APPENDIX G

Erosion Threshold Assessment

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INTRODUCTION

JTB Environmental Systems Inc. has been contracted to undertake a tractive force (also known as a shear stress) analysis of the watercourses within the Innisfil Creek Subwatershed Study. Selected nodes which corresponded with the hydrological analysis were analyzed. In all, eight (8) sites were selected:

1. Innisfil Creek immediately upstream of its confluence with the Nottawasaga River
2. Beeton Creek immediately upstream if its confluence with Bailey Creek
3. Bailey Creek immediately upstream of its confluence with Beeton Creek
4. Penville Creek immediately upstream of its confluence with Innisfil Creek
5. Beeton Creek at Catchment 202 downstream of Tottenham
6. Innisfil Creek at Catchment 308 100 metres upstream of County Road 27
7. Cookstown Creek upstream of the confluence with Innisfil Creek
8. Bailey Creek downstream of Catchment 211

These sites were selected based on number of criteria, including representativeness of the overall system, access, safety, and relationship with hydrological nodes through a separate study in the subwatershed process (as indicated by Greenland International Consulting Inc.).

The fundamental goal of fluvial ecosystem assessment, maintenance, restoration and monitoring is to maintain a condition that resembles its natural predisturbed state as closely as possible. Achievement of this goal entails maintenance of the target system's structure and function both locally and within its broader landscape or watershed context. To measure the degree of success in achieving such goals, physical, chemical, and biological evaluation data are necessary to verify that an ecosystem is performing as it should. To achieve long-term success, fluvial ecosystem maintenance should, where possible, address the causes and not just the symptoms of potential ecosystem disturbance. Sometimes these causes are obvious, and sometimes they are far removed in time and space from the ecological damage.

The changes that stress fluvial systems impair their value for both human use and environmental services. Stresses can arise from (1) water quantity or flow mistiming, (2) morphological modifications of the channel or riparian zone, (3) excessive erosion and sedimentation, (4) deterioration of substrate quality, (5) deterioration of water quality, (6) decline of native species, and (7) introduction of alien species. In most systems, these conditions arise from rapid or poorly-planned development where no predictive studies of channel adjustment have been undertaken.

LAND USE

The Nottawasaga basin prior to human settlement was well forested. After massive deforestation of the area was complete in the 1870's (MacMillan, 1992), and before any reforestation program was enacted, the land within the basin was subjected to active erosion by wind. Remnants of aeolian dunes are found in the south and west parts of the basin. It is suggested that the presence of dunes on the bed of glacial Lake Algonquin in the region of the Innisfil Creek basin would look something like the dunes found at Hepworth (Chapman and Putnam, 1984: p71, photo 28). This blowing sand could possibly have been material which may have increased sediment loading of the river.

The bedrock geology of the basin is Palaeozoic consisting of limestones, shales and dolomites which overlap each other in such a manner as to give a concentric pattern across the entire area of Southern Ontario and the middle Great Lakes States. Surface deposits are a mixture of these Palaeozoic materials and debris of Precambrian age which were either deposited during ice advance or retreat of the last glacial period (the Wisconsinan). These deposits were subsequently reworked by the waters of Lake Algonquin, 11,000 to 12,000 years before present (Chapman and Putnam, 1984). The glacial history of the basin is described in Deane (1950) and Chapman and Putnam (1984).

With the exception of pockets of settlements of varying size, the basin is primarily comprised of agricultural land use across the flat Algonquin Sand Plain. Agriculture has been practiced in this area for over 100 years, and it is fair to assume that over this time there have been a number of channel alignments to accommodate farming practices. At the very least, in an attempt to gain access to as much crop land as possible, riparian vegetation zones along a number of the creeks and rivers have been removed with cropping and tilling to the edge of the banks. This has resulted in sediment delivery to the watercourses at rates greater than would normally occur, with a corresponding response by each system.

Of particular interest is the calibre of the sediment in these systems. They contain a high degree of silt and clay which would represent pulverized topsoil/sand mixtures consistent with long periods of agricultural activity. When large enough accumulations of this material comprise a river bed, the D_{50} of the matrix is altered and becomes significantly finer over time.

In areas where there is little agricultural activity the watercourses contain bed materials consistent with the surrounding surficial geology (ie in the Base Borden property near Angus).

TRACTIVE FORCE ANALYSIS

Tractive force analysis is an essential component of any development / environmental study in that it allows investigators to determine erosion-sensitive reaches and provides guidance for the delivery of flow volumes from stormwater management facilities.

The concept of tractive force analysis is relatively simple: a stream system or watercourse develops over many years with respect to the timing and volume of flow contributions by groundwater (baseflow contributions) and overland flow (volumes greater than baseflow in streams), by the process of erosion and sediment transport. Therefore a watercourse develops a cross-sectional area and profile in the downstream direction that allows for the transfer of water and sediment from headwaters to mouth. When alterations to the hydrologic regime of a watershed occur, the response of the watercourse is to change either its cross-sectional area (via lateral or vertical erosion) or to modify its gradient (becoming steeper or more gentle depending on the conditions). These changes are not immediate in most cases nor are they limited to a particular temporal boundary as cumulative impacts usually prevent re-establishment of a natural flow regime.

Development of rural or agricultural lands to a more impervious surface is one such alteration which has in the past resulted in considerable change to stream systems. Paved surfaces and reduced infiltration result in two major impacts in streams: first, rapid delivery of flow to the watercourse causes increased flow competence and thereby sediment transport and erosion; second, a decrease in infiltration causes a potential decrease in baseflow contributions as subsurface hydropotential gradients are altered.

The preferred management strategy to the groundwater recharge issue is the development and maintenance of infiltration galleries within stormwater management ponds. However the problem of accelerated erosion by overflows during storm events is a more serious and complicated matter.

Stormwater management ponds will discharge excess water during periods of high input to surrounding stream systems. The delivery of that excess flow has the potential to cause erosion by either increased flow velocity or lower velocity over extended periods of time. Both conditions will result in channel alterations downstream of the structure, particularly in erosion-sensitive reaches. The challenge for managers is to effectively create stormwater management strategies which do not impact receiving watercourses and contribute to accelerated (faster than natural rate) erosion.

METHODOLOGY

Tractive force analysis (also known as excess shear, excess velocity, excess stream power) allows geomorphologists to guide engineers as to the rate and timing of stormwater discharge from such ponds. The methodology to undertake such analyses includes the following:

1. a stream walk is undertaken at the start of the assessment to document overall watercourse conditions and to identify areas of potential erosion risk. During this walk notations of changes in soil type and

bed characteristics are made and digital photographs are taken. A further purpose of the creek walk is to choose potential cross-sections for further study. The number of cross-sections chosen reflects the concerns of the study TOR.

2. a rapid reach assessment is undertaken which identifies particular concerns with respect to channel form, bank properties, riparian conditions, substrate and flow characteristics. A numerical score of out of 100 results which can be used comparatively to select reaches for further study.
3. once all potential cross-sections have been identified choices are made as to which ones would require further analysis. This decision is based on relative stability to other reaches and the proximity to areas of concern or specific interest: in particular areas of differing soil type, proximity to structures, or proximity to catchment nodes with respect to the hydrological modeling which this work complements.
4. each cross-section is monumented for future use. Cross-sectional measurements of channel and bankfull area are made at tight intervals to get a detailed indication of form. Local slope is determined using a leveling exercise. This cross-sectional data is input into a flow model along with information on channel roughness (Manning's 'n') to determine stage/discharge relationships and specific velocities.
5. bed samples are collected and returned to the lab for grain-size analysis, bank samples are also collected. The grain size distribution is used in the tractive force analysis.
6. critical shear stress for the bed material (pavement and subpavement) is determined using standardized methods for the D_{10}, D_{50} and D_{90} fraction of each sample.
7. boundary shear stress is determined from the cross-sectional profile, slope and roughness components measured in the field. Comparisons are made between the critical and boundary shear at bankfull stage to establish erosion potential for each fraction.
8. critical discharge to match the critical/boundary shear relationship is then mathematically determined and reported to the engineer for placement in the hydrological model as a threshold value. The hydrological model is then run against the threshold value to determine exceedence for the pre-development and post-development scenarios; this is input into the decision matrix for the sizing of the stormwater management pond.
9. reporting includes critical shear, critical discharge, critical velocity, stream power and erosion potential for the selected cross-sections. These other critical thresholds are reported in case there are issues surrounding the use of shear stress as a decision-making tool.
10. recommendations are made from the perspectives of fluvial functioning of the watercourse as a component of the final report.

GENERAL SITE CHARACTERISTICS

Each creek system in the study has its own specific characteristics which reflect the variability of flows incumbent on them and the land use activities of the surrounding landscape. Generally speaking, however, most sections of the streams in his analysis are rather entrenched and disconnected with their floodplains, except during very high flow events. There is a general lack of riparian buffer over the majority of total stream length; however where this buffer occurs the entrenchment decreases and there is some more appropriate connection between the creek and the floodplain (in particular on sections of Beeton, Bailey and Cookstown Creeks). Agricultural practices provide the majority of land use activities, with some small- to medium-sized settlements in each watershed.

