University of Waterloo
Faculty of Environmental Studies

Determining Correlation Between Baseflow and Surficial Geology Using GIS

Conestoga-Rovers & Associates
Waterloo, Ontario

Prepared by:
Darren M. Cope
ID 00189393
2B Geography
January 10, 2003

??? Midwood Cres.
Waterloo, Ontario
N2L 5N4

January 10, 2003

Dr. Philip Howarth
Geography Department Chair
University of Waterloo
Waterloo, Ontario
N2L 3G1

Dear Sir:

This report was prepared for my 2B work report, and is titled “Determining Correlation Between Baseflow and Surficial Geology Using GIS.” This report was completed for Conestoga-Rovers & Associates, and is the second of four reports required by the Co-operative Education Program as part of my Bachelor of Environmental Studies Honours Co-op degree. This report attempts to find a correlation between stream baseflow levels and the underlying surficial geology type by using a Geographic Information System (GIS).

Conestoga-Rovers & Associates (CRA) is a worldwide firm providing services in engineering, environmental consulting, construction and information technology.

The GIS Group, in which I worked under supervisor Scott Bruce, is involved with the development of the e:DAT (Electronic Data Access Tool) GIS software which CRA provides for its clients.

This report was written entirely by me and has not received any previous academic credit at this or any other institution. I would like to thank David Smetana, of Conestoga-Rovers & Associates, for valuable assistance in choosing the scope and purpose of the report, as well as input and feedback on methodology. I would also like to thank Harold Miller of Conestoga-Rovers & Associates, for input on methodology, and Brian Verspagen, also of CRA, for his help in procuring data. I received no other assistance.

Sincerely,

Darren M. Cope
ID 00189393

Table of Contents

List of Figures

List of Tables

Summary

The purpose of this report is to determine if there is a correlation between stream base flow levels and the underlying surficial geology type. A methodology was developed using a Geographic Information System (GIS). Data from the Oak Ridges Moraine area of Southern Ontario, Canada was analyzed in ArcView 3.2 in order to determine if there is any correlation between the measured stream baseflow values and the surficial geologic unit.

The scope of this report is threefold. Firstly, this report introduces some background information regarding the Oak Ridges Moraine, and some theory behind baseflow monitoring by discussing previous literature. Secondly, data used during analysis is presented and discussed. Thirdly, this report develops and explains a methodology for determining correlation between stream baseflow levels and surficial geology type. The final goal of this report is to analyze the results obtained, and present conclusions.

Spatial data, including baseflow values, surficial geology, catchment areas and streams were analyzed in order to determine if there is a correlation between stream baseflows and the underlying surficial geology type. Results showed high correlations for some surficial geology types, and low correlation for others.

Conclusions made in this report are that more flow data points need to be analyzed in order to form sound judgments, and therefore all results obtained are questionable. Approximately half of the surficial geology types were found to be areas of recharge, and half of discharge. The areas of discharge tend to be located in the upstream portion of the watershed, while downstream areas are more likely areas of recharge.

1.0 Introduction

The Oak Ridges Moraine is an area of glaciofluvial and glaciolacustrine sediment deposited as an ice-margin feature by the Laurentide Ice Sheet at the end of the last glaciation in Southern Ontario, Canada (Dyke, 1999). The Oak Ridges Moraine is located in an East-West strip north of Toronto, running from Rice Lake in the East to the Niagara Escarpment in the West (Figure 1). The Oak Ridges Moraine is one of the most important groundwater resources in Canada (Cheng et. al., 2000), as approximately 250,000 people rely on the Moraine for their water supply (Dyke, 1999). For this reason, study of the water resources in the Oak Ridges Moraine area is of the utmost importance.

Conestoga-Rovers & Associates Ltd. (CRA), was hired to perform a base flow monitoring program in the Oak Ridges Moraine area—the York-Peel-Durham Baseflow Monitoring Program. This report was prepared at the same time as CRA's report for the above project (Conestoga-Rovers, 2002), using a different analysis procedure.

The object of this report is to determine if there is a correlation between stream base flow and the underlying geologic unit, as stated by Hinton et. al. (1998). Using GIS analysis techniques, this report attempts to prove Hinton's statement "Groundwater discharge is closely correlated with the surficial geology map units" (Hinton et. al, 1998). If this statement is correct, groundwater discharge will occur in certain geologic units, while recharge will occur in others. In order to test this hypothesis and determine in which geologic units discharge and recharge occurs, data from the Oak Ridges Moraine Project of the Terrain Sciences Division of Natural Resources Canada (Natural Resources

Canada, 2002), and Conestoga-Rovers & Associates, Ltd. (CRA), is integrated into a Geographic Information System (ESRI's ArcView 3.2) to perform spatial analysis.

The scope of this project will be limited to two specific watersheds, the Bowmanville-Soper Creek watershed, and the Oshawa Creek watershed (Figure 2). This was done in order to simplify the methodology.

2.0 Literature Review

2.1 Stream Flow Monitoring

Stream baseflow measurements are the "simplest method to estimate spatial distribution of groundwater discharge . . ." (Hinton, 1995). By taking measurements of stream baseflow using the velocity-area method and/or the volumetric method at many points along the course of a stream, it is possible to calculate discharge in the areas between sampling locations. In order to accomplish this, the baseflow measurements for each segment of the stream are subtracted from the total baseflow of all upstream segments to determine the net increase or decrease in flow in that stream segment (Hinton, 1995). An increase in baseflow identifies areas of groundwater discharge, while a decrease in baseflow identifies areas of infiltration and therefore recharge of groundwater.

2.2 Sources of Error

There are many possible errors associated with sampling stream baseflow. One is the assumption that all stream flow is a result of discharge. This, however, is not necessarily true, as extraction from the stream (e.g. for drinking water or irrigation), other forms of input (e.g. storm sewers, rainfall), and evaporation are not considered. Since these variables are often difficult to measure, or occur without knowledge, Hinton recommends that stream baseflow measurements are only "intended to be a preliminary tool for regional hydrogeologic investigations" (Hinton, 1995). In some cases, corrections are made to data when these events are recorded, and volume values are available (e.g. municipal water treatment plants, rainfall). In such a case, the value must be added or subtracted, as necessary, to all measured values downstream of the event in order to correct for the associated change in flow (Hinton, 1995).

