost walls and will be heated. It is anticipated that the slab elevation will be near existing grade with minor grading required. Depending on the final location and elevation of the buildings, footings may be founded in either glacial till, bedrock or both. To minimize differential settlement in the instance that footings are founded on both bedrock and till, a net allowable bearing pressure of 150 kPa is recommended for footings on undisturbed till or on a till/bedrock interface. Footings on properly-prepared bedrock may be designed to a bearing pressure of 1000 kPa.

Footing bases in the till may experience some softening due to the proximity of the groundwater table. Areas which become softened should be over excavated about 300 mm and backfilled with gravel such as 100 mm minus granular material.

All footings on soil should have a minimum soil cover of 1.2 m for frost protection and provisions for adfreeze protection at the perimeter walls. For footings on bedrock a minimum soil cover of 0.6 m is recommended for frost protection. Walls can be backfilled with site material provided they do not act as a retaining wall and the slab is above exterior grade. If the slab is founded below grade, the backfill should consist of gravel and drainage should be provided.

For design of the slab on grade it is recommended that a subgrade modulus of 45 MN/m³ be used for the site tills. If the subgrade is built up using a minimum of 300 mm of well-compacted rock fill a subgrade modulus of 60 MN/m³ can be used. The slabs should be bedded on a minimum of 150 mm of Class "B" gravel or clear stone. If fill is required to achieve the final subgrade elevation, the site tills are suitable if placed in lifts no greater than 250 mm loose thickness and compacted to at least 100 percent of Standard Proctor density.

It is understood that the graveled yard around the buildings will be used for parking and equipment manoeuvring. Based on the subgrade conditions at the site, it is recommended that the traffic areas be constructed using a minimum of 300 mm of rock fill as a subbase and 150 mm of Class "C" or Class "B" gravel as the surface course.

8.4 Disposal Cell

Due to the high water table and upward hydraulic gradients under the proposed foot-print of the RDF, an underdrain system will be required for hydraulic control. ~~This will also serve as a line of defense should a leak in the landfill liner occur.~~

DELETE

It is our understanding that several cells are proposed for the landfill, each covering an area of about 5 ha. Cells will consist of perimeter dykes which will be about 4 m high. It is understood that a 3 m high dyke will divide individual cells. It is understood the site preparation will consist of clearing, grubbing and stripping of all rootmat and topsoil from within the foot-print of the disposal cell including the dykes. Within this layer will be large volumes of cobbles and boulders which are not suitable for construction. Glacial till from on or near the site is to be used for construction of the dykes and regrading of the subgrade soils.

Based on the findings of the geotechnical investigation, the exposed ground after clearing and grubbing will be located near or within the water table and on bedrock at some locations. It is understood that the subgrade will be graded to provide a minimum separation of 1 m between the water table and liner, and at least 300 mm above bedrock. Drainage will be required within the subgrade to prevent disturbance of the subgrade soils. Where fills are placed to grade the subgrade, the materials should be placed in lifts not exceeding 300 mm in loose thickness and should be compacted to at least 98 percent of Standard Proctor density.

The subgrade should be stabilized soon after it is exposed by placing a filter fabric and a minimum of 300 mm of Class "B" gravel. The gravel along with interceptor ditches where groundwater is present will provide a stable base on which to construct the liner. The gravel can be placed in a single lift and should only be compacted with 3 static passes with a 7 to 10 tonne roller to prevent a build up of pore pressure and deflection in the subgrade. This will limit the maximum density which can be achieved. Where conditions are very stable, the use of a filter fabric may not be required.

Final loadings on the subgrade soils from the overlying landfill are expected to be in the order of 250 to 300 kPa. Based on the subgrade conditions and subgrade preparation as outlined above, the site will be suitable for supporting the construction. A factor of safety of at least 3 is obtained against a bearing capacity failure, and at least 1.5 against a slope stability failure through the foundation soils. Total and differential settlements due to compression of the subgrade will not exceed 20 mm, which is well within tolerable limits for this type of construction.

The silty sand and sandy clay till can be used to construct the dykes provided the moisture content is maintained within 2 percent of optimum moisture content. To achieve this, the material should not be stockpiled, but should be placed and compacted as it is being excavated. The material should be placed in loose lifts not exceeding 300 mm and compacted to a minimum of 98 percent of Standard Proctor maximum dry density.

As the height of the dykes increases there may be a temporary buildup of pore pressures causing large deflections under the construction vehicles. Areas may have to be left a day to allow some dissipation of the pressure before adding new fill. The material is susceptible to strength loss when worked in wet

conditions, therefore all surfaces should be rolled and sloped to prevent ingress of moisture from precipitation.

Final slopes on the dykes should be no steeper than 3 horizontal to 1 vertical. The soil is susceptible to erosion and should be protected by either granular materials or vegetative cover.

8.5 Disposal Cell Liner

The proposed disposal cell liner system is a composite liner using a combination of flexible membrane liners (FML), low permeability soil and either a geosynthetic clay liner (GCL) or a soil bentonite liner. The following sections discuss the requirements for placing the soil liner and stability considerations for the liner system.