CHANNEL FORM AND FLOW ANALYSIS

Flow Analysis:

Table 1 shows the results of flow conditions for a sampling period in the summer of 2003. Of importance to note is the fact that discharges are quite low, with the exception of one cross-section, while velocities appear relatively high. This is due to the rather strong gradients along some sections of the creek system, and the fact that the bed material (fine clays) provides little frictional resistance as a roughness element.

Table 1: Low Flow Conditions

Creek, Site	Local Slope	Top Width (m)	Wetted Perimeter (m)	Flow Area (m^2)	Flow Depth (m)	Mean Velocity ($m\ sec^{-1}$)	Discharge ($m^3\ sec^{-1}$)
Innisfil D/S	0.001	11.58	11.71	2.94	0.47	0.36	1.06
Beeton D/S	0.001	5.28	5.51	1.69	0.57	0.58	0.98
Bailey D/S	0.002	3.36	3.44	0.70	0.31	0.44	0.31
Penville D/S	0.003	3.55	3.68	0.43	0.20	0.37	0.16
Beeton U/S	0.004	1.43	1.46	0.11	0.13	0.31	0.03
Innisfil U/S	0.003	6.83	7.38	1.26	0.42	0.48	0.61
Cookstown	0.003	4.61	4.67	0.96	0.31	0.51	0.49
Bailey U/S	0.003	4.00	4.04	0.36	0.19	0.31	0.11

Table 2 shows the bankfull dimensions of the existing channel. This information indicates the maximum capacity of the channel form before flow spills into the floodplain area. Because of the high entrenchment in these streams, bankfull flow area for most cross-sections is extremely high.

Table 2: Bankfull Flow Conditions

Creek, Site	Local Slope	Top Width (m)	Wetted Perimeter (m)	Flow Area (m^2)	Flow Depth (m)	Mean Velocity ($m\ sec^{-1}$)	Discharge ($m^3\ sec^{-1}$)
Innisfil D/S	0.001	16.24	17.47	23.27	1.92	1.10	25.63
Beeton D/S	0.001	7.33	8.34	6.93	1.39	1.13	7.83
Bailey D/S	0.002	6.62	7.26	4.66	0.98	0.95	4.43
Penville D/S	0.003	4.97	5.75	3.29	0.88	1.08	3.55
Beeton U/S	0.004	4.80	5.63	3.26	1.08	1.26	4.09
Innisfil U/S	0.003	9.17	10.87	9.59	1.42	1.44	13.80
Cookstown	0.003	9.00	10.20	10.52	1.56	1.49	15.65
Bailey U/S	0.003	7.43	8.02	5.08	0.99	1.15	3.55

Hydrological results from Greenland International Consulting Ltd. indicate the 2-year return flows are quite low (refer to Table 6). Because these flows are excessively lower than bankfull capacity, an erosive situation results as the channels undergo a form of channel evolution in order to maximize energy distributions. The resulting collapse of sidewalls and banks delivers excess sediment into the watercourses, which then is redistributed downstream. During the high portion of a storm hydrograph this sediment is easily transported along the channel, however during the falling limb of the hydrograph, as flow competence decreases, sedimentation of the bed occurs. This dumping of excess amounts of sediment in the channel can result in flow diversion and increased bank erosion risk during the next high flow storm event. This is one explanation for the excessive channel capacity in some reaches of the watercourses.

The manner in which creeks respond to inputs from precipitation will have a direct impact on the stability of the channel. If a high-energy, short-duration rainstorm were to pass through this basin, the creeks may respond with a rapid rate of change of discharge (usually associated with urban areas or under extremely wet or dry conditions; or in this case lands which are artificially drained using tile tecnology) as opposed to responding with a lower rate of change of discharge (usually under conditions of high infiltration capacity of the soil). A rapid rate of change will more likely result in greater instability by nature of the forces involved on the bed, banks and in the fluid. As much as the amount of change in discharge caused by precipitation is important, from both a geomorphological and biological perspective it is the rate of change (which is indicated by basin conditions) that is of greater importance. Geomorphologically, slow rates of increase in fluid speed (as associated with increases in discharge) have a lesser effect on bed instability than faster rates of change. In fact, a slow rate of change may selectively remove some of the finer particles on the bed, allowing the larger particles to flip or rotate in such a manner as to armour the bed, enhancing stability for a period of time. Faster rates of change could have the effect of removing the entire contents of the bed, replacing it with material from upstream.

The Concept of Channel Maintenance and Alluvial River Behaviour: Implications for Water-taking

The concept of channel maintenance derives from an understanding of the behavior and characteristics of self-formed alluvial channels. Alluvial refers to material moved by running water. Alluvial channels, composed of sediments deposited by the river itself, are free to adjust their form and substrate, and to a lesser extent, their gradient. Because of this, an alluvial river develops over time a cross-section and substrate reflecting the quantities of water and sediment and the sizes of sediment brought to it, and reflecting the channel boundaries. ***Channel maintenance flows are intended to maintain the physical characteristics of the stream channel such that the transport capacity of the channel is preserved.*** The methodology for determining the minimum amount of water to maintain these channels is based on an understanding of the hydrology, sediment transport processes and channel characteristics at water claim sites, fluvial process study sites and gravel bed channels in general. Assessment relies upon available historical records and measurements initiated to develop these claims including streamflow, sediment transport, channel geometry, and channel substrate measurements.

The claimed streamflow is the minimum amount necessary to transport all of the bedload sediment through the claim reaches, thereby preventing long-term accumulation of sediment and associated reduction in channel size, and maintaining the ability of the channels to transport the mass and size classes of available sediment. The claimed streamflow is generally less than all of the streamflow in any channel because the finer size classes of sediment are supply-limited. While sediment historically moved by unclaimed low flows will temporarily accumulate in the channels, the claimed high flows have the ability to remove the temporarily accumulated finer sediment such that the ability of the channels to pass flows and convey water downstream is maintained over the long-term.

Alluvial channels, composed of sediments deposited by the river itself, are free to adjust their form and substrate, and to a lesser extent, their gradient. Because of this, an alluvial river develops a cross section and substrate that over time reflects the quantities of water and sediment and the sizes of sediment brought to it. While this form, in any given period, responds to the variability of flow and sediment, observations of natural alluvial channels demonstrate that the channel, over time, develops a cross-sectional form reflecting an integration of these temporal variations. Thus, despite considerable variability, natural alluvial channels subject to larger flows characteristically have greater widths and depths than those carrying smaller flows. Many studies have generalized this observation that stream channels are larger where larger volumes of flow occur (Leopold, 1994). In general, channels have a cross-sectional area, width, and depth at bankfull discharge that is related to the range of flows capable of eroding and transporting the alluvial deposits constituting the channel boundaries.

A variety of observations support the generalization that alluvial channels are both adjustable and, over time, establish channel sizes and forms consonant with the flow and sediments available to them. In a given river reach, or length of stream, repeated measurements of cross sections of a channel reveal maintenance of the channel form as the river migrates across the valley floor (Leopold and Wolman, 1960). Similarly, observations of channel width following a period of high flood flows, show an increase in width and subsequent narrowing following a period of average or more normal annual flows (Wolman and Gerson, 1978).

In an open channel in which both the bed and banks are fixed boundaries, and no sediment is being transported, the depth and velocity of the flow and the profile of the water surface for a given discharge are controlled by the gradient or slope of the channel, the resistance to flow imparted by the boundary materials and the channel size and shape. In contrast, in a channel with mobile boundaries where the flow may alter both the form of the bed as well as the position of the bed and banks through erosion and deposition, channel size and shape reflect a dynamic interaction of erosion, transport and deposition. At low flow little or no sediment may be in motion. As flow increases, smaller particles may be entrained with progressively larger particles in motion at successively higher flows. With increasing flow, the energy available to transport sediment generally increases. Depending on the particle sizes available, the sediment may be transported as suspended or bedload. In general, smaller particles (suspended sediment) are moved by all flows, while larger flows are needed to move the larger particles making up the channel bed. Consequently, as bed-material size increases, the discharge required to cause changes in channel morphology increases.

While there is much variability across the entire spectrum of alluvial channels, distinctive broad regional similarities characterize different kinds of rivers. Among alluvial rivers, gravel-bed and sand-bed rivers have been differentiated (Simons and Simons, 1987). Gravel-bed alluvial rivers are those whose beds are primarily composed of unconsolidated material with median sizes larger than sand, that is, greater than 2mm. Gravel-bed channels are characteristic of many of the channels of the Credit River basin. In many such channels, both bed and banks are dominated by gravels. Gravel-bed rivers typically have a pavement or armor layer of coarser materials covering the bed channel. Although suspended sediment usually constitutes more of the total sediment load than bedload, it plays a less important role in determining channel morphology (Leopold, 1992).