Measurement error when sampling flow rates is unavoidable. Various measurement error values are given in the literature, although all are quite similar. Hinton states that measurement errors are 10% of the total discharge for velocity-area measurements, and less than 4% for volumetric measurements (Hinton, 1995). A later article by Hinton states a value of 5% for measurement error. (Hinton et. al., 1998). When dealing with measurement error, it is important to know that as the total flow increases, the magnitude of measurement error increases as well. The error may eventually become equal to or larger than the change in flow between successive measurement locations. When this occurs, it becomes impossible to determine if the change in flow is as a result of discharge/infiltration, or simply due to measurement error.

2.3 Geology

There are many different theories on the origin and formation of the Oak Ridges Moraine complex. One of the most accepted is presented by Barnett, et. al., in the paper *On the origin of the Oak Ridges Moraine*. This paper presents a model of the Oak Ridges Moraine area, and suggests that the moraine was formed in four stages. The first stage of formation is subglacial sedimentation, followed by subaqueous fan sedimentation, fan to delta sedimentation and finally ice-marginal sedimentation (Barnett, et. al., 1998). Underlying a large portion of the Oak Ridges Moraine is a layer of Newmarket Till. This till is an effective aquitard in the areas where it is present. However, in many areas the Newmarket Till has been eroded away, or incised by channels. In these areas, local aquifers may be present (Desbarats et. al., 2001).

3.0 Data

For this project, several different datasets were used. Below is a list of the data used and a brief discussion of each dataset.

3.1 Flow Data

The stream flow data that was used in this analysis was collected in the field by Conestoga-Rovers & Associates as part of the York-Peel-Durham Baseflow Monitoring Program. Stream flow data for the Bowmanville-Soper Creek watershed was collected on September 8th and 9th, 2002. Oshawa Creek data was collected on August 26, 2002. Flow data was measured in cubic metres per second, and this information is contained in a point theme that also contains x-y coordinates, and a unique location name for each sampling point. The flow values represent the base-flow level of the stream. Base flow is the level of stream flow assumed to come from groundwater discharge, and as such, does not include run-off from rainfall events or other external sources of water. To ensure rainfall had no affect on the results, all stream flow monitoring was performed at least three days from the last measured rainfall (Conestoga-Rovers, 2002). The flow monitoring locations are shown in Figures 4 and 6 for the Bowmanville-Soper Creek and Oshawa Creek watersheds respectively.

3.2 Catchment Areas

Stream catchment area data is contained in a polygon theme. Each polygon represents the catchment area of the stream flowing through it. These catchment areas were derived from a 10 metre resolution Digital Elevation Model (DEM) of the Oak Ridges Moraine area by Conestoga-Rovers & Associates for the purposes of the York-

Peel-Durham Baseflow Monitoring Program (Conestoga-Rovers, 2002). The catchment area data is shown in Figures 4 and 6 for the Bowmanville-Soper Creek and Oshawa Creek watersheds respectively.

3.3 Surficial Geology

The surficial geology theme is a polygon theme that represents the geology of the area. This data was obtained from the Geological Survey of Canada. This data was derived from line interpretations on 1:50 000 hardcopy base maps (Natural Resources, 2002). The dissolved Surficial Geology layer is shown in Figures 3 and 5 for the Bowmanville-Soper Creek and Oshawa Creek watersheds respectively.

3.4 Watershed Areas

A polygon layer was created showing major watersheds in the Oak Ridges Moraine area. This layer, similar to the catchment area layer, was derived from a 10 metre Digital Elevation Model (DEM) of the Oak Ridges Moraine.

3.5 Streams

A line theme representing streams in the study area was obtained for this analysis, but not directly used in any calculations. The stream data is illustrated in Figures 4 and 6 for the Bowmanville-Soper Creek and Oshawa Creek watersheds respectively.

3.6 Contour Lines

A line theme containing contour lines with a 10 metre interval was obtained for this analysis, but not directly used in any calculations.

4.0 Methodology

The following steps were performed using ArcView 3.2 from Environmental Systems Research Institute Inc. (ESRI).

4.1 Watershed Selection

The first step in this project was the selection of suitable watersheds in which to perform the analysis. Criteria for the selection of suitable watersheds included the distance from urban areas, completeness of catchment coverage, number of flow measurement locations within the watershed, and currentness of data. The Bowmanville-Soper Creek, and Oshawa Creek watersheds were chosen, as both areas are outside of the highly urbanized Greater Toronto Area, and have a large number of flow measurement locations which had recent flow values measured by CRA, as opposed to more dated measurements taken by other organizations. These factors made both the Bowmanville-Soper Creek and Oshawa Creek watersheds a suitable choice for the purposes of this study.

4.2 Clip

The second step was to perform a clip operation on all of the available data. The watershed boundaries for the two selected watersheds (Bowmanville-Soper Creek and Oshawa Creek) were selected from the watershed theme, and used as the "clip theme" in the clip operation. The streams, surficial geology, flow data, and catchment area themes were all used as "input themes" in the operation. The clip process removes all data from the "input theme" which falls outside of boundary represented by the "clip theme." This procedure was done in order to simplify the subsequent procedures by excluding all irrelevant data from outside the study watersheds. This step also helps to reduce overall file size and therefore processing time, and helps to avoid confusion during analysis.

4.3 Dissolve

Following the clip operation, a dissolve function was run on the surficial geology layer. The dissolve function merges all adjacent polygons with the same attribute into a single polygon, essentially "dissolving" polygon edges where they are not necessary. The surficial geology layer was dissolved based on the Unit field. The Unit field contains a numeric value representing the type of surficial geology in the associated polygon. This operation therefore ensures that the overall number of polygons is as small as possible, while still having all surficial geology data accurately represented. After the dissolve operation was run, surface areas for each polygon were recalculated.