8.5.1 Clay Liner

The composite liner will include up to one metre of clay having a hydraulic conductivity of less than 5×10^{-6} cm/s. The tills in borrow sources throughout the area consist of clayey sands and sandy clays which have laboratory measured remolded permeabilities typically less than 1×10^{-7} cm/s at their natural moisture contents. Achieving the required 5×10^{-6} cm/s field hydraulic conductivity can be accomplished by placing the material within 2 percent of its natural moisture content. An initial lift having a thickness of 150 mm of material no larger than 50 mm should be placed on the GCL if used. If soil bentonite is used, the maximum particle size can be increased to 150 mm and lift thickness to 300 mm. Intermediate lifts should not exceed a thickness of 300 mm and should have a maximum particle size of 150 mm. The top lift should not exceed 150 mm with a maximum particle size of 12 mm exposed at the interface between the membrane and the clay. All lifts should be compacted to at least 98 percent Standard Proctor density. The till to be used should be excavated in a manner which avoids large clods from being placed which are difficult to compact to a low permeability.

The soil liner should be protected from drying by applying moisture while the surface is exposed. Application of the FML should be carried out as the final lift is being completed to minimize exposure time for the clay. The clay liner will have at least 900 mm of cover as protection against frost damage should the waste not be placed over the entire cell during winter. This amount of cover will provide adequate protection of the clay due to frost penetration.

8.5.2 Liner Stability

It is understood that much of the subgrade on the site will be sloped up to about 10 percent. Within the composite liner system, there are areas of concern with overall stability against sliding of the landfill waste. These areas include the interface between the geotextile and the flexible membrane liner (FML), the

interface between the drainage net and the FML, and within the bentonite of the geosynthetic clay liner. The following design parameters were used to assess the overall sliding stability based on a literature review:

<u>Interface</u>	<u>Friction Angle</u>
FML/Geotextile	8°
FML/Drainage Net	8°
GCL	9°

A stability analysis was carried out using a slope height of 25 m, a friction angle of 30° for the waste, a unit weight for the waste of 9.4 kN/m³ and a liner slope of 10%. Slopes of 3 horizontal to 1 vertical were used for the final waste slope.

PC Slope was used to assess the stability, and for the interface conditions shown above, a factor of safety of less than 1 was obtained for all interfaces noted above. It is recommended that a textured FML be used throughout the site where the base slope exceeds 5% to obtain a factor of safety of at least 1.3 and the GCL be substituted with a soil bentonite liner.

8.6 Sedimentation Ponds

Two sedimentation ponds are proposed for the site. Both ponds are to be located near or in wetlands to the northwest and south of the residuals disposal cell. Test pits and swamp probes throughout these areas indicates much of the areas are underlain by peat of variable thickness. Sands, glacial till, sands and gravel, cobbles and boulders and glacial till are present around the perimeter of the ponds. The water table is presently at ground surface.

It is understood that perimeter dykes will be constructed above the elevation of the existing ground to provide storage and containment. It is anticipated that the dykes will be about 3 m above existing grade. The floor of the ponds will not be lined but may be covered with a granular mat to facilitate cleanout of accumulated silt.

To construct the dykes all rootmat, topsoil and any peat encountered should be removed from below the foot-print of the dykes, and the area dewatered. The dykes can be constructed using the glacial tills from the area. The locations of the dykes should be selected to minimize the amount of peat removal required. If the subgrade is wet and soft, the initial lift of fill for the dykes should be placed dry of optimum and compacted with a minimum of 10 passes with a 10 tonne vibratory roller. Subsequent lifts should not exceed 300 mm and be compacted to at least 98 percent of Standard Proctor density.

Slopes of no steeper than 3 horizontal to 1 vertical are recommended for the sedimentation ponds. The exterior slope should be provided with a granular toe drain to prevent seepage of water at the face of the slope. The toe drain should consist of a gravel blanket which extends into the slope at least one half the distance from the crest of the slope to the toe. Positive drainage from the blanket should be provided.

The interior slopes of the ponds should have a minimum cover of 300 mm of rock fill for stability and erosion protection. Exterior slopes should be protected from erosion with a vegetation cover or granular surfacing.

8.7 Fire Pond

It is understood that water for fire fighting will be stored on site in a dedicated fire pond which will be lined with a flexible membrane liner to retain an adequate supply of water. Site tills will be suitable for construction of the perimeter dykes and should be constructed as noted above for the sedimentation ponds. If the ponds are excavated below grade, under drains should be provided underneath the FML, to protect it from upward heads of water. Toe drains will not be required for the dykes.

8.8 Leachate Holding Tank

An above ground leachate holding tank having a capacity of about 500,000 litres is to be located at the west side of the site. The tank is to have a diameter of about 10 m. Soil conditions are expected to consist of 1 to 4 m of dense silty sand till with cobbles and boulders overlying bedrock. The tank will be located in a containment area surrounded by earth dykes and lined with 300 mm of low permeability soil. The perimeter dykes and liner on the floor can be constructed using the sandy clay till from the site and should be compacted in lifts no greater than 300 mm and compacted to at least 98% of Standard Proctor density. The surface should be protected with a layer of gravel at least 150 mm thick to prevent erosion and loss of moisture. A concrete ring foundation is anticipated for the tank base. Bearing pressures from the tanks are expected to be about 75 kPa. Settlements associated with this pressure would not exceed 10 mm and the factor of safety against an overall bearing capacity failure would be at least 3. The ring foundation should be backfilled with a well graded gravel such as Class "C" and should be provided with positive drainage. The ring wall should be designed using at rest earth pressures using an earth pressure coefficient of 0.5 and a unit weight of the fill of 22 kN/m³. The surcharge effects from the loaded tank must be incorporated into the lateral pressure on the ring foundation.

200,000 gal = 850,000 Ltr.

9.0 HYDROGEOLOGICAL RECOMMENDATIONS

Based on Site A hydrogeologic characteristics and potential groundwater contaminant pathways, two principal recommendations, development of a leachate interception system contingency plan and detailed design of a groundwater monitoring network are presented. These recommendations are discussed in more detail below.