Much of the bedload in these channels is composed of fine silts, clays and sand particles. This sediment is mobile over a large range of flows and is often supply limited, that is, the stream has more energy than is needed to move the available material. The coarser sediment, which makes up much of the bed, and which is mobile only during higher flows, may be transport limited; that is, the supply is not limited but movement is controlled by the energy of the streamflow. Emmett (1976) suggested the existence of two distinct phases of bedload transport in armored channels: a first phase in which finer sediment moves over the coarser substrate, and a second phase in which the coarser channel-forming materials become mobile (Jackson and Beschta, 1982; Beschta, 1987; Ashworth and Ferguson, 1989; Warburton, 1992).

It is commonly observed that most, if not all, alluvial rivers are subject to episodic floods. That is, the flow overtops the river banks and spills over the adjacent lands. Floodplains are formed by lateral movement of the channel and deposition of bars and by vertical accretion resulting from deposition of sediment by floods. To the extent that the adjacent land is the product of deposition by the existing river it is, by definition, a floodplain. The floodplain therefore is a flat area adjacent to the channel constructed by the river in the present hydrologic regimen. Deposits and surfaces other than the floodplain may exist on the valley floor. If they are alluvial, that is riverine in origin, they may constitute terraces (topographic surfaces) or terrace deposits laid down by the river under a different and/or earlier hydrologic regimen. Although there is some evidence to suggest that the bankfull stage, i.e., height of the floodplain, in many rivers corresponds to a discharge of a relatively constant frequency, for example every 1 to 2 years (Wolman and Leopold, 1957; Emmett, 1975), variability is encountered among river sites in a given region and in different regions (Williams, 1978). Similarly, in some rivers there is a close correspondence between flows during which much of the sediment load is transported over the long-term (effective discharge) and bankfull flow.

Rapid Reach Assessment for Erosion Sensitivity: A rapid reach assessment for erosion sensitivity was undertaken to identify reaches of the watercourses which were at risk for erosion if changes in land use patterns or flow characteristics were to occur in the watershed. The assessment form is a visual assessment which characterizes instream substrate, morphological diversity and flow conditions, channel stability at base flow, bank stability and riparian vegetation zone width; and scores them as either poor, marginal, suboptimal or optimal according to guidelines on the form. A total score out of 20 is determined for each category, and a sum out of 100 determines the overall sensitivity to erosion. The following table summarizes the data collected during this assessment and highlights sites which are at risk.

Table 3: Erosion sensitivity according to rapid reach assessments conducted at each site under baseflow conditions. Categories are explained on the Data Collection Sheet provided in Appendix 1.

Creek, Site	Instream Substrate Characterization	Morphological Diversity of Flows	Channel Stability (Base Level)	Bank Stability	Riparian Vegetative Zone Width	Total Score (100)	Erosion Sensitivity Category
Innisfil D/S	14	11	14	12	11	62	**Moderate Medium**
Beeton D/S	4	5	9	4	5	27	**High**
Bailey D/S	4	5	9	4	5	27	**High**
Penville D/S	5	5	9	4	5	27	**High**
Beeton U/S	6	7	11	6	7	37	**High**
Innisfil U/S	6	7	11	6	7	37	**High**
Cookstown	8	9	14	8	14	53	**Moderate High**
Bailey U/S	8	9	10	5	7	39	**High**

Note:		
	Low Sensitivity	**75-100**
	Moderate Sensitivity	**50-74**
	Moderate High Risk	*50-59*
	Moderate Medium Risk	*60-69*
	Moderate Low Risk	*70-74*
	High Sensitivity	**0-49**

Values in Columns 2-7 represent field scores from the Rapid Reach Assessment Form. Each category has a maximum value of 20, indicating the most optimal situation. A value of 0 indicates extremely poor conditions. High sensitivity to erosion indicates the reach is exhibiting at least two areas of concern, one of which being bank stability. Note a Moderate sensitivity category may be at high risk for bank erosion problems yet may be masked by high values in the riparian vegetation category, therefore this category is split into high, medium and low risk to erosion.

Erosion sensitivity at all Sites is quite high. Clearly these streams are at risk for further erosion if interventions are not set in place and if alterations to land use and/or hydrologic properties occur.

Shear Stress Analysis: A shear stress analysis was performed on the sediments with respect to the channel geometry conditions at bankfull stage. At base flow there was no indication of sediment transport on the bed at any of the sites, so it is safe to say that the channels are not mobilizing sediments under base flow conditions (which is an indication of a slight degree of stability).

The following table shows the grain size statistics for each site. The column τ_o/τ_{cr} indicates whether under bankfull conditions the D_{50} size fraction would be expected to be set in motion: if the value in this column is greater than 1.0, bed mobility of this size fraction will occur. The final column indicates the critical velocity under which the D_{50} fraction could be expected to be transported, as determined using Komar (1976) relationship

$$U_c = 57D^{0.46}$$

Where Uc is the critical velocity, and D is particle size in cm. This information is presented as an alternative to using shear stress in determining sediment transport potential.

Table 4: Shear Stress assessment and erosion potential of existing bed materials based on flow geometries at bankfull stage. D10, D50 and D90 are representative grain sizes of the 10th, 50th and 90th percentile; τ_{cr} **D50** *represent the critical shear stress required for initiation of movement for the 50th percentile size particle;* τ_o *represents the boundary shear stress acting on the particles under bankfull stage;* τ_o/τ_{cr} *represent the relationship between critical and boundary shear stress (a value >1.0 indicates the particles in that size range should be in motion) for the 50th percentile; and* U_c D_{50} *represents the critical velocity in metres per second required to initiate transport for the 50th percentile fraction; erosion potential is based on the relationship between critical shear and average shear for each section with respect to bankfull velocities, as per the Shear1 module in Qualhymo and other hydrological models:*

Site	D_{10} mm	D_{50} mm	D_{90} mm	τ_{cr} D_{50}	τ_o	τ_o/τ_{cr} D_{50}	U_c D_{50} (m/s)	Stream Power	Erosion Potential (N M sec^{-1})
Innisfil D/S	0.151	0.426	0.799	0.31	18.79	60.571	0.16	250.892	66.63
Beeton D/S	0.134	0.912	11.530	0.66	13.61	20.483	0.17	76.647	23.15
Bailey D/S	0.266	0.506	1.560	0.37	19.19	52.057	0.14	86.730	49.45
Penville D/S	0.246	0.753	7.870	0.55	25.84	47.117	0.19	104.252	50.89
Beeton U/S	0.124	0.595	1.780	0.43	42.29	97.575	0.13	160.148	122.94
Innisfil U/S	0.272	0.508	0.852	0.37	41.70	112.699	0.14	405.246	162.23
Cookstown	0.111	0.351	2.840	0.26	45.81	179.189	0.12	459.593	266.99
Bailey U/S	0.319	2.070	18.380	1.51	29.07	19.282	0.28	104.252	22.17

Column 7 shows the boundary shear | critical shear relationship at bankfull stage. Clearly the median particle diameter in the bed matrix is erodible at bankfull stage at all locations. This is a natural condition and reflects functional process which should not be altered. Note the excessive values for Column 7 for the upstream site on Innisfil Creek and on Cookstown Creek.

From the analysis of shear we can determine, given the dimensions of the channel at various locations, the critical discharge for setting the median particle in motion. These values are then input variables to the flow exceedence exercise which is undertaken in the hydrological model. Table 5 shows the critical discharges based on channel dimensions and existing bed material size characteristics. Appendix 2 contains the cross-section and flow information; Appendix 3 contains the grain size results for the bed samples. These critical discharges have been provided to the Hydrologist at Greenland International Consulting Ltd.

Table 5: Critical Depths and Discharges for each site to entrain D_{50} *fraction bed material:*

Site	Critical Depth (m)	Critical Discharge (m^3 sec^{-1})
Innisfil D/S	**0.032**	**0.0008**
Beeton D/S	**0.068**	**0.0006**
Bailey D/S	**0.019**	**0.0004**
Penville D/S	**0.019**	**0.0003**
Beeton U/S	**0.012**	**0.0004**
Innisfil U/S	**0.012**	**0.0001**
Cookstown	**0.009**	**0.0007**
Bailey U/S	**0.052**	**0.0001**

The critical discharges are quite low for all of the study sites. This is expected considering that the bed material in all watercourses is comprised of pulverized sediment delivered overland off agricultural lands, and in the fact that the overall slopes of these systems is rather low, resulting in settling and storage of sediment. For the most part the fineness of the bed material is reflected in the low critical discharges.

HYDROLOGICAL ANALYSIS

Greenland International Consulting Ltd. will complete the complimentary hydrological analysis to which this data and these results are input. There has been considerable discussion of the implications of these results between the Hydrologist and Geomorphologist to ensure clear understanding of the results and to provide for accurate and seamless integration of the results.