4.4 Calculating Percent Composition

In order to calculate the percent composition, the next step performed was a Union of the newly dissolved surficial geology theme and the clipped catchment areas theme. The Union process combines the features from both themes into one single theme containing the attributes of both original themes. This process creates a unique polygon for each combination of catchment area and surficial geology that contains the attributes of both themes. Surface areas were calculated for each of these newly formed polygons. To calculate the percent composition of each catchment area, this newly calculated area was divided by the total area of each catchment, and the resulting value was multiplied by 100. This calculation gives a value (hereafter referred to as percent composition) representing the percentage of each catchment area that is associated with each surficial geology type. The results of this breakdown are presented in Table 1.

4.5 Calculating Change in Flow Values

To determine how much the flow changes in each catchment area, the flow values for the upstream point(s) (where the stream enters the catchment area) were subtracted from the flow values for the downstream point (where the stream exits the catchment area). This was done by displaying the necessary themes (streams, flow data points, catchment areas) and then visually determining which points lie upstream of the location in question. Points which were determined to be upstream had their flow value subtracted from the downstream point. The value calculated in this step is referred to as the derived flow in the remainder of the methodology. For points that had no upstream monitoring locations, it was assumed that all flow for that point came from the catchment area, so therefore the measured flow value was entered into the derived flow column.

If this methodology were to be performed with a large number of points, this step would become laborious, as well as prone to error. Ideally, an extension such as ESRI's ArcView Network Analyst could be used in order to automatically calculate which points are upstream of each selected point. This would greatly speed up the process, as well as reduce the chance of error.

4.6 Normalization

To compare the values across multiple catchments, it is necessary to normalize the derived flow values. To accomplish this, the derived flow for each catchment was multiplied by all of the percentage composition values for that catchment. This calculation gives a value that can be compared with other values for the same surficial geology type, regardless of the catchment area size.

5.0 Analysis

The normalized value calculated in the above step was used in all further steps to ensure that all flow values are independent of catchment area. In order to combine the results from each individual polygon into a single value for each surficial geology unit type, the attribute table was summarized based on geologic unit. The summarize operation essentially searches the selected field in the attribute table, and combines all duplicate entries into one row, giving summary statistics of the attribute fields from each item having that same value. In this case, the attribute table was summarized on geologic unit, and the average, minimum, maximum, standard deviation and variance were calculated for the normalized value field. The summarize operation also automatically calculates a “Count” field, which simply gives the number of records that were found for each unique value in the geologic unit field. The resulting table is included in this report as Table 2.

As can be seen in Table 2, approximately half of the geologic unit types present in the study area were areas of recharge (highlighted in blue in Table 2), and half are areas of discharge (highlighted in red in Table 2). A graphical interpretation of this is provided in Figure 7. Areas of high discharge are found in the central area of the Oak Ridges Moraine (ie. the Northern section of Figure 7), and discharge tends to decrease downstream, until recharge becomes predominant. Overall recharge also tends to increase further downstream. This result tends to agree with results obtained by Hinton in both the Humber River and the Duffins Creek watersheds (Hinton, M.J. et. al., 1998, Hinton, M.J., 1995).

The high standard deviation and variance values obtained for many of the geologic units show a very weak correlation between surficial geology and change in base flow in many cases. However, in areas of Moraine Deposits – medium-coarse sand, Glacial River Deposits – gravel, Moraine Deposits – fine sand, Glacial River Deposits – sand and gravel, and Halton Till, the Standard Deviation of the normalized values is relatively low (between 0.22 and 3.92). This shows that in all of the areas associated with these surficial geology types, there is a consistent change in base flow (ie. There is a high correlation between baseflow values and surficial geology unit). However, in the other areas, there is much greater deviation, with standard deviation values ranging to 16.23. These high standard deviation values reflect a low correlation between stream baseflow and surficial geology.

All surficial geology units have at least one polygon which was identified as an area of recharge, and one identified as an area of discharge (see Minimum and Maximum fields in Table 2). This is exemplified by the Glacial Lake Deposits - sand and gravel type, which is has a Minimum value of -27.7946 and a Maximum value of 0.5968. This may be due to the fact that there are factors other than surficial geology (e.g. slope, evaporation rates, etc.) influencing the change in baseflow in any given area, and the effects of the surficial geology may not be significant enough to compensate for these other factors.

6.0 Conclusions/Recommendations

- Approximately half of the surficial geology types are areas of recharge (highlighted in blue in Table 2 and Figure 7), and half are areas of discharge (highlighted in red in Table 2 and Figure 7)
- Discharge rates tends to be highest in the upstream portions of streams, and decrease in a downstream direction – eventually to the point of recharge. Recharge also tends to increase in a downstream direction (See Figure 7)
- Overall results are questionable, possibly due to the small number of flow data points used in the analysis. More flow data points should be used to ensure the sample is large enough on which to base sound conclusions
- Standard Deviations for some surficial geology units are relatively low, while others are quite high (see Table 2)
- Software such as ESRI's Network Analyst extension for ArcView 3.2 would greatly aid in the calculation of derived flow values by automating the calculations, and therefore increasing speed and accuracy of the procedure. This would enable many more points to be processed, and therefore more reliable results could be obtained
- Factors other than surficial geology (e.g. slope, evaporation, etc.) may have an impact on changes in baseflow

7.0 Acknowledgements

I would like to thank the following people for their help in the creation of this work report: David Smetana, of Conestoga-Rovers & Associates, for valuable assistance in choosing the scope and purpose of the report, as well as input and feedback on methodology; Harold Miller of Conestoga-Rovers & Associates, for input on methodology; Brian Verspagen of Conestoga-Rovers & Associates for procurement of necessary data; and Cathy Cope for proof-reading and input on style.

References

Barnett, P.J., Sharpe, D.R., Russell, H.A.J., Brennand, T.A., Gorrell, G., Kenny, F., & Pugin, A. (1998). On the origin of the Oak Ridges Moraine. *Canadian Journal of Earth Sciences, 35(10),* 1152-1167.

Conestoga-Rovers & Associates. York Peel Durham groundwater management strategy study Aquifer characterization study (Stream baseflow assessment program) Draft, (2002). Unpublished.

Desbarats, A. J., Hinton, M.J., Logan, C. E., & Sharpe, D R. (2001). Geostatistical mapping of leakance in a regional aquitard, Oak Ridges Moraine area, Ontario, Canada. *Hydrogeology Journal*, 9(1), 79-96.