9.1 Leachate Interception System - Contingency Plan

Calculated groundwater velocities indicate potential exists for relatively rapid migration of groundwater from the RDF to Nine Mile River. Such groundwater could migrate to Nine Mile River via the fractured granite; discharge to surficial units; initially migrate through the granite aquifer and discharge into down gradient wetland areas or a combination of the above. Estimated groundwater travel times of as little as 94 days in the fractured granite have been calculated from the toe of the RDF to Nine Mile River. Short-circuiting of groundwater flow via adjacent wetlands could significantly reduce this travel time. It will be important to minimize the time-lag between detection of groundwater contamination and implementation of measures designed to protect Nine Mile River, given such short travel times.

In addition to the underdrain required for the hydraulic control under the RDF, it is recommended that a contingency plan for a leachate interception system be developed as a component of landfill development on Site A. Conceptually such a plan would include additional hydrogeologic assessment in the area between the RDF and Nine Mile River, design of appropriate remedial measure(s) to capture contaminated groundwater migrating from the RDF, and could also include prior installation of an appropriate remedial measure(s). Installation of a remedial measure(s), prior to any evidence of groundwater contamination, will probably be required on a contingency basis, given the short groundwater travel times. The need and justification for such a remedial approach should be specifically addressed in developing this contingency plan.

Detailed down-gradient hydrogeologic assessment between the RDF and Nine Mile River is required, since this area was not a focus for any previous Site A hydrogeologic assessment. This work will need to establish groundwater flow relationships between the fractured granite, existing surficial units, wetland areas and Nine Mile River. Groundwater contaminant transport to Nine Mile River entirely within fractured granite, or via discharge of contaminated groundwater to down-gradient surficial units and/or wetlands, must be established to effectively locate any required remedial measure(s). This assessment will likely include installation of monitoring wells, seepage meters, hydraulic testing (e.g., aquifer/pumping tests) and water level measurement monitoring.

A study of remedial options could assess the effectiveness of passive versus active systems such as interceptor trenches, french drainage systems and/or interceptor drive points/wells should these become

WHY is a contingency plan required? If not - Devote it!

necessary. Location and configuration of the selected system should be supported by the down-gradient hydrogeologic assessment.

On a conceptual basis, in order to collect shallow groundwater in the down-gradient discharge zone, a drive point system is considered to be more practical than an open collection trench or buried french drains. Total collection of groundwater in trenches and drains along the 1100 m length of this RDF would result in high volumes of groundwater which would discharge freely from the down-gradient southern end of the interceptor to wetlands leading to Duck Pond. A well point system however permits individual plume management collection points to be operated specifically where monitoring indicates plume movement (e.g.; between two or more wells). This target-driven interception of leachate would result in less water volume requiring treatment.

Based on preliminary estimates of hydraulic conductivity for the saturated sand units (0.0018 cm/s mean) and well capture zone analysis, a well spacing in the order of 30-50 m is indicated (including overlap between well capture zones) for areas where the sand units occur. Well depths would probably range from 2.5 to 5.0 m below grade, with 0.75 m screens set to top of bedrock. Detailed spacings and system design will require more detailed analysis. In-situ pumping tests with observation wells and groundwater flow modeling (e.g., FLOWPATH® Visual MODFLOW) could be used to further evaluate the conceptual model of flow interactions, assess the effectiveness of potential remedial options and aid in design of the selected option (e.g., well spacing, trench configuration).

The decision whether to install all or some components of the remedial measure(s) must be carefully considered in development of this contingency plan. Results of the down-gradient assessment, schedule and location of landfill cells, characterization of leachate quality, monitoring plans, remedial system implementability (e.g., winter construction), and regulatory concerns should all be weighed in making this decision.

9.2 Groundwater and Surface Water Monitoring Programs

Comprehensive and effective groundwater and surface water monitoring programs will need to be developed and implemented prior to start-up of any landfilling at Site A. These monitoring programs must include water quality, water level and/or discharge (i.e., for surface water) measurements, and sediment quality. A critical component of these monitoring programs must be collection of seasonally representative baseline data prior to operation of the landfill, given the apparent existing impacts on Nine Mile River from existing up-gradient sources.

Conceptually, detailed design of the monitoring programs should carefully consider the following elements:

- number and position of monitor points

- collection of seasonally representative baseline data
- monitoring frequency
- leachate quality
- eventual selection of water quality "indicator" parameters
- consistent sampling protocols
- long-term data management
- monitor station maintenance and replacement, if appropriate
- installation of additional monitoring wells/stations, if appropriate

9.2.1 Key Monitoring Wells

A large number of groundwater and surface water monitoring points have been used for the hydrogeologic investigation of Site A and many of these points will be incorporated into the monitoring programs needed for Site A. The key wells for long term surveillance include those wells located at critical contaminant release pathways. During the initial years of operations, these include the down-gradient wells at monitor well nests MW-1, MW-2, MW-3; MW-4, MW-5, MW-6, MW-7, MW-8, MW-9, MW-20, and MW-21.

The short groundwater travel times to Nine Mile River, additional down-gradient hydrogeologic assessment, detailed RDF design, and possible installation of a contingency remedial measure(s), may require installation of additional groundwater or surface water monitoring stations. Perhaps during the first portion of Site A's operating life (e.g., quarter-life, third-life), a tiered monitoring system will be appropriate. Such a tiered system could provide both detailed monitoring data near operationally active areas and integration of this information with other data that is collected throughout the remainder of the site.