Comparing the 2, 5 and 100 Year Storm with bankfull dimensions (Table 6) is an accurate way of identifying which cross-sections actually represent the formative process of channel development, and are a true representation of channel form in undisturbed, vegetated watersheds. The theory behind the relationship is found in the fact that current thought states the formative discharge for a channel is the bankfull or channel full discharge. If the % value of the 2, 5 or 100 year storm to bankfull discharge is greater than 200%, this is an indication that the form of the channel at that location more closely represents the precipitation that enters the channel. In all cases, it appears the traditional relationship between the 1.2-2 year storm and bankfull dimensions does not hold; this is indicative of the response of the systems to imposed stresses. In the case of the creeks within the Innisfil watershed, land use activities such as agriculture, with its proximity to stream courses and its use of tile drainage to get water off the land quicker are likely factors in this result.

Table 6: 2, 5 and 100 year storm discharges as a function of bankfull discharge. Storm values based on preliminary results provided by the hydrologic model for each watercourse.

Creek, Site	Local Slope	Bankfull Discharge (m^3 sec^{-1})	2 Year Storm as % of Bankfull	5 Year Storm as % of Bankfull	100 Year Storm as % of Bankfull
Innisfil D/S	0.001	25.63	57.31	319.50	1306.28
Beeton D/S	0.001	7.83	44.19	197.44	853.00
Bailey D/S	0.002	4.43	56.88	323.70	1481.94
Penville D/S	0.003	3.55	76.90	389.01	1412.11
Beeton U/S	0.004	4.09	21.76	95.35	535.94
Innisfil U/S	0.003	13.80	9.85	104.27	471.88
Cookstown	0.003	15.65	10.03	48.17	181.02
Bailey U/S	0.003	3.55	35.49	213.23	1053.52

Flow Duration Exceedence: Flow duration exceedence thresholds are determined through shear stress analysis of the median particle size in the channel and the stresses acting to initiate its movement: in other words the relationship between critical shear stress (or shearing strength) and boundary shear stress at some particular flow volume. In most cases it is relevant to rely on the channel forming discharge, in most instances this correlates with the bankfull or channel full discharge. While higher-than-bankfull depths will exert further stress on the boundary (theoretically), in fact there is a dissipation factor that is currently being researched that shows higher-than-bankfull depths do not have the expected effect on boundary shear. At the moment the definitive answer eludes us, therefore we shall rely on the bankfull stage for our analysis.

Our data indicates that at all of the sites there is excessive mobilization of the median fraction of the bed material. This in and of itself would be cause for concern, however we take the position that it may not be overly disconcerting for the simple reason that there is no apparent limit of sediment supply in the upstream reaches of these sites. If there were restrictions on sediment moving into the reaches, then bed erosion would clearly result at bankfull stage. We note from field evidence that this is not the case as sediment removed from the bed in those reaches is replaced by material upstream. If for some reason the upstream supply were to diminish (for instance if someone hardened the banks to restrict lateral migrations of the channel), then there would not be that replacement component and the bed would suffer severe erosion. In some gravel-bed rivers this results in an armouring of the bed, creating resistance to additional erosion, however we caution that this is not always the case and each stream systems needs to be assessed independently.

Low Flow Analysis: The other side of the excess water situation is the condition of the creek systems when there is less than bankfull stage, and there are demands for surface water for irrigation and other purposes. From the perspective of fluvial geomorphology, limited flows are of as great, if not greater concern than flood flows, because streams create a form which allows absorbance of flood flows; they do not achieve a form which protects from low flows.

Any taking of surface water from streams such as these ones presents potential problems of decreased supply in the downstream reaches. Therefore, any water taking must consider the needs of the channel for sediment transport, as well as the needs of the system as a whole for aquatic habitat, and in the case of urbanizing systems, dilution of 'grey' water from treatment plants. It is the concern of this study component to consider only those needs of the system that relate to conveyance of sediment and water through the creeks, and the possible channel adjustments which may result from decreased flow volumes. As such, then, it is important to consider the question from the perspectives of channel maintenance and alluvial river behaviour.

Water withdrawal from surface watercourses can be achieved in a couple of different manners: first by rapid, large volume withdrawals of overbank flow during spring freshet periods; and second by removal of small volumes of flow over longer periods of time, up to the required volume. Either strategy has its advantages and disadvantages.

The advantage of the rapid large volume approach is the stream is impacted upon only once during the year, and at a time when withdrawal is less likely to cause impairment to channel functioning. The disadvantage of this approach becomes apparent when spring freshet volumes are low because of low precipitation throughout the year. In this case, freshet volumes may not cause overbank flow, or, volumes may just exceed overbank flow, and withdrawal would ensure that there would be no contributions to the floodplain. This has implications for channel functioning. However, if large volumes of spring freshet were available, then this approach would have minimal apparent impact on the system.

The advantage of the slower approach to water-taking is that there is no requirement of a spring freshet before flows can be obtained, so in lower water availability years the required volumes may still be obtained. From a geomorphological perspective, a slower withdrawal will have lesser impact on stream processes. The disadvantage of this approach involves taking water when flow approaches historically low baseflow levels. Therefore, a threshold volume of water must remain in the channel, under which no artificial withdrawals can be made.

Channel / Floodplain Relationships: Discharge of water and sediment in rivers varies greatly in space and time. Discharge is normally confined below the banks of channels, but occasionally the channels are not able to contain the volume of discharge and water and sediment spill over onto the adjacent land surfaces. Adjacent to perennial rivers these surfaces are usually alluvial floodplains, which are created by the fluvial system to accommodate the larger, less frequent flows.

Alluvial floodplains result from the storage of sediment within and adjacent to the river channel. Two principal processes are involved. The first is the accumulation of sediment, often coarser sediment, within the shifting river channel. Sediment is commonly deposited, for example, on the slip-off slopes on the inside of meander bends to produce point-bars. As the river migrates in the direction of the outside of the bend, the point-bar grows and the floodplain deposit is augmented. Much of the sediment is only temporarily stored in the point-bar and it may be moved further downstream from time to time. This type of within-channel accumulation that can occur at any point within the channel, is mainly associated with below-bankfull discharges.

Secondly, suspended sediment carried by overbank discharges across the valley floor may settle and provide a further increment of floodplain sediment, either generally over the flooded surface, or occasionally, locally along the channel margins. Where floodplain sediments comprise both coarse and fine material, most of the coarse fraction is the result of deposition by lateral accretion within the channel, and some of the fine material may result from overbank accretion; where the floodplain sediment is comprised largely of fine material it is likely that most will be deposited within a channel.

Removal of large portions of overbank flow decreases the deposition of sediment on the floodplain, thereby increasing the concentration of sediment in transport within the channel. Since the transport of sediment is a random and discrete process, sediment in transport will be deposited at some location in the channel, and this sedimentation can result in some of the difficulties noted above. Therefore, it is important that overbank flows are allowed to exist, and that increased flows over the course of a year are allowed to move sediment which has accumulated.

Deposition of suspended load on the floodplain is important for a number of reasons. Firstly, and most importantly, this systematic removal of fine material from suspension aids in the prevention of accumulation of fines in the channel itself. Sedimentation in this manner has direct implications for aquatic habitat quality as well as presenting concerns from a sediment transport perspective: fines can cement gravels and prevent them from being entrained. This restricted sediment transport results in an increase in energy in the flow that can then cause increased bank erosion. Secondly, there are advantages for overbank vegetation from accumulating sediment, including provision of a sediment layer for germination as well as the delivery of minerals and nutrients which the vegetation may require.

The principal issue with changing land use and/or changing hydrological characteristics of a watershed is that there is the potential for alteration of the channel-floodplain relationship, in particular those mentioned above, but including potential water-table and groundwater recharge effects.

SUMMARY STATEMENTS BASED ON THE COLLECTED DATA:

Based on the data collected and summarized above, we make the following statements:

(i) The streams move most of the sediment found on the streambed

Streamflow at the study streams are capable of transporting most of the sizes of material that make up the bed and some of the banks. This can be determined qualitatively by observing the materials along the channel after the spring snowmelt. Recently moved particles on bars are often loose, imbricated and fresh in appearance lacking attached organic material. Recently moved particles can often be seen collected behind obstructions such as large rocks, organic debris or other flow obstacles. Scour and fill in the absence of long-term aggradation and degradation also indicates that sediment transport of the material that makes up the bed and banks has occurred.

(ii) The finer size sediment moves before the larger sediment

The transport of finer particles before the transport of coarser particles is well documented in the literature on gravel bed rivers (Milhous, 1973 as cited in Komar, 1987). The smaller mass of smaller grains requires less shear stress be applied to initiate movement than for larger particles (Vanoni, l964). Although a number of factors, such as settling of fine particles into deep pockets in the bed and exposure of large particles, act to reduce the magnitude of the size effect on mobility, finer particles generally begin moving at shear stresses and discharges lower than those for larger particles (Wiberg and Smith, 1987).