Dyke, L. (1999). Regional groundwater and stream chemistry survey, Oak Ridges Moraine, Ontario. *Current Research* 1999-E; Geological Survey of Canada. 111-121.

Hinton, M.J. (1995). Measuring stream discharge to infer the spatial distribution of groundwater discharge. *Geological Survey of Canada Contribution Number 38595*.

Hinton, M.J., Russell, H.A.J., Bowen, G.S., & Ahad, J.M.E. (1998). Groundwater discharge in the Humber River watershed. *Geological Survey of Canada.* available from http://sts.gsc.nrcan.gc.ca/orm/pdf/Hinton_98_1.pdf.

Natural Resources Canada. (2002). Oak Ridges Moraine. Retrieved Dec.12, 2002, from http://sts.gsc.nrcan.gc.ca/orm/

Sharpe, D.R., Dyke, L.D., Hinton, M.J., Pullan, S.E., Russell, H.A.J., Brennand, T.A., Barnett, P.J., & Pugin, A. (1996). Groundwater prospects in the Oak Ridges Moraine area, southern Ontario: Application of regional geological models. *Current Research* 1996-E; Geological Survey of Canada. 181-190.

Figures

Figure 1: Location of the Oak Ridges Moraine

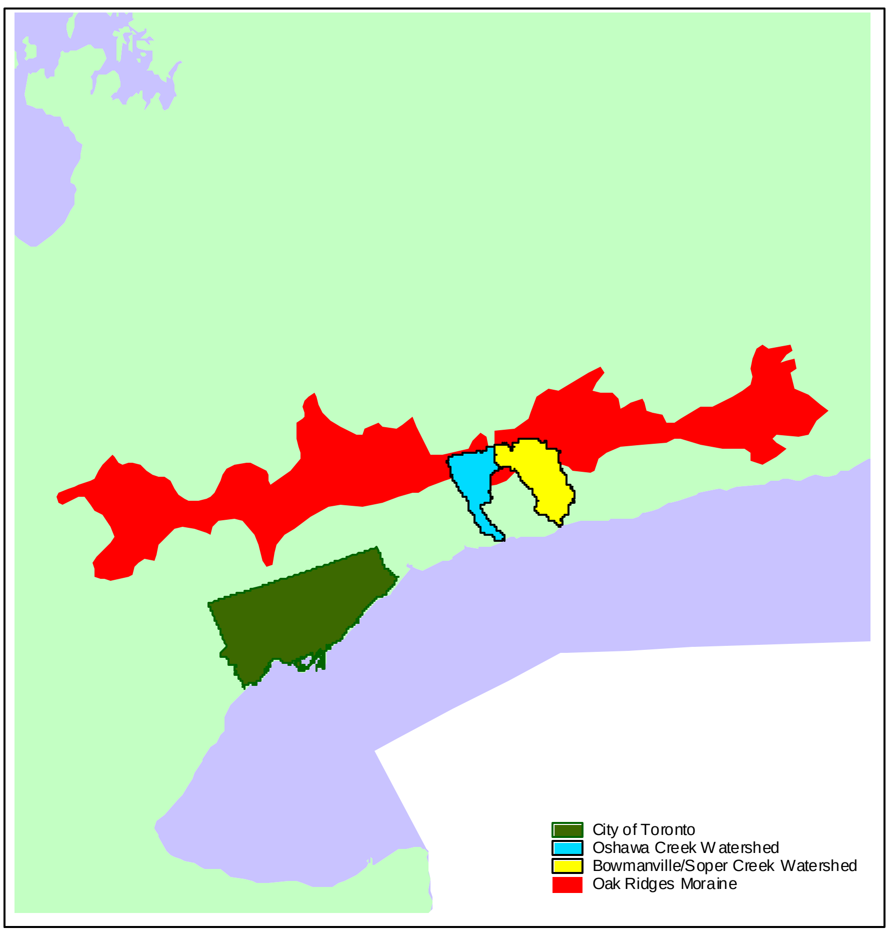

Figure 2: Location of Bowmanville/Soper Creek and Oshawa Creek Watersheds

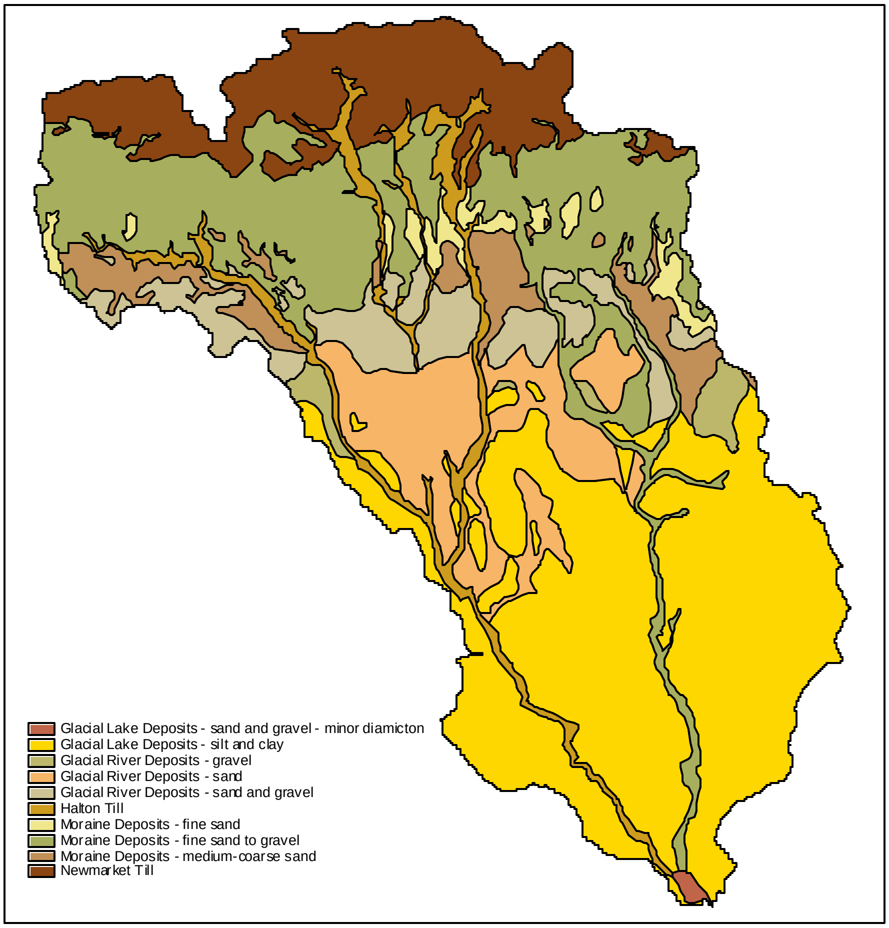

Figure 3: Surficial Geology Data (Bowmanville/Soper Creek Watershed)