9.2.2 Monitoring Frequency

Establishment of adequate seasonally representative baseline monitoring data is especially critical to landfill development. Quarterly monitoring should be implemented for the first two years at Site A to provide an adequate seasonal record. Building upon the late spring - early summer data already collected as part of the detailed Site A assessment, the second monitoring event should be implemented in the fall of 1996. To avoid missing collection of this seasonally important data, the second sampling round should proceed even if review of the Site A detailed engineering reports have not been completed by some reviewers (e.g., NSDOE). Given the apparent impacts on Nine Mile River from existing up-gradient sources, it is in the Owner's long-term interest to establish an adequate baseline of seasonal data.

Monitoring frequency will be a particularly important element of the monitoring program design, given the estimated short groundwater travel times at Site A. At least two different monitoring frequencies will probably be required to adequately monitor potential groundwater and surface water impacts in the vicinity

of Site A during RDF operation. Monthly, quarterly and semi-annual/annual monitoring frequencies are expected for various groundwater and surface water monitoring points. For monitoring points in close proximity to operating or closed RDF areas, monthly monitoring may be required for shallow granite, surface water and possibly deeper granite monitoring points. Once seasonal baseline conditions are established, semi-annual or annual monitoring may be appropriate for water table wells within the sand till and clay till units. During the first portion of Site A's operating life, more distant granite wells and surface water stations may require less frequent monitoring, and results of the additional down-gradient hydrogeologic assessment should be used in determining the sample frequency of such stations.

9.2.3 Sampling Parameters

As indicated previously, the proposed RDF will represent a significant departure from past landfill operations in Nova Scotia and traditional landfilling operations in general. These operational changes are expected to result in substantial changes to "typical" municipal landfill leachate quality (see Table 9.1). At present, the specific nature of anticipated leachate quality is not known. Obtaining a better understanding of the expected leachate quality is important in establishment of analytical parameters that will be monitored. During design of the monitoring program this issue should be addressed through a combination of literature research, data from similar RDF facilities operated by the Owner, and landfill design information. Regular leachate quality monitoring is expected as part of the RDF operation and these results should be integrated into appropriate monitoring programs.

Once baseline conditions and initial operational features are determined, groundwater and surface water monitoring programs may make use a limited set of "indicator" parameters rather than complete analytical analyses to track chemical changes in site conditions. Traditional landfill indicator parameters have included: pH, alkalinity, conductance, hardness, chloride, nitrogen compounds (e.g., ammonia, nitrate), sulfate, total dissolved solids (TDS), suspended solids (SS), biological and chemical oxygen demand (BOD and COD, respectively), trace metals (e.g., iron, manganese), dissolved gases (e.g., oxygen, hydrogen sulfide), and microorganism (e.g., coliform bacteria). The degree to which all or some of these traditional indicator parameters will continue to be appropriate for the RDF leachate is not known, given the uncertain nature of its quality as previously discussed. Additional parameters (e.g., arsenic, uranium and radon) may also have to be considered to address real or perceived concerns. While some consideration of representative indicator parameters should be made during the monitoring program design, it is expected that selection of appropriate indicators will depend upon both on-going down-gradient monitoring results and leachate quality monitoring, and will be made after monitoring RDF activities for several years.

9.2.4 Other Issues

Several other items should also be addressed during the monitoring program design. Standard sample collection protocols should be established to minimize data variability introduced by use of different

Table 9.1 Typical Landfill Leachate Chemistry

Parameter	Chemical Concentration
pH	5-8
Alkalinity	200-5000
Total Solids	2000-5000
Soluble Salts (chloride, sulfate ions)	100-3000
COD	1000-30000
BOD	200-20000
Total N	20-1000
P	<1-10
Fe	50-800
Pb	1-10
Zn	25-250

Notes:

1. All parameters in mg/L except pH.
2. Leachate values from Henry and Prasad, 1991.
3. These parameters are from a municipal solid waste landfill with no significant waste diversion

9.3 Groundwater Supply Development Potential

Probably not necessary - just drill a well!

In comparison to Nova Scotia ranges, Halifax County wells typically exhibit a slightly smaller specific capacity, and geometric mean well yield potential.

Based on the current groundwater quality information, it is concluded that good quality groundwater sufficient for potable use could be obtained from the granite bedrock aquifer along the watershed divide up-gradient of the RDF. Minimal water quality treatment is anticipated. However, potential constraints may include iron and manganese in excess of aesthetic drinking water guidelines, and, to a lesser extent,

radon, uranium and arsenic. All of these parameters can be treated with commercially-available water treatment equipment.

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Suite 108, 3845 Dutch Village Road
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To: *CHRIS SHORTAN*
Company:

Fax:

Date:

Pages: *11* (including this one)

Message:

Comments on JWA Report.

are these going to be properly abandoned or sent to landfill?
\$23,000/well

All soil samples recovered were stored in moisture tight containers and returned with the rock core to our Dartmouth laboratory for classification and testing. Samples remaining after testing will be stored until further direction is obtained.

Within the foot-print of the RDF thirty-one piezometers were installed in the bedrock and seven piezometers were installed in the overburden. The piezometers are designated temporary monitoring wells RD-1 to RD-31 and are located at the corresponding borehole locations (Figure 1.2). PVC casing with diameters of 25 mm and 51 mm were used for the piezometer construction. Details of the piezometer construction are shown on the Borehole Records in Appendix 1a.