A number of researchers have suggested that the transport regime of gravel bed rivers can be described in terms of two or more distinct phases of transport (Emmett, 1976; Jackson and Beschta, 1982; Ryan and Troendle, 1996). In the first phase (Phase I), finer material bedload moves over a coarser substrate; usually this is sand or fine gravel stored in pools or along channel edges or behind obstructions. This "first phase" transport begins at a discharge of about 1/3 to 1/2 of bankfull discharge (Ryan and Troendle, 1996). In the second phase of transport (Phase II), coarser grains (typically gravel and coarser material) including material making up the riffles in the channel are transported. This phase is associated with flows sufficiently large to disrupt portions of the streambed and to transport at higher rates a wider range of sediment sizes. Generally Phase II transport begins at discharges corresponding to 7/10 to about bankfull discharge. The observation at sites that finer sediment was in motion prior to the movement of the rocks is consistent with the concepts of Phase I and Phase II transport.

(iii) The streams are 'supply limited'

Each watershed supplies a range of particle sizes to the channel. Some of these particles are moved easily by the flow (the finer sizes) and others, the larger sizes, are moved only with higher flows. When there are no constraints on the availability and mobility of bed material, bedload transport rates are said to be hydraulically limited. When there are constraints on the availability and mobility of bed material, bedload transport rates of those sediment sizes that are constrained are said to be supply limited. In other words, the streams have the ability to move the sediment they presently move with less than all the water presently flowing through the channel in most instances.

(iv) There are significant erosion risks within all watercourses:

The data clearly indicates that certain locations within this study area are prone to erosion and will require intervention if there are changes to either land use practices or hydrological variables within the watersheds. Therefore it is important that any plan of development contain a detailed stream geomorphology assessment, to be conducted over at least one year (four full flow seasons), with specific duties centred on water volumes and channel morphological adjustments (erosion and sedimentation). This study has been a snapshot, rapid assessment and should not be considered the definitive treatise on the Innisfil Creek subwatersheds.

(iv) Post-development flows should match Pre-development flows:

The watercourses in this study, while actively eroding, are in equilibrium with existing conditions of overland and in-channel flow. Altering the distribution of flows from the headwater areas would rob the lower reaches of flow energies required to maintain the channel. This would throw the system into a form of channel evolution where it tries to equilibrate with new flow regimes; the result would be accelerated erosion and sediment delivery downstream to receiving bodies, interfering with their functioning.

(v) Matching the outflow hydrograph shape is the best way to maintain the systems:

Tractive force, critical shear, excess shear and other derived properties of flow erosion are inappropriate for applying management strategies to post-development flow scenarios. Fluvial geomorphological theory proves that it is the rate of change of discharge on the rising and falling limbs of hydrographs that are responsible for channel maintenance and therefore natural rates of erosion and channel migration. Through the use of hydrograph shape alteration to accommodate development scenarios, practitioners have created more problems than they have solved. The solution is simple, model the outflow to the stormwater structure so that the hydrograph shape is consistent with pre-development shape, and no further damage to a system can result. It is only when a severe existing problem exists that alteration to a hydrograph shape should be considered, and then very carefully.

EROSION AND SEDIMENTATION

There are two areas of potential concern regarding erosion potential. First, as flow rises to accompany flood passage through a reach, there is an increase in flow velocity and a corresponding increase in shear stress on the bed. The result is a scouring of the bed as the flood wave passes through the reach. Once flows start to recede, decreased flow competence allows for the settling out of transported material from upstream onto that recently scoured bed, filling in the scoured area. The decreasing volume of flow passing through as a flood wave recedes decreases the shear stress on the bed, and less scour results. However, finer material that is in transport from upstream continues to move through the reach until flow competence decreases, and sedimentation of the finer material occurs over the coarser material that should have been moved by the wave. This causes sedimentation of the bed. While this sequence of events occurs naturally in streams, there is a requirement of bankfull flows which have the ability to remove both the accumulated fine sediment and the coarser material below, starting the sequence all over again. Removal of bankfull flows then results in decreased erosion potential of the beds and may result in sedimentation.

Secondly, decreased flow volumes can enhance erosion of banks. In areas where undercut banks exist, continual cutting by a new flow surface level has been shown to increase the potential of that bank to be cut, delivering relatively large amounts of sediment to the channel at highly localized regions. Additionally, lack of overbank flows contributes to bank dewatering and the reversal of hydropotential gradients, effectively drying out the bank and making it more susceptible to erosion by weaker than expected flows.

The movement of sediment, as suspended load, solution load, or bedload, through a drainage system is of fundamental importance in environmental management. Firstly, sediment movement influences the character of the channel network and changes can alter the nature and the loci of erosion and deposition, and channel geometry. Such changes may affect channel navigability, flooding, property boundaries, and the stability of bridges, embankments, and other engineering structures. Secondly, the turbidity of flows influences water quality and any increase in sediment concentration may damage fish and other biota in the system and the quality of water used for domestic and industrial purposes.

Removal of large portions of overbank flow decreases the deposition of sediment on the floodplain, thereby increasing the concentration of sediment in transport within the channel. Since the transport of sediment is a random and discrete process, sediment in transport will be deposited at some location in the channel, and this sedimentation can result in some of the difficulties noted above. Therefore, it is important that overbank flows are allowed to exist, and that increased flows over the course of a year are allowed to move sediment which has accumulated.

Cause of Erosion on the Innisfil Creek Subwatershed Watercourses: The cause of erosion on watercourses is usually attributed to fluvial erosion caused by excess flows or rates-of-change of flow. This is however not the entire picture on these watercourses. It can be accepted that the low roughness contributed by the fine sediments along the beds contributes to competent flow velocities (as seen in Tables 2 and 4), which moves material along the bed and may contribute to sidewall erosion. However there are two further conditions which are at work in this situation.

First, agricultural land use practices where cropping activity impinges on any riparian buffer along a creek leaves the banks exposed to accelerated erosion during high flow events. Additionally, this lack of buffer provides no protection from possible damage due to machinery movement near the creeks. It also provides no protection from accelerated sediment transport overland when the lands are not in full crop; this delivery of vast quantities of sediment alters the energy balance of the streams and results in flow diversions, particularly around temporary bars. This situation has been observed on Beeton, Bailey, Cookstown and Innisfil Creeks during the summer of 2003.

Second, the use of tile drainage technologies to remove water off the land as quickly as possible acts to modify the natural flow hydrograph to which these systems were developed. Because of this alteration, the systems have been undergoing a series of adjustments, stopping these adjustments for periods of time as near-equilibrium situations are approached. Further alterations to the hydrographs, possibly caused by development in upstream reaches, throws the equilibrium situation off, again requiring adjustment. While the creeks in the Innisfil Subwatershed appear to be relatively stable, they in fact are not; this is evident in a number of places where bank erosion is accelerated (eg Beeton Creek).

The only way to partially mitigate this situation is to work with local landowners and provide education around farming near creek systems. It would be virtually impossible to retrofit a solution to the tile drainage issue. Consideration should be given to this in the near future.

LOW CRITICAL DISCHARGES BASED ON SHEAR ANALYSIS:

In sand-bed systems it is not surprising to find that critical discharges for erosion of the D_{50} fraction are very low. Controlling for these low critical discharges in SWM facilities can be problematic due to the large volume of storage required. In order to come to a better understanding regarding management of erosion it is necessary to acquaint ones self with the principles of sediment transport. What follows is a brief treatise on sediment transport theory.

Theoretical Constructs:

The theory into channel stability and mobilization of sediment has a long history, going back to comments documented by the Royal Society in London in the 17th Century. Detailed research into erosion and sediment transport began in the late 19th Century and has been active in an on-and-off series ever since. In order to provide a small degree of understanding of the complexity of sediment transport, a very brief summary of relevant literature is presented.

Channel Stability

An investigation of channel stability requires investigation of numerous properties of both the physical nature of the drainage basin and channel as well as the hydraulic properties of the movement of fluid and material. These properties can be grouped according to their relation to the watershed as a whole, the valley which contains the fluvial system, and the in-channel processes that are ever present under all flow conditions.

Watershed variables include morphometric parameters of the drainage network. Parameters such as: 1) the drainage density (the ratio of total length of channel segments within a drainage basin to the area of the basin; Strahler, 1964), indicate how quickly a basin responds to input of precipitation, which has an impact on the magnitude of changes within the channel; 2) drainage texture, an indication of the pattern of the channel segments which are influenced by the slopes within the basin, which in this part of Canada are usually dendritic (in bedrock channels drainage texture is determined more by the presence of faults in the underlying bedrock and is characterized by a more rectangular pattern); 3) the constant of channel maintenance, which indicates the number of square metres of watershed surface necessary to maintain one metre of channel length (Schumm, 1956); 4) the relief ratio, which measures the overall steepness of the basin (Schumm, 1956); 5) the sinuosity of the channel, or the amount the channel departs from a straight line length, which can be an indicator of how well the channel dissipates energy in the form of fluid velocity and may also indicate the propensity of the channel to erode banks at the point of inflection; and 6) the bifurcation ratio, which gives an indication of the rate of increase in stream size from one order to the next, are all important parameters which affect the stability of channels.