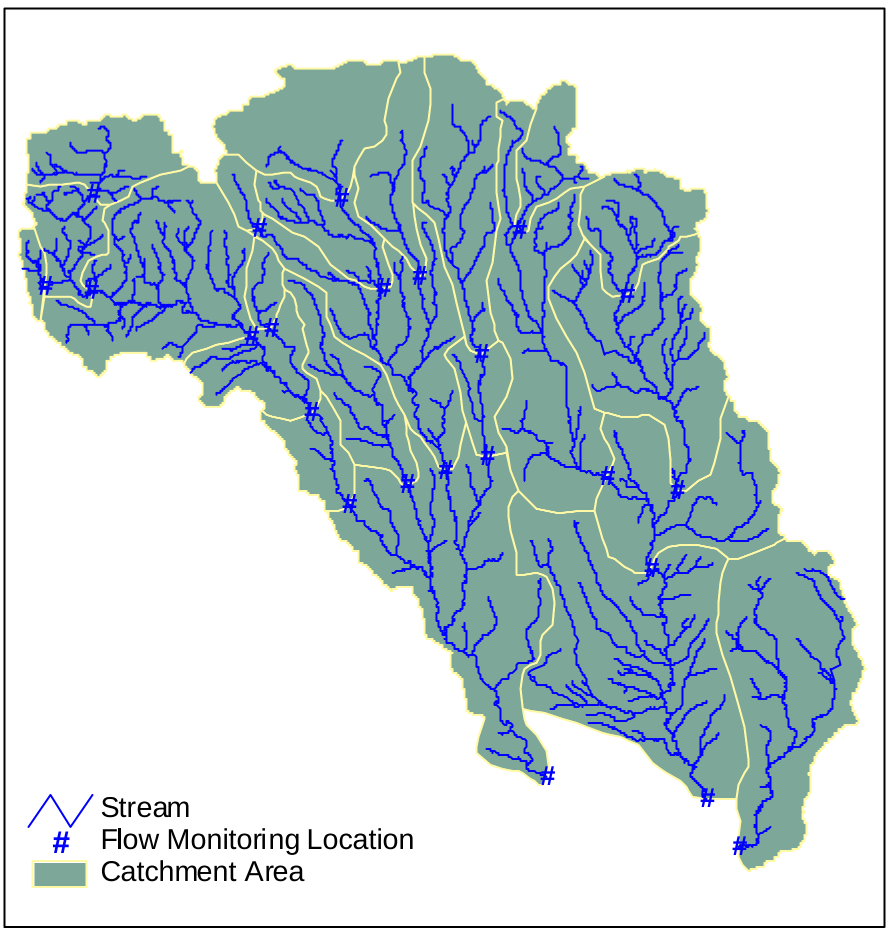

Figure 4: Catchment Areas and Flow Monitoring Locations (Bowmanville/Soper Creek Watershed)

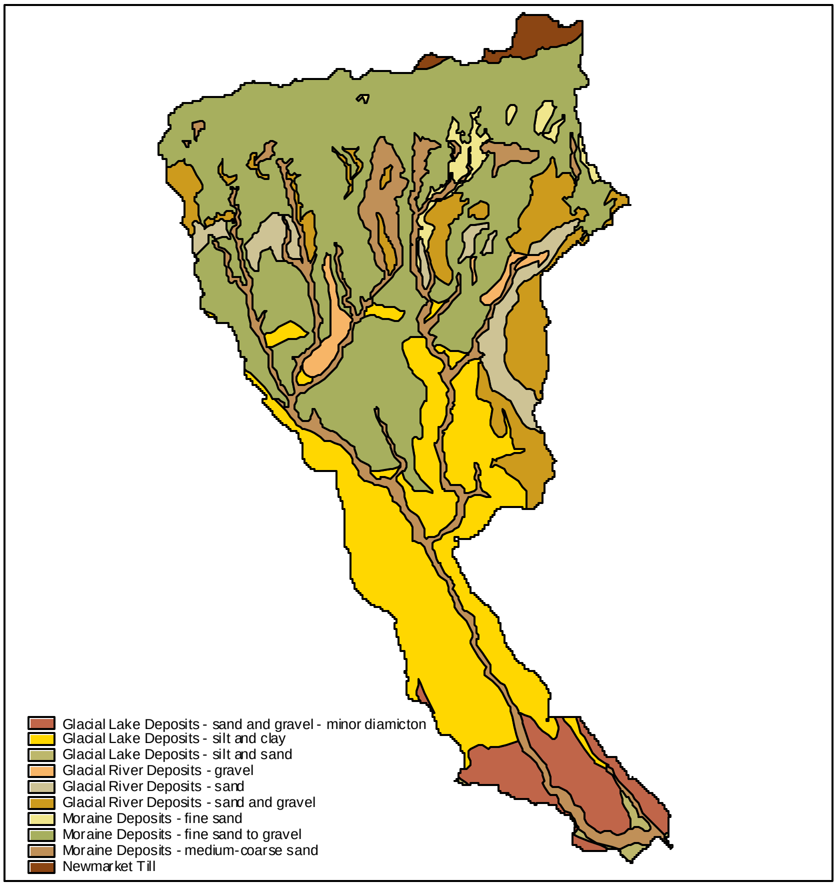

Figure 5: Surficial Geology Data (Oshawa Creek Watershed)