Borehole and test pit elevations and locations were surveyed by Dexter Construction Company Limited. Elevations are given with reference to Geodetic datum.

2.2.3 Previous Work

Ten auger probes were excavated as part of the intermediate investigation in 1995. Detailed descriptions of the soils encountered are included in the auger probe records in Appendix 1c.

2.3 Hydrogeological Investigations

2.3.1 Approach

The hydrogeological program was carried out in two stages. Stage 1 investigation, conducted between April 19 and May 24, 1996, involved drilling all of the deepest monitor wells (15 m bedrock holes) and selected bedrock holes first, at 12 locations around the site. Packer and hydraulic testing were done, water samples were collected for inorganic chemistry characterization, and water levels were measured. The information was combined with hydrogeological data from the geotechnical program, and a preliminary characterization of the hydraulic properties of the site was made.

The preliminary information was presented to the Project Technical Manager and the decision was made to proceed with Stage 2. Information collected from Stage 1 provided critical information for the design of Stage 2 monitor well nests, screen and sand pack settings, and individual monitor well depths, as well as preliminary information for the RDF design components. Stage 2 investigations, carried out from May 27 to July 12, 1996, involved construction of the remaining shallow monitor wells and monitor well nests, detailed water quality sampling, hydraulic testing, surveying, and stream sampling.

Temporary RDF Monitor Wells

The 38 monitor wells within the RDF foot-print had variable diameters (51 mm, 38 mm and 25 mm); typically had 0.6 m thick bentonite seals; were not grouted to ground surface; were completed within 0.2 m of grade; and were sealed with locking "J-plug" well seals.

Grout should be pumped down hole before each of the temporary monitor well casings and screens are removed, and the boreholes permanently sealed. An approved grout mixture should be emplaced with a pressure grouting system.

2.3.3.3 Monitor Well Development

The purpose of well development is to remove drilling fluids, solids, or other particulates which may have been introduced into the aquifer or deposited on the boring wall during drilling. Properly developed monitoring wells enable the collection of groundwater samples which are chemically and physically representative of the aquifer.

Prior to hydraulic testing or sample collection, each well was subjected to vigorous pumping with a Hydrolift III inertial pumping system to remove as much water as practical, with a minimum of three casing volumes of groundwater, from each newly constructed well. Table A6.1, Appendix 6 summarizes combined pre-construction and post-construction volumes of groundwater removed during the development process, and observations for hydraulic testing. The combination of borehole pumping prior to monitor well installation, and the post-construction well development should minimize water quality influences from drilling and well construction.

2.3.4 Hydraulic Testing

More than 135 hydraulic response tests were performed on the perimeter wells and RDF wells. Three types of hydraulic tests were performed to estimate hydraulic conductivity at each borehole:

- Water level recovery measurements were made after well development on all open bedrock boreholes (hydraulic conductivity is representative of the saturated borehole interval).
- Multiple packer injection tests were performed on the deepest hole at each location (is representative of depth-specific intervals).
- Slug tests were performed on each completed monitor well (Hydraulic conductivity is representative of the sand-packed zone).



in the drumlin consists of stiff to hard, reddish brown, sandy clay to clayey sand, with gravel and numerous cobbles and boulders. The sandy clay till of the drumlin extends towards the southern sedimentation pond where the sandy clay till underlies the layer of cobbles and boulders with a matrix of sand.

Twenty-six grain size analyses were performed on samples taken during the testpit and borehole investigation in the drumlin. The gradation ranged from a silty sand to a sandy clay with gravel. The average of the grain size analysis gave 13% gravel, 39% sand, and 48% silt and clay sized particles. The gradation ranged from 3- 25% gravel, 31- 47% sand, and 39-57% silt and clay sized particles. Results of hydrometer testing on twenty-five samples gave an average of 12% clay sized particles with a range of 1-19%. The fine portion of the soils had a plasticity index which ranged from non-plastic to 17 with an average of 10 for the thirty-five samples tested. The soil classification ranged from silty sand (ML) to sandy clay with gravel (CL). Moisture contents ranged from 8 to 14% with an average of 11% for the forty-seven samples tested.

Hydraulic conductivity testing was performed in the laboratory for two remolded samples from BHB1 and BHB5 in the drumlin. The hydraulic conductivities were 2×10^{-8} cm/s and 2×10^{-7} , cm/s respectively. Hydraulic conductivity tests were also performed at five points on the Standard Proctor curve for six samples from the drumlin to establish a moisture/density/hydraulic conductivity relationship. The results of all hydraulic conductivity tests are summarized in Table 3.4. Plots of hydraulic conductivity versus moisture content and dry density versus moisture content are included in Appendix 4d.

The fine portions of three sandy clay till samples were tested for clay mineralogy using X-Ray powder diffraction. No evidence of significant clay minerals was found in the sandy clay till samples. The predominant minerals in the sandy clay till samples included quartz, albite, muscovite and orthoclase. The results of X-Ray powder diffraction are summarized in Table 3.5.

3.5 Silty Sand Till

The western portion of the site is overlain by compact to very dense brown silty sand till with gravel, and varying amounts of cobbles and boulders. The till is consistent with a granite till. The thickness of the silty sand till in the area of the RDF ranged from zero to greater than 4.6 m in TP-107, with an average of 1.3m. The silty sand till extends west towards the northern sedimentation pond where the till underlies the sand and cobbles and boulders layers.