Other watershed variables include the geology of the basin, the thickness of the drift that overlies the bedrock and as such is available for transport under optimal conditions, soil conditions, elevation, climate, local weather conditions (including amount, timing and intensity of precipitation events), and the dominant land use of the watershed (both rural and urban land use affects watershed inputs in a number of ways).

Variables which involve the valley of the fluvial system are very important, because unlike the watershed variables, which may have a delayed influence on stability within the channels, valley variables have more immediate impact. These include valley slopes, channel gradient, the nature of the bank material related to its erosiveness (the degree of cohesiveness), the amount of unvegetated soil within the floodplain,the amount of sediment available for transport into the system, floodplain land use, and the presence or absence of vegetation near the channel or on the banks. Some of these variables are related, such as the amount of unvegetated soil in the floodplain and the amount of sediment available for transport, which can cause increased suspended sediment concentrations under the right conditions. The degree of cohesiveness of the bank and the presence of bankside vegetation are also importantly related. Exposed tree roots, or root wads, act in the same manner as a rough boundary on the bottom of the channel, creating turbulence and subsequently adding to the erosive power of the channel. If the banks are cohesionless, and therefore more susceptible to erosion, this increased turbulence caused by root wads can increase the suspended and bed load of the channel. If the banks are cohesive at the point of root wad exposure, the result is a scouring of the bed, creating a pool at the downstream end of the root wad.

Watershed and valley variables have had a limited degree of investigation over the years, especially in how they relate to stability in the channel. This should not lessen their importance in the grand scheme of things, rather they should undergo more detailed study at the level of scientific investigation that is available today.

Probably the most intensely studied of all variables within any given fluvial system are the in-channel variables and processes. Due to the fact that investigation is intense, a listing of the variables here would not do them justice. Rather, a combining of the variables is more prudent.

Factors within the channel which have a direct impact on the stability of the channel are: 1) fluid speeds; 2) width of the channel; 3) mean depth; 4) discharge; 5) antecedent flow conditions; 6) the nature of the substrate; 7) the particle size, degree of packing or imbrication and the orientation of the bed material; 8) water temperature; 9) the percentage of undercut banks; 10) riffle-pool sequences; 11) the presence or absence of vegetation, either fallen trees in the channel (which cause vegetation jams) or underwater grasses which can act as a sediment trap; and 12) the number of tributary inputs that have confluent junctions.

These 12 factors have a number of sub-variables within each. For example, it is not only the fact that there are variable fluid speeds within the channel, but the distribution of those speeds and the direction of the flow is also important. Also, particle packing, imbrication and orientation have sub-variables such as the degree to which particles protrude into the flow, the way that they are stacked on top of one another (which influences the pivoting angle of the grains) and the relative sizes of the grains to one another on the bed (which may provide 'hiding' places for other grains, reducing the likelihood that they would be entrained into the flow).

Bed Material Transport:

Alluvial river channels are dynamic, they are constantly changing to reach some form of equilibrium through erosion and deposition processes within the channel. This equilibrium may be better reached if there were no inputs into the system, such as sediment from overland flow or bank erosion, or changes to stream direction such as those observed by the addition of a fallen tree into the channel. The way channels attempt to attain equilibrium is through movement of bed material. This movement has been the focus of a considerable amount of study over the years, related to the amount of movement, the size, shape and density of the particles being moved, the competence of the stream to move various particles of different sizes and shapes, and the hydrodynamic theories of particle entrainment with the identification of the numerous inter-related variables that must work at the same time.

General Theories

Probably the first extensive study into the movement of bed material by a river system was conducted by Gilbert (1914), who tried to solve the problem of what happens to mine tailings that have been excavated. His treatise became the focal point for all studies that followed, and remains to this day one of the most cited pieces of literature in North America.

Studies have concerned themselves with the amount of material that is actually moved by rivers. Middleton (1976) noted in his study that the 'delivery ratio', or the amount of material that is moved from source to any downstream location in the system, is less than 10% for basins larger than 100 miles^2. That is, less than 10% of the material eroded and delivered to the smallest tributaries is discharged by the main stream leaving the drainage basin.

The way that material which is transported along the bed has undergone different theories over the years. Initially, it was thought that bed material moved continually, as long as there was a competent velocity present. As that velocity slowed to below competent levels, material was deposited on the bed and was re-entrained once that fluid velocity passing over the particle became competent again.

Einstein (1937) showed that the movement of material over a bed was a random phenomenon, that particles moved in a series of steps of random length separated by periods of rest which were of random duration. Bagnold (1977) found that bedload transport in natural rivers is unsteady both in time and cross-sectional distribution. He found that two-fold variations in total river transport rate can occur within a several minute period, and that "streams" of solids wander at random laterally over the bed. He concludes by saying that at any given discharge and gradient an alluvial river can transport a bed load of a given mean grain size at a greater rate the shallower the flow depth. Kuhnle and Southard (1988) showed by studying the bedload transport rate every 30 seconds in gravel bed flumes that the nature of the bed material determined the rate of transport, not just the velocity of the fluid (a reaffirmation of the work of Laronne and Carson, 1976 and others). They found that coarse bed channels had lower transport rates than smoother channels. This revised predictions of the amount of material moved in a given time for a given channel, and reinforced the fact that channels behave in different manners. Wilcock and Southard (1989) found that not only do transport rates depend on the coarseness of the channel but on the population of grain sizes available for transport on the bed surface. But, the grain size distribution of the bed surface depends on the mobility of various grains on the bed, so, the actual mobility of material on the bed depends on the grain size of the available material as well as the flow velocity.

Ashmore (1991) found that bedload pulses are generated within the stream by aggradation and degradation within short reaches of the stream, and that measured pulses of bedload in the stream appear as "waves" of aggradation and are accompanied by clusters of migrating unit bars. Hoey and Sutherland (1991) postulate that transport rates are more dependent on whether or not the channel reaches in question are in equilibrium with the water flow. They suggest that the bedload equation of Bagnold (1980) overpredicts transport rates in channels that are in equilibrium or are aggrading, and underpredicts transport rates for channels that are degrading.

Ashworth and Ferguson (1989) reinforced that the relative size of the grains on the bed is more important than the absolute size of the grains, particularly as it relates to the threshold shear stress for gravel entrainment, but also found that precise equal mobility of small and large particles was "approached" at higher shear stresses and transport rates.

Hassan et al. (1991) discuss the complexity of bed material movement. They identify 3 categories of variables that control bed movement: sedimentological characteristics of the bed (texture, packing, armouring, bed forms), hydraulic conditions of the flow (discharge, velocity, duration), and characteristics of individual moving particles (size, shape, roundness). These characteristics show that for any given flow condition over the exact same bed one can expect any number of different bedload transport rates.

Movement of bed material results in the formation of structures on the bed, which may be so transitory as to last for a few minutes (i.e. ripple-marks) or as stable as to last for a considerable amount of time (i.e. gravel bars). Considerable work has been done in this area, this review will touch on those that relate to gravel-bed channels. Laronne and Carson (1976) identified three types of structures in gravel-bed rivers. Open structures were those where particles on the bed are arranged in such a manner that they do not come in contact with one another, closed structures are those where particles are in close contact with one another, and infilled structures occur where particles fill in the voids between stationary bed fragments while rolling or sliding. These smaller particles 'seal' interparticle spaces, contributing to the strength of the bed, resisting movement due to armouring. These structures are offered as proof of movement of bed material, answering critics who feel that, in Southern Ontario, there are insufficient conditions for bedload transport. The presence of imbricated structures further proves the notion of bedload transport. Because imbricate structures are characterized by upstream dipping of particles, their formation can only be attributed to bed movement (Laronne and Carson, 1976). Further proof of bedload transport is offered by Milne (1982), Lambert and Walling (1988) and others.

Theories of Flow Competence

The movement of bed material has been attributed to flow competence, that is, the ability of a particular flow velocity to move bed material of a particular size range. This is important in fluvial geomorphological studies because it allows the prediction of movement of material from a measurable parameter, fluid velocity.

Although investigations into the competence of a river have been carried out since before the turn of the century, it is probably the work of Gilbert (1914) that first called attention to the importance of this matter. He outlined eight factors that must be taken into consideration when dealing with the capacity of fluids to transport material: slope, discharge, fineness of the material, particle form, fluid velocity, uniformity of the material, the relationship between load and energy, and the processes of flume transportation. His work, using flumes and material of uniform sizes paved the way for further investigations into the theories of flow competence, both in flume and natural river systems and using uniform and natural materials.

Hjulstrom (1935) was the first person to graphically show the relationship between fluid velocity and the erosion, transportation and deposition of material finer than 100mm in diameter. His argument was that, all other things being equal, velocity of the fluid was the determining factor in the erosion, transportation and deposition of material within river systems. This was in spite of his recognition of the wide scatter of data points and the fact that different velocities will produce different results. This work renewed interest in the problem of flow competence.