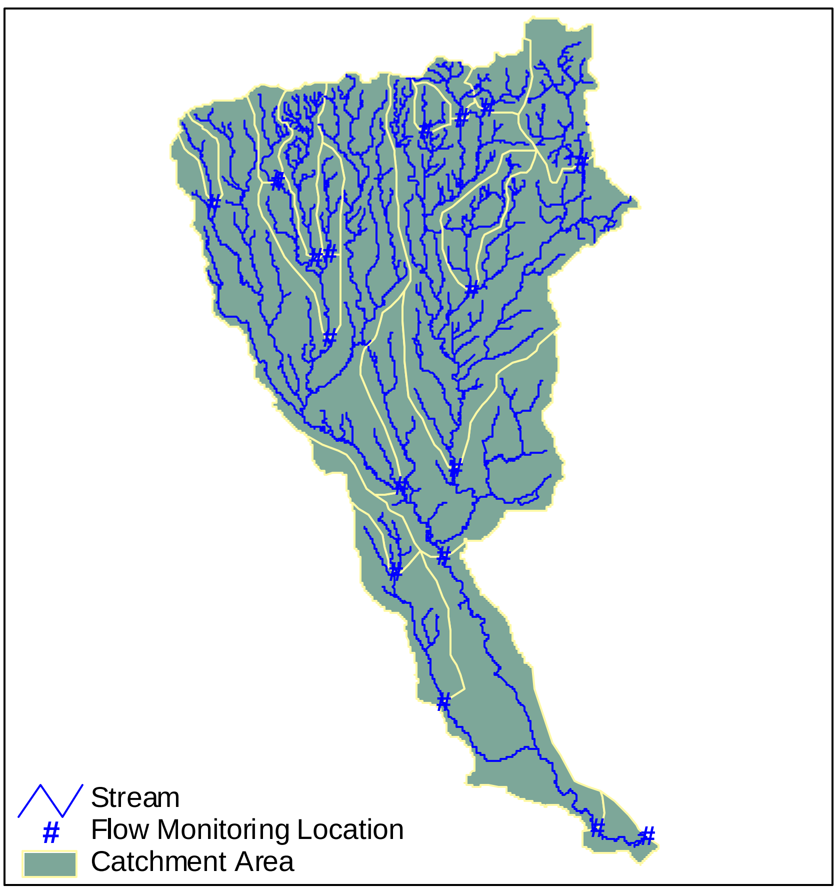

Figure 6: Catchment Areas and Flow Monitoring Locations (Oshawa Creek Watershed)

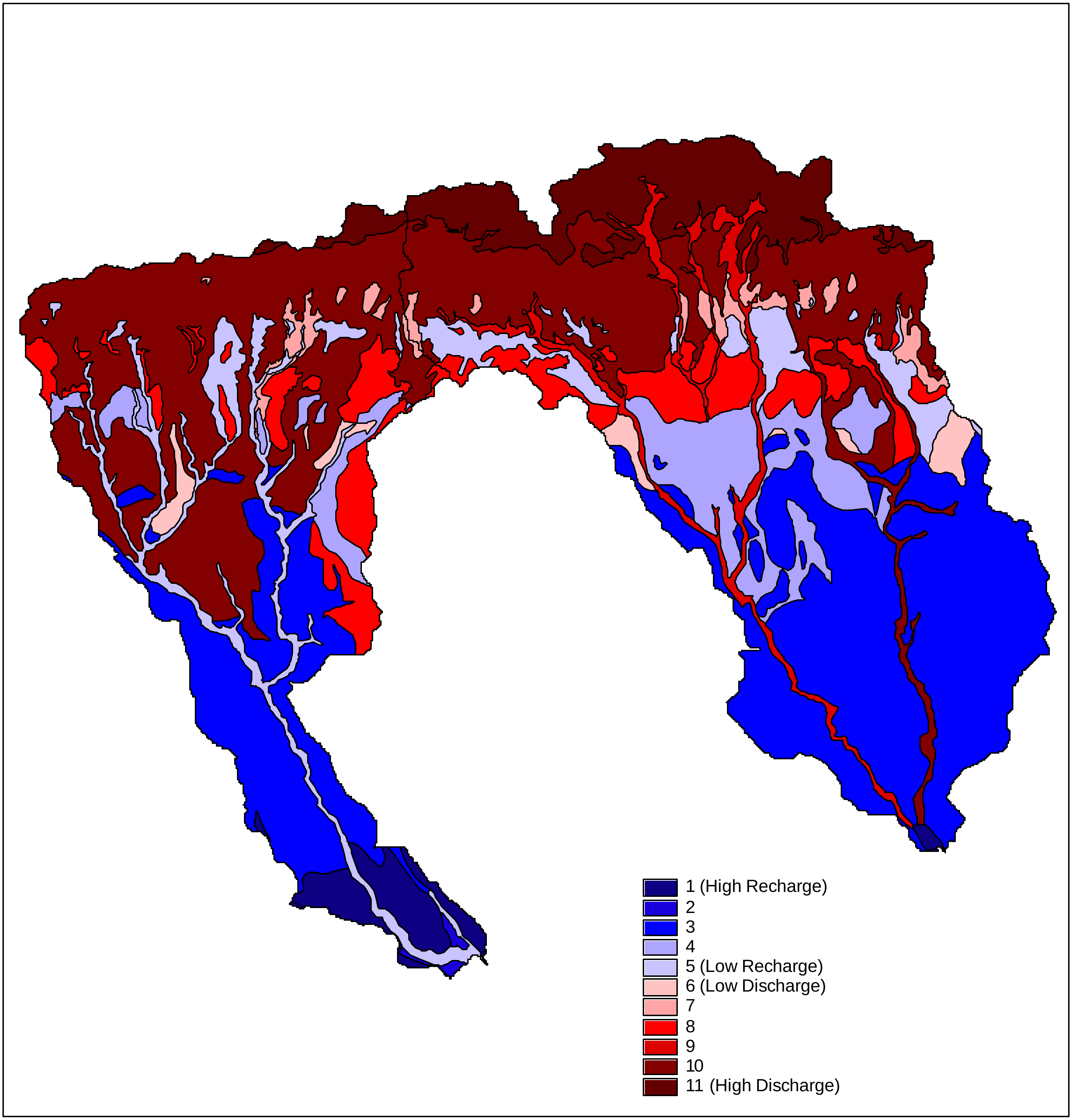

Figure 7: Surficial Geology by Rank (Bowmanville/Soper Creek and Oshawa Creek Watersheds)