Laboratory testing is summarized in Appendix 4a. The grain size curves and soil classifications according to the Unified Soil Classification System for all samples tested are shown in Figures A4.b1 to A4.b42 in Appendix 4b. Plasticity charts for all samples tested are included as Figures A4.c1 to A4.c11 in Appendix 4c. Results from these tests show that the till in the western portion of the site may be classified as sandy silt (ML) to silty sand (SM) with varying amounts of cobbles and boulders.

The optimum moisture content for minimum hydraulic conductivity ranged between 8 and 10 per cent.



The bedrock granitic definition does not impact the site design or expected performance
predominantly underlain by monzogranite. Section 3.6 presents more details on bedrock geology and structure.

4.1.5 Hydrogeology

Groundwater flow patterns in Nova Scotia generally follow the topographic drainage patterns. Groundwater, which is derived from recharging precipitation both locally and in up-land areas, flows laterally through the overburden and bedrock aquifers to discharge points in springs, swamps, streams and lakes. The regional groundwater flow direction is north to south following the regional topography. In Nova Scotia, groundwater flow pathways are short, generally less than a few kilometres (Lin 1975) from point of recharge to points of discharge in streams, lakes and wetlands. Groundwater in overburden deposits and shallow bedrock (e.g., less than 30 m below grade) is generally recharged within the local watershed. Deep groundwater flow may be recharged in highlands areas along South Mountain, and is expected to discharge into the Atlantic Ocean.

Groundwater flow in granite bedrock is primarily through interconnected fractures, joints and faults (i.e., secondary porosity) developed in the upper few hundred metres of bedrock. The degree of fracturing, and groundwater flow potential, decreases with depth in granites. The upper few tens of metres of rock which were exposed to weathering and glacial action are typically highly fractured, and considered to be the pathway for groundwater movement.

secondary
Averaged hydraulic properties of the granite aquifer are best determined from pumping tests performed on domestic and commercial water wells completed within granite. Table 4.1 summarizes hydraulic properties and water supply development potential for granite aquifers in Nova Scotia. Granites in Nova Scotia typically exhibit geometric mean transmissivity, storage coefficient and hydraulic conductivity values of 1.1 m²/day, 5×10^{-4} , and 3.6×10^{-4} cm/s, respectively. Granite in Halifax County exhibits slightly higher average values for these parameters, possibly due to greater degree of fracturing associated with proximity to Meguma bedrock-granite contacts.

In comparison to the granite aquifer, fine-grained till units overlying the granite typically have lower hydraulic conductivities than the granite. No water supply pumping tests are available for these units.

4.1.6 Water Supply Development Potential

Most rural residents and about 50 % of the total population of Nova Scotia rely on groundwater from individual drilled or dug wells for potable water supply. Due to its widespread occurrence, the granite aquifer, although considered a poor water supply source for commercial and industrial applications, remains an important rural water supply resource.

6.0 PRELIMINARY CONTAMINANT FATE AND MOBILITY ASSESSMENT

This section describes the probable plume migration pathways which would occur if there was a leak in the landfill liner and identifies the natural attenuation mechanisms applicable at this site.

6.1 Probable Plume Migration Pathways

The critical release pathway for contaminated seepages which may be released from this engineered RDF is the upper few metres of fractured granite bedrock underlying the RDF liner system, and/or the more permeable sandy surficial deposits immediately west of the RDF.

Based on groundwater flow directions, the main vector of groundwater transport from the RDF is west and southwest via bedrock depressions situated north and south of the drumlin hill. The clay materials comprising this hill will likely intercept westward movement of groundwater, and divert flow towards the wetlands to the north or south of the drumlin.

During the early years of land filling, all seepage movement should be west to wetlands and streams in the vicinity of MW-20, MW-3 and MW-21 and Sedimentation Pond No. 1. The up-ward vertical hydraulic gradients in this area should limit plume migration to the upper bedrock or overburden units.

The primary receptor to potential release of leachate from this RDF is the Nine Mile River and intervening associated wetlands. The organic matter associated with wetlands will provide some attenuation as plumes discharge to the surface water environment.

Nine Mile River has significant flows and some degree of alkalinity and a pH in the order of 6.1. If leachate enters Nine Mile River it is expected to discharge at relatively slow rates along a wide front, and will likely pass through associated wetlands prior to reaching the river. Contaminant attenuation at Nine Mile River will involve processes such as dilution, dispersion, and various redox reactions as the relatively anoxic groundwater plumes enter a highly oxidizing surface water environment.

A typical subsurface contaminant release and migration scenario at this locality would be as follows: Contaminated seepage, if released from the RDF liner system, would be expected to migrate downward into the fractured granite bedrock, and then flow horizontally westward along the upper few metres of weathered and fractured bedrock. Based on the apparent up-ward net groundwater flow directions west of the RDF, seepage would most likely discharge to the wetlands west of the RDF prior to reaching Nine Mile River, and then migrate to Nine Mile River in the overburden or as direct overland flow.

MUST INCLUDE A LEAK-IN
PARAGRAPH - double liner
- extremely low likelihood
of escape & monitoring in leachate
extractor pump, leak detector pump. However, if any
release should unlikely occur...

7.0 CONCLUSIONS

7.1 Geology

Three hydrogeological units were identified on the RDF - sandy clay till, sandy till, and granite bedrock. Each unit offers different capacity to transmit, and to naturally contain and attenuate potential leachate seepages.