Church and Gilbert (1975) suggested that a non-cohesive bed exists in three states: normal, where materials are resting in a non-disperse state; overloose, where materials are resting in a disperse state, normally due to the presence of a large volume of water within the sediment; and underloose, where materials are resting in a state of close packing or imbrication. While most of the work to date has been done on normal boundaries, they argue, it is the other two states that occur most often in reality. They suggest, then, that a lower-than-experimentally-derived velocity will be needed to move a particle off an overloose boundary, and a higher-than-experimentally-derived velocity will be needed to move a particle off an underloose boundary. Church and Gilbert also noted that instantaneous velocity fluctuations can result in up to times the fluctuation in lift and drag forces at the bed, allowing for up to four times the size particle being able to be moved than would be originally predicted.

Moving away from velocity measurements, Baker and Ritter (1975) started to use mean shear stresses to predict competence. Bagnold (1977) suggested that hydraulic properties of the flow need to be determined through the measurement of gravity gradient, flow depth, mean velocity, grain size and effective threshold values of velocity and stream power. Miller et al. (1977) state that the characteristics of the sediment are the proprietary factors in competency. Bradley and Mears (1980), moving out of the laboratory and into the field determine that, among other things, macroturbulent or other flow aberrations may entrain particles but go unrecorded in mean-value determinations of flow velocity or tractive force. Costa (1983) challenged the use of average velocity and shear stress measurements, stating that the forces of Bernoulli lift is very active in downstream transport. Brayshaw et al. (1983) showed how the arrangement of particles on the bed, and how they project into the flow, distorts the fluid stream to produce a distinctive pressure field which has significance for the entrapment or the entrainment of particles depending on their positions relative to the cluster. Andrews (1983) postulated that bed material size distribution affects the forces acting on a given particle by either hiding the particle from the flow or by the fact that the force necessary to start a large particle rolling over a smaller one is less than the force required to start a smaller particle rolling over a larger one. Other authors looked at the types of channels in a natural system (Carling, 1983), the condition of the boundary and particle size of the sediment (Carson and Griffiths, 1985; Ashworth and Ferguson, 1989; Ferguson et al., 1989), the effect of grain pivoting angles (Komar and Li, 1986; Li and Komar, 1988), particle collisions (Carling, 1990), sedimentation by river-induced turbidity currents (Chikita, 1990), and how friction angle and particle protrusion are affected by the variability of shear stresses within water-worked sediments (Kirchner et al., 1991).

As one tries to define the extensive number of variables necessary to start a particle in motion, the level of investigation becomes more and more microscopic. Komar and Carling (1991) sum up the problem of this microscopic evaluation of fluid and sediment hydraulics by stating that flow-competence relationships will differ from stream to stream, under different flow conditions, depending on their unique patterns of grain sorting and material sources.

Other Factors

There are a number of other factors that play a role in the stability of alluvial river channels. Probably the most important is the amount of input into the system in the form of precipitation. Langbein and Schumm (1958) looked at sediment yield in relation to the amount of mean annual precipitation, but it is important to note that it is not only the amount of precipitation that falls over a basin, but the rate that the precipitation enters the system (Beebe et al., 1991). A fast rate of input, and subsequent fast rate-of-change of fluid velocities has been shown to remove a gravel bar consisting of particles up to 8 centimetres in intermediate diameter after one short-duration high energy summer storm in July, 1991.

The presence of instream and side-channel vegetation is one such factor. Mosley (1982) noted that the presence of Willow trees scattered about in a river channel affected channel form, in some cases promoting bar construction immediately downstream and in others leading to deep scour of the bed. Such cases are localized, yet the influence of a newly-fallen tree can alter fluid patterns and riffle-pool sequences for a distance downstream. Vegetation at the edge of the bank may also play a more significant role in channel form. Although touched on only briefly in the literature, the type, quantity and age of vegetation roots exposed by eroding banks has a varying degree of impact, the smaller roots acting as stabilizers of the bank, the larger tree roots acting as a rough boundary (Thorne, 1990), creating turbulence and subsequent erosion of the bank and bed downstream (Bellamy et al., 1992).

Antecedent flow conditions can lead to a stabilization of a channel over a short period of time. Continued base flow conditions, such as those experienced in the summer of 1991 in this study area, can remove almost all of the fine sediment on the bed, leaving only the larger particles available for transport. The reduced flow conditions and the removal of the finer material results in a situation where shear stresses are not great enough to entrain the particles that are left on the bed (Komar, 1987). Such a dependence can lead to the formation of armoured beds, most obvious in gravel rivers. Wilcock and Southard (1989) found that the decrease in the mobility of the fine and coarse fractions as a system adjusts toward equilibrium (as happens under base flow conditions), is explained by the development of a partial static armour, which helps to decrease the mobility of finer fractions.

Summary:

Research into erosion and sediment transport is very complicated. Clearly there are an infinite number of possible variables and permutations of variable interaction that can result in sediment erosion and mobility, each of which are site- and condition-specific. This makes prediction of erosion a challenging task.

Numerous hydraulic models have incorporated erosion modules based on the shear stress relationships found in a representative cross-section and specific flow. These relationships represent, in a small way, the current state of the science which was applied to real-world situations at the time of their incorporation. The difficulty with these modules is they are based on average conditions, and while there is some rigour to the calculations, current research shows the modules do not consider some of the more important variables in erosion and sediment mobility.

Problem Statement:

The erosion study component within the larger (ICSWS) study has concluded that low critical discharges are required to ensure that stability of the D_{50} fraction of the bed material occurs (as per standard accepted methodologies). In large systems such as the Innisfil system, matching these critical discharges is a challenge.

The current state of research indicates a lack of an appropriate methodology to deal with this specific issue. Standard methods such as excess shear and excess cumulative shear result in these low critical discharges; however the fact remains that as flows in the natural system exceed these discharges, the beds of these watercourses do not change with time. This indicates that the shear-based approach is not accurately reflecting stresses on the sediment in the systems; there must be some other factor which inhibits sediment mobility when the equations predict transport.

Fine-grained Sediment Transport

Coarse-grained (>2mm) and fine-grained sediment transport (<1mm and most notably the <63 micron fraction) are vastly different in that some of the factors that affect large-grain sediment mobility do not exist in the fine-grained fraction, and vice-versa. Application of criteria for coarse-grained transport to this <1mm fraction is not appropriate.

Fine-grains have chemical and electro-static forces which help tie them together (we refer to the forms as 'flocs' (see the work of Stone, Droppo and Krishnappan for details)). In addition, fine grains tend to behave as 'bulk' sediments rather than individual particles when acted upon by driving forces. This is evident when we view ripple and dune migration in sand systems: the ripple and dune forms migrate as a bulk unit over time. While we can visualize individual grain mobility in sand during ripple/dune migration, the movement of the 'form' indicates the concept of 'random steps of random length' (Einstein, 1937) clearly does not apply. This fact is supported in Aeolian research into sediment transport mechanics as well.

When we get material that is finer than sand (silts/clays) the breakdown of static forms like ripples and dunes is indicative of the stability of the bulk sediments with respect to process. Instead of migration as a unit, we can envision that entire beds may mobilize and migrate downstream in a layer-peeling fashion as velocity increases. While there is little research into this phenomenon, it can be visualized thusly:

- As inputs increase due to a storm event, flow depth in a river increases with a corresponding increase in velocity (see Leopold, Wolman and Miller, 1964 for the initial treatise on the autocorrelation of discharge with width, depth and velocity).
- As velocity increases it becomes competent for the size of the bed material, and sediment transport of the first 'layer' of the bed begins. While entrained, the sediment dampens the velocity, and material then is released by the stream to float downstream (note it takes more energy to entrain sediment than to transport it, when a fine sediment is 'released' by flow it will transport downstream for a distance before settling out).
- Velocity then can increase slightly as the flow is entraining less material, and then will entrain the next 'layer' and the process continues. The time scale of these 'cycles' is very short (on the order of seconds) which is why we don't visually observe the phenomenon as it occurs.

While this is a very simplistic generalization of the process, it should help understand this form of sediment mobility.

The other way fine grains can be mobilized relates to the influence of turbulence in creating lifting forces at very precise locations on the bed. This has been likened to 'micro-bed explosions' and occurs where irregularities in channel form are present (Beebe, 2003).

Unfortunately, there is little research completed on silt/clay sediment transport. Research has focussed solely on the relationship between fine grains (<63 microns) and chemical transport, as these grains have the ability to attract and transport chemicals from one location to another (see works by Art Horowitz for examples). Researchers have recently focussed on flocs as bulk units, but again an acceptable treatise on silt/clay beds is not available.

Erosion Modelling using Shear Stress

Particle motion is the result of an imbalance between push forces and drag forces. In order to initiate movement, push forces attempt to overcome the forces working to keep the particle stationary. This results in shear stress, which is a calculated value that is determined from channel design. In studying the push forces that must overcome the resisting forces to cause particle movement, the necessary shear stress is referred to as the critical shear stress denoted as τ_c. Critical shear stress is a result of the size and submerged weight of a particle as well as the packing of the particles. In most cases, the critical shear stress of a bed is determined using the D_{50}, the grain diameter that splits the grain size profile in half.