Tables

Table 1: Percent Composition of Catchment Areas

Catchment ID	Surficial Geology Type	% of Catchment Area
OSH-005		
	Glacial Lake Deposits - silt and clay	5.60
	Glacial River Deposits - gravel	3.60
	Glacial River Deposits - sand	2.90
	Glacial River Deposits - sand and gravel	5.50
	Moraine Deposits - fine sand	0.10
	Moraine Deposits - fine sand to gravel	68.40
	Moraine Deposits - medium-coarse sand	14.00
	OSH-005	**100.10**
OSH-006		
	Glacial Lake Deposits - silt and clay	11.10
	Glacial River Deposits - gravel	2.20
	Glacial River Deposits - sand	8.10
	Glacial River Deposits - sand and gravel	15.90
	Moraine Deposits - fine sand	5.50
	Moraine Deposits - fine sand to gravel	43.70
	Moraine Deposits - medium-coarse sand	13.60
	OSH-006	**100.10**
OSH-008		
	Glacial River Deposits - sand	6.90
	Glacial River Deposits - sand and gravel	31.90
	Moraine Deposits - fine sand	0.10
	Moraine Deposits - fine sand to gravel	50.30
	Moraine Deposits - medium-coarse sand	10.90
	OSH-008	**100.10**
BOW-002		
	Glacial Lake Deposits - silt and clay	3.92
	Glacial River Deposits - gravel	0.82
	Glacial River Deposits - sand	19.66
	Glacial River Deposits - sand and gravel	40.64
	Halton Till	16.06
	Moraine Deposits - medium-coarse sand	18.91
	BOW-002	**100.01**
BOW-005		
	Glacial Lake Deposits - silt and clay	19.25
	Glacial River Deposits - gravel	38.18
	Glacial River Deposits - sand	24.87
	Glacial River Deposits - sand and gravel	7.06
	Halton Till	10.65
	BOW-005	**100.01**
BOW-010		
	Halton Till	12.34
	Moraine Deposits - fine sand	2.41
	Moraine Deposits - fine sand to gravel	31.60
	Newmarket Till	53.66

Catchment ID	Surficial Geology Type		% of Catchment Area
		BOW-010	**100.01**
S-075			
	Moraine Deposits - fine sand		2.18
	Moraine Deposits - fine sand to gravel		86.51
	Moraine Deposits - medium-coarse sand		1.16
	Newmarket Till		10.16
		S-075	**100.01**
BOW-003			
	Glacial River Deposits - sand		10.80
	Glacial River Deposits - sand and gravel		28.14
	Halton Till		6.29
	Moraine Deposits - fine sand		8.20
	Moraine Deposits - fine sand to gravel		39.70
	Moraine Deposits - medium-coarse sand		6.48
	Newmarket Till		0.39
		BOW-003	**100.00**
BOW-004			
	Glacial River Deposits - sand		35.54
	Glacial River Deposits - sand and gravel		37.74
	Moraine Deposits - fine sand to gravel		26.72
		BOW-004	**100.00**
BOW-006			
	Glacial River Deposits - gravel		0.25
	Glacial River Deposits - sand		1.27
	Glacial River Deposits - sand and gravel		39.99
	Halton Till		13.00
	Moraine Deposits - fine sand to gravel		23.36
	Moraine Deposits - medium-coarse sand		22.13
		BOW-006	**100.00**
BOW-008			
	Moraine Deposits - fine sand to gravel		83.77
	Moraine Deposits - medium-coarse sand		16.23
		BOW-008	**100.00**
BOW-009			
	Halton Till		13.75
	Moraine Deposits - fine sand		3.23
	Moraine Deposits - fine sand to gravel		66.23
	Moraine Deposits - medium-coarse sand		0.19
	Newmarket Till		16.60
		BOW-009	**100.00**
BOW-011			

Catchment ID	Surficial Geology Type	% of Catchment Area
	Moraine Deposits - fine sand	40.81
	Moraine Deposits - fine sand to gravel	59.19
	BOW-011	**100.00**
BOW-013		
	Moraine Deposits - fine sand to gravel	49.61
	Newmarket Till	50.39
	BOW-013	**100.00**
BOW-014		
	Halton Till	8.31
	Moraine Deposits - fine sand to gravel	4.51
	Newmarket Till	87.18
	BOW-014	**100.00**
BOW-015		
	Moraine Deposits - fine sand to gravel	19.21
	Newmarket Till	80.79
	BOW-015	**100.00**
OSH-001		
	Glacial Lake Deposits - sand and gravel - minor diamicton	50.60
	Glacial Lake Deposits - silt and sand	17.60
	Moraine Deposits - medium-coarse sand	31.80
	OSH-001	**100.00**
OSH-001B		
	Glacial Lake Deposits - sand and gravel - minor diamicton	27.50
	Glacial Lake Deposits - silt and clay	60.30
	Glacial Lake Deposits - silt and sand	0.20
	Moraine Deposits - medium-coarse sand	12.00
	OSH-001B	**100.00**
OSH-002		
	Glacial Lake Deposits - sand and gravel - minor diamicton	1.60
	Glacial Lake Deposits - silt and clay	98.40
	OSH-002	**100.00**
OSH-003		
	Glacial Lake Deposits - silt and clay	100.00
	OSH-003	**100.00**
OSH-004		
	Glacial Lake Deposits - silt and clay	40.70
	Glacial River Deposits - sand	6.20
	Glacial River Deposits - sand and gravel	21.50