- The best capacity to contain and attenuate leachate is provided by the sandy clay till which overlies the eastern and up-gradient portions of the RDF (Figure 8.1). The combination of thick overburden (1.2 to 10.4 m with an average thickness of 3.4 m), high soil pH (mean 6.6), alkaline groundwater associated with these materials, relatively high inorganic carbon content (2 %), measurable organic carbon content (mean 0.55 %), and low in-situ (10^{-6} cm/s) and moulded (10^{-6} to 10^{-8} cm/s) hydraulic conductivity suggests the fine-grained materials on Site A should provide a reasonable degree of natural attenuation for leachate, *and as such provide a further level of protection in addition to the engineered liner at the site.*
- The silty sand and sand and gravel till units overlie the central and down-gradient portions of the RDF. The sandy till is relatively thin, ranging from nil over the central portions of the RDF, increasing to 4.6 m along the toe areas near the drumlin and wetlands and, averaging 1.3 m over the RDF. Due to its moderately high hydraulic conductivity (range 2×10^{-4} to 2×10^{-2} cm/s mean 2×10^{-3} cm/s), and lower proportions of clay minerals and cation exchange capacity, this material offers minimal natural containment and treatment capacity, limited to dilution and dispersion along the flow path.
- The shallow fractured granite bedrock unit also offers minimal natural attenuation capacity. Granites exhibit a wide range of K (range $<1 \times 10^{-6}$ to 3×10^{-2} , geometric mean 4.9×10^{-4} cm/s) and typically contain minimal clay or carbonate mineralization, and groundwater can migrate relatively unchanged through the rock mass.

7.2 Geotechnical

- Overburden thickness beneath the RDF ranged from nil (at bedrock outcrops) to 10.4 m, with an average thickness of 2.2 m. Approximately 22% of the site exhibited < 1 m of overburden thickness. These areas, and identified areas of bedrock exposure must be considered in the subgrade preparation and liner construction.
- Depth to static water table beneath the RDF ranged from ground surface to 5.6 m below grade, averaging 1.4 m. Attention to shallow groundwater seepage will be required in landfill subgrade and liner construction.

- Scale house, 10 m x 8 m
- Administration building, 25 m x 8 m
- Maintenance building, 10 m x 24 m

All buildings will be slab on grade construction with concrete frost walls and will be heated. It is anticipated that the slab elevation will be near existing grade with minor grading required. Depending on the final location and elevation of the buildings, footings may be founded in either glacial till, bedrock or both. To minimize differential settlement in the instance that footings are founded on both bedrock and till, a net allowable bearing pressure of 150 kPa is recommended for footings on undisturbed till or on a till/bedrock interface. Footings on properly-prepared bedrock may be designed to a bearing pressure of 1000 kPa.

Footing bases in the till may experience some softening due to the proximity of the groundwater table. Areas which become softened should be over excavated about 300 mm and backfilled with gravel such as 100 mm minus granular material.

All footings on soil should have a minimum soil cover of 1.2 m for frost protection and provisions for adfreeze protection at the perimeter walls. For footings on bedrock a minimum soil cover of 0.6 m is recommended for frost protection. Walls can be backfilled with site material provided they do not act as a retaining wall and the slab is above exterior grade. If the slab is founded below grade, the backfill should consist of gravel and drainage should be provided.

For design of the slab on grade it is recommended that a subgrade modulus of 45 MN/m³ be used for the site tills. If the subgrade is built up using a minimum of 300 mm of well-compacted rock fill a subgrade modulus of 60 MN/m³ can be used. The slabs should be bedded on a minimum of 150 mm of Class "B" gravel or clear stone. If fill is required to achieve the final subgrade elevation, the site tills are suitable if placed in lifts no greater than 250 mm loose thickness and compacted to at least 100 percent of Standard Proctor density.

It is understood that the graveled yard around the buildings will be used for parking and equipment manoeuvring. Based on the subgrade conditions at the site, it is recommended that the traffic areas be constructed using a minimum of 300 mm of rock fill as a subbase and 150 mm of Class "C" or Class "B" gravel as the surface course.

8.4 Disposal Cell

Due to the high water table and upward hydraulic gradients under the proposed foot-print of the RDF, an underdrain system will be required for hydraulic control. ~~This will also serve as a line of defense should a leak in the landfill liner occur.~~

DELETE



Slopes of no steeper than 3 horizontal to 1 vertical are recommended for the sedimentation ponds. The exterior slope should be provided with a granular toe drain to prevent seepage of water at the face of the slope. The toe drain should consist of a gravel blanket which extends into the slope at least one half the distance from the crest of the slope to the toe. Positive drainage from the blanket should be provided.

The interior slopes of the ponds should have a minimum cover of 300 mm of rock fill for stability and erosion protection. Exterior slopes should be protected from erosion with a vegetation cover or granular surfacing.

8.7 Fire Pond

It is understood that water for fire fighting will be stored on site in a dedicated fire pond which will be lined with a flexible membrane liner to retain an adequate supply of water. Site tills will be suitable for construction of the perimeter dykes and should be constructed as noted above for the sedimentation ponds. If the ponds are excavated below grade, under drains should be provided underneath the FML, to protect it from upward heads of water. Toe drains will not be required for the dykes.

8.8 Leachate Holding Tank

An above ground leachate holding tank having a capacity of about 500,000 litres is to be located at the west side of the site. The tank is to have a diameter of about 10 m. Soil conditions are expected to consist of 1 to 4 m of dense silty sand till with cobbles and boulders overlying bedrock. The tank will be located in a containment area surrounded by earth dykes and lined with 300 mm of low permeability soil. The perimeter dykes and liner on the floor can be constructed using the sandy clay till from the site and should be compacted in lifts no greater than 300 mm and compacted to at least 98% of Standard Proctor density. The surface should be protected with a layer of gravel at least 150 mm thick to prevent erosion and loss of moisture. A concrete ring foundation is anticipated for the tank base. Bearing pressures from the tanks are expected to be about 75 kPa. Settlements associated with this pressure would not exceed 10 mm and the factor of safety against an overall bearing capacity failure would be at least 3. The ring foundation should be backfilled with a well graded gravel such as Class "C" and should be provided with positive drainage. The ring wall should be designed using at rest earth pressures using an earth pressure coefficient of 0.5 and a unit weight of the fill of 22 kN/m³. The surcharge effects from the loaded tank must be incorporated into the lateral pressure on the ring foundation.

200,000 gal = 850,000 L

9.0 HYDROGEOLOGICAL RECOMMENDATIONS

Based on Site A hydrogeologic characteristics and potential groundwater contaminant pathways, two principal recommendations, development of a leachate interception system contingency plan and detailed design of a groundwater monitoring network are presented. These recommendations are discussed in more detail below.

9.1 Leachate Interception System - Contingency Plan

Calculated groundwater velocities indicate potential exists for relatively rapid migration of groundwater from the RDF to Nine Mile River. Such groundwater could migrate to Nine Mile River via the fractured granite; discharge to surficial units; initially migrate through the granite aquifer and discharge into down gradient wetland areas or a combination of the above. Estimated groundwater travel times of as little as 94 days in the fractured granite have been calculated from the toe of the RDF to Nine Mile River. Short-circuiting of groundwater flow via adjacent wetlands could significantly reduce this travel time. It will be important to minimize the time-lag between detection of groundwater contamination and implementation of measures designed to protect Nine Mile River, given such short travel times.

In addition to the underdrain required for the hydraulic control under the RDF, it is recommended that a contingency plan for a leachate interception system be developed as a component of landfill development on Site A. Conceptually such a plan would include additional hydrogeologic assessment in the area between the RDF and Nine Mile River, design of appropriate remedial measure(s) to capture contaminated groundwater migrating from the RDF, and could also include prior installation of an appropriate remedial measure(s). Installation of a remedial measure(s), prior to any evidence of groundwater contamination, will probably be required on a contingency basis, given the short groundwater travel times. The need and justification for such a remedial approach should be specifically addressed in developing this contingency plan.

Detailed down-gradient hydrogeologic assessment between the RDF and Nine Mile River is required, since this area was not a focus for any previous Site A hydrogeologic assessment. This work will need to establish groundwater flow relationships between the fractured granite, existing surficial units, wetland areas and Nine Mile River. Groundwater contaminant transport to Nine Mile River entirely within fractured granite, or via discharge of contaminated groundwater to down-gradient surficial units and/or wetlands, must be established to effectively locate any required remedial measure(s). This assessment will likely include installation of monitoring wells, seepage meters, hydraulic testing (e.g., aquifer/pumping tests) and water level measurement monitoring.

A study of remedial options could assess the effectiveness of passive versus active systems such as interceptor trenches, french drainage systems and/or interceptor drive points/wells should these become

WHY is a contingency plan required? If not - Develop it!

sampling personnel. Specific procedures for incorporation of monitoring program data into the site data base should be considered to minimize loss of field and analytical data. Monitoring stations will require periodic maintenance to ensure collection of representative data and to expedite monitoring. Monitoring design should include procedures for monitoring station inspection, scheduled maintenance (e.g., well re-development), and replacement of stations, as appropriate. As site operations progress and conditions change, there may be need to modify the existing monitoring networks. The adequacy of existing stations should be specifically re-assessed on a regular basis (e.g., 3 to 5 years) to help assure collection of relevant monitoring data.

9.3 Groundwater Supply Development Potential

~~Drinking water~~ and wash water will be needed for any facilities on this site. This could come in the form of surface water associated with the Front End Processing Plant or an on-site groundwater supply. No investigations of on-site groundwater development potential have yet been carried out. Test drilling using air-rotary water well drills or equivalent would be needed to evaluate well yield potential for any on-site buildings associated with this RDF. It is anticipated that this work would be implemented as part of any site development stage, unless a surface source of potable water will be used.

Probably not necessary - just drill a well!

The granite bedrock is an important water supply source for rural areas of Halifax County, and supplies most of the residences in Goodwood, and points south. Table 4.1 summarizes well yield and hydraulic properties for 39 domestic and commercial water wells throughout Halifax County, and for 66 wells completed in granites throughout Nova Scotia (NSDOE Pumping Test Inventory, 1971-1995).

In comparison to Nova Scotia ranges, Halifax County wells typically exhibit a slightly smaller specific capacity, and geometric mean well yield potential.

Based on the above assessment, and extrapolation of the mean on-site granite hydraulic conductivity for a typical 61 to 90 m deep, 155 mm to 203 mm diameter well, cased through the upper 12 to 20 m of bedrock, domestic water supply wells capable of yields in the order of 20 to 90 L/min, with good quality groundwater should be possible in the immediate area. This is consistent with the range of yields reported for 38 pumping tests of wells completed in granite in Halifax county (NSDOE Pumping Test Inventory, 1973-1995). Drilled wells completed in this aquifer can be expected to yield between 4 and 230 L/min, (geometric mean 18 L/min), of good quality groundwater.

Based on the current groundwater quality information, it is concluded that good quality groundwater sufficient for potable use could be obtained from the granite bedrock aquifer along the watershed divide up-gradient of the RDF. Minimal water quality treatment is anticipated. However, potential constraints may include iron and manganese in excess of aesthetic drinking water guidelines, and, to a lesser extent,