Shear stress acting at a given point is referred to as the boundary shear stress. Boundary shear stress is determined from multiplying the specific weight of water, the hydraulic radius and the slope. Once the boundary shear stress manages to exceed the critical shear stress, particle movement is initiated.

From a mathematical approach it can be observed that as the hydraulic radius is increased, the boundary shear stress will also increase. Hydraulic radius is determined by (width x depth) ÷ (2 x depth + width) which for most channels will approximate the depth of the channel. From this it can be seen that as depth increases, so too will boundary shear stress, leading to a greater chance of exceeding the critical shear stress.

In determining the shear stress values, velocity is often overlooked. It is not accounted for in figuring the critical shear stress or the boundary shear stress. What is found is that as the velocity increases, another variable becomes more evident. Earlier it was discussed that for a particle to remain stationary the drag forces must balance out with the push forces. However, the acknowledgement of velocity introduces another force known as *lift forces*. As a velocity profile is created over top of the particle, a velocity gradient is created which acts much like the wind passing over an airplane wing. As this gradient is increased it draws the particle up. In addition to the lifting ability, increased velocity also results in increased turbulent eddying downstream of the particle. This increase in eddying aids in dislodging the particle, reducing the effects of packing. As a result, the critical shear stress must be higher to be able to resist the lift forces that are created.

If we put velocity aside and keep the conditions constant, time should not be a factor in the transport of sediment. Hydraulic radius, slope and the specific weight of water do not increase in intensity nor do they slowly eat away at a particles position. In theory, the statement stands true that, for a calculated critical shear stress, the boundary shear stress must be greater in order to initiate movement. This means either hydraulic radius, slope or the specific weight of the water must change. Once velocity is brought into account, one must consider the ability of flow to slowly scour out an area. It is possible to discharge high flows down a channel for a short duration and not result in particle movement simply because the flow was not given enough time to "unpack" the particle. Flow duration is a factor that must be noted when looking at the risk of particle movement.

Examining the relationship of flow to sediment transport is the most obvious and simple method to use in studying sediment transportation. It is simple to gauge flow through a channel and to regulate that flow. On a flat bed, flow is going to be a primary concern since a stopped flow halts the movement of particles. In the event that a particle is resting on a slope, there will still be a shear stress involved due to the gravitational pull. In this case it may be beneficial to analyze the balance of forces to determine the stability of the bed. Shear stress should not be looked at independently of flow velocity because that would mean ignoring major forces acting on the particle. It is more feasible to look at flow throughout a channel length if it is assumed that the particles that are within the channel have already reached equilibrium with their submerged weight and the drag force.

One final consideration is related to the derivation of the important variables. Shear stress is a derived property which is not directly measurable and is difficult to interpret. Additionally, in order to put management practices in place, a shear stress analysis is time consuming and ripe for misinterpretation. Velocity/discharge relationships, however, are not derived properties of flow but are actual physical properties: you can see them and measure them directly without relying on empirical studies and constants based on spreads in the data.

Another proposed method of looking at the stability of a channel reach is to observe the stream power. Stream power is the product of the specific weight of water, discharge and again, slope. This follows the theory that a stream will try and take on a form that will expend the least amount of energy, resulting in the least amount of stream power. This area is still being explored further as the data is being applied to more specific fluvial applications.

Shear Modules within Hydraulic Models

Shear modules within larger hydraulic models represent approximations in order to facilitate calculations. These modules, such as Shear1, rely on generalized forms for cross-sections and in doing so may miss some of the intricacies of shear distribution which occur in complex channel forms. Some existing shear modules have been in place for more than 15 years and may not reflect the current state of knowledge relating to shear stress as they tend not to be updated once incorporated and accepted as a methodology. In addition, computational power has increased significantly to the point where complex modelling potential is widespread and not limited to a few larger computer systems, meaning more complicated calculations can be easily run to attain a more complete result.

This does not necessarily mean the shear modules are out-of-date and should be replaced, it simply means that results from running such modules should be carefully considered before being applied in each case.

Mitigating Erosion

When critical discharges are as low as they are and bankfull to 100 year discharges are as high as they are in this case there is a potential for significant erosion. While the creeks in this study are at a state of equilibrium with current processes, development of these lands from current agricultural to urban/suburban land use will alter that equilibrium and there will be adjustments. The degree and nature of the adjustments cannot be determined within the scope of this study; a more detailed examination of each of the systems is required. Nonetheless, it is clear that erosion of the beds of these creeks will occur.

Bed erosion is a natural process. As a storm hydrograph moves through any of these systems, bed mobility results. During the falling limb of the hydrograph, sediment in transport from upstream becomes deposited and the net effect of the storm is no apparent change in the bed elevation (all other things being equal). However, when land use is changed from one that provides sediment (agricultural) to one that limits sediment delivery (urban/suburban), the cumulative net effect of storms is a lowering of the bed. Over time, the banks oversteepen as the channel becomes more entrenched and they start to collapse. This process is called channel evolution in response to altered flow regimes.

Mitigating this process response is difficult. In order for creeks such as these to retain their overall form while undergoing land use transformations requires no change in hydrological processes—that is, simply match the existing pre-development storm hydrograph with the post-development storm hydrograph. This is not possible given current technologies and the state of science in engineering and fluvial geomorphology. The standard response to slowing delivery of water off impervious surfaces is to integrate stormwater management facilities into the water cycle, which deliver flow at a much slower rate. Matching stormwater output to critical discharges is at the heart of erosion mitigation.

In the Innisfil system, the low critical discharges require stormwater facilities which are very large, as they have to retain a large volume of water during storms and allow for slow discharge. This is an impractical solution to the problem because of the size of the required SWM ponds—they would be excessively large.

Bank Shear versus Bed Shear as an Erosion Threshold

It has been suggested by some practitioners in geomorphology that instead of using bed shear strength as the determining factor in establishing critical discharges, the bank shear strength should be substituted. In systems where bank strength and bed material strength are relatively similar, such as gravel systems, this may be an appropriate procedure. The logic behind this approach is clear; in order to minimize lateral migration of channels maintaining stresses below erosive thresholds should keep a channel from cutting on outside bends. In systems where sediment supply is not limited, or where land use is not expected to change, this should not present a problem.

In the Innisfil system, bank strength averages two orders of magnitude greater than that of the bed material. In addition, it is expected as land use changes from agriculture to urban/suburban the sediment supply for the creeks will become increasingly limited. The result is an anticipated acceleration of bed lowering, with corresponding bank adjustment during the channel evolution phase. Therefore it is not recommended that the bank strength be used as the determining factor for critical discharge.

What has not been factored in to this analysis is where the mobilized sediment will eventually deposit. It is safe to say that as fine sediment migrates through the tributary systems into the main branch of the Nottawasaga

River, the eventual sink for the sediment is the Minesing Swamp. This in and of itself would be a long-term concern.

New Science

The Innisfil Creek SWS is in a position to develop new science and practice. As far as can be established through both the consulting and academic communities, there has been no research, either applied or theoretical, which could assist the Study Team in their analyses. Standard methodologies which have been successfully applied in other basins in Ontario and elsewhere do not transfer well to this watershed, and in fact might not apply in more than 75% of the Nottawasaga River Drainage Basin. New science needs to be developed prior to development in this watershed.

Implications of Control based on Critical Discharge

Utilization of shear modules and standard metholdologies such as the one in the Innisfil Creek SWS can lead to conditions of overprediction or underprediction of erosion and sediment transport. Application of these conditions will result in either overcontrol or undercontrol in the SWM facility. Some implications of these situations include:

- Overcontrol
    - SWM Facility too large
    - Loss of flow to creek system—SWM system will not utilize outflow as predicted
    - Loss of base flow input from shallow groundwater flow
    - Accumulation of sediment in channels as a result of decreased flow competence
    - Flow redirection caused by sediment accumulation resulting in risk of bank erosion—unpredictable lateral migration
    - Channel evolution due to lack of flow—decrease in channel capacity over time
    - Cumulative impacts as more SWM Facilities are brought on-line

- Undercontrol
    - SWM Facility too small
    - Higher peak flows to the creek systems as delivery of water off impervious surfaces is faster
    - Erosion of bed and banks as channel adjusts to higher energy regime
    - Long-term evolution of the channel as it adjusts to new inputs
    - Cumulative impacts as more SWM Facilities are brought on-line.

Vision of Watercourses over time: Alternatives

There are a number of possible alternatives. The alternative which is selected depends entirely on the overall long-term vision for the watershed, and how willing managers are to allow for instability in the short-term to create the long-term goal. Alternatives include:

1. Do not allow development to proceed in the watershed;
2. Allow the watercourses in areas of development to naturally adjust with minimal SWM control;
3. In accordance with the 2003 SWM Manual, compare the pre-development water budget with the post-development water budget and use infiltration to make up the difference. This requires retaining the 40 cm/hectare or 25mm storm, whichever is higher;
4. Allow for SWM control to remove peaks in storms in combination with erosion control to allow for