Catchment ID	Surficial Geology Type	% of Catchment Area
	Moraine Deposits - fine sand to gravel	23.30
	Moraine Deposits - medium-coarse sand	8.30
	OSH-004	**100.00**
OSH-009		
	Glacial River Deposits - sand	4.00
	Glacial River Deposits - sand and gravel	9.40
	Moraine Deposits - fine sand to gravel	74.00
	Moraine Deposits - medium-coarse sand	12.60
	OSH-009	**100.00**
OSH-010		
	Glacial River Deposits - sand and gravel	7.70
	Moraine Deposits - fine sand to gravel	92.30
	OSH-010	**100.00**
OSH-011		
	Glacial River Deposits - sand and gravel	1.60
	Moraine Deposits - fine sand	8.90
	Moraine Deposits - fine sand to gravel	67.50
	Moraine Deposits - medium-coarse sand	1.80
	Newmarket Till	20.20
	OSH-011	**100.00**
OSH-012		
	Glacial River Deposits - sand and gravel	7.20
	Moraine Deposits - fine sand to gravel	88.80
	Moraine Deposits - medium-coarse sand	4.00
	OSH-012	**100.00**
OSH-013		
	Glacial River Deposits - sand and gravel	6.50
	Moraine Deposits - fine sand to gravel	87.60
	Moraine Deposits - medium-coarse sand	5.90
	OSH-013	**100.00**
OSH-014		
	Moraine Deposits - fine sand to gravel	100.00
	OSH-014	**100.00**
OSH-015		
	Moraine Deposits - fine sand to gravel	86.50
	Newmarket Till	13.50
	OSH-015	**100.00**
S-007		

Catchment ID	Surficial Geology Type	% of Catchment Area
	Glacial Lake Deposits - silt and clay	100.00
	S-007	**100.00**
S-011		
	Glacial Lake Deposits - silt and clay	88.90
	Glacial River Deposits - sand	5.84
	Moraine Deposits - fine sand to gravel	5.26
	S-011	**100.00**
S-050		
	Glacial Lake Deposits - silt and clay	47.94
	Glacial River Deposits - gravel	14.25
	Glacial River Deposits - sand	16.62
	Glacial River Deposits - sand and gravel	2.97
	Moraine Deposits - fine sand to gravel	16.56
	Moraine Deposits - medium-coarse sand	1.66
	S-050	**100.00**
S-080		
	Glacial River Deposits - sand and gravel	1.04
	Halton Till	23.14
	Moraine Deposits - fine sand	7.74
	Moraine Deposits - fine sand to gravel	15.57
	Moraine Deposits - medium-coarse sand	7.25
	Newmarket Till	45.26
	S-080	**100.00**
S-083		
	Moraine Deposits - fine sand to gravel	20.86
	Newmarket Till	79.14
	S-083	**100.00**
BOW-001		
	Glacial Lake Deposits - silt and clay	45.66
	Glacial River Deposits - gravel	0.11
	Glacial River Deposits - sand	41.67
	Glacial River Deposits - sand and gravel	0.03
	Halton Till	12.52
	BOW-001	**99.99**
BOW-007		
	Glacial River Deposits - sand and gravel	11.86
	Halton Till	6.93
	Moraine Deposits - fine sand	1.42
	Moraine Deposits - fine sand to gravel	51.77
	Moraine Deposits - medium-coarse sand	19.25
	Newmarket Till	8.76
	BOW-007	**99.99**

Catchment ID	Surficial Geology Type	% of Catchment Area
BOW-012		
	Glacial River Deposits - sand and gravel	0.31
	Halton Till	1.74
	Moraine Deposits - fine sand to gravel	94.18
	Moraine Deposits - medium-coarse sand	3.76
	BOW-012	**99.99**
S-056		
	Glacial Lake Deposits - silt and clay	1.77
	Glacial River Deposits - gravel	1.50
	Glacial River Deposits - sand	4.76
	Glacial River Deposits - sand and gravel	17.89
	Moraine Deposits - fine sand	10.67
	Moraine Deposits - fine sand to gravel	42.05
	Moraine Deposits - medium-coarse sand	21.35
	S-056	**99.99**
S-100		
	Glacial Lake Deposits - silt and clay	6.35
	Glacial River Deposits - gravel	2.19
	Glacial River Deposits - sand	22.31
	Glacial River Deposits - sand and gravel	14.35
	Moraine Deposits - fine sand	4.65
	Moraine Deposits - fine sand to gravel	29.72
	Moraine Deposits - medium-coarse sand	11.51
	Newmarket Till	8.91
	S-100	**99.99**
OSH-007		
	Glacial River Deposits - gravel	4.30
	Glacial River Deposits - sand	21.00
	Glacial River Deposits - sand and gravel	1.00
	Moraine Deposits - fine sand to gravel	55.90
	Moraine Deposits - medium-coarse sand	17.70
	OSH-007	**99.90**
OSH-016		
	Moraine Deposits - fine sand	0.50
	Moraine Deposits - fine sand to gravel	85.70
	Newmarket Till	13.70
	OSH-016	**99.90**

Table 2: Normalized Flow Summarized on Surficial Geology Unit

Description	Count	Normalized Flow				
		Average	Minimum	Maximum	Standard Deviation	Variance
Glacial Lake Deposits - sand and gravel	3	-9.0616	-27.7946	0.5968	16.2259	263.2792
Glacial Lake Deposits - silt and sand	2	-4.8317	-9.6677	0.0043	6.8391	46.7738
Glacial Lake Deposits - silt and clay	14	-0.7894	-17.3508	1.9825	4.8428	23.4527
Glacial River Deposits - sand	16	-0.7358	-15.8346	2.1485	4.1175	16.9540
Moraine Deposits - medium-coarse sand	23	-0.1695	-17.4677	3.0232	3.9201	15.3674
Glacial River Deposits - gravel	10	0.1887	-0.0791	0.6376	0.2272	0.0516
Moraine Deposits - fine sand	14	0.3685	-0.5371	2.1246	0.7062	0.4987
Glacial River Deposits - sand and gravel	22	0.3785	-3.9218	2.8397	1.4177	2.0098
Halton Till	11	0.3817	-4.7576	6.3519	2.6204	6.8664
Moraine Deposits - fine sand to gravel	32	1.8325	-2.6004	11.8918	2.9618	8.7723
Newmarket Till	14	2.3636	-0.0255	12.4239	4.1563	17.2745
Total	*161*			*Average:*	4.3668	36.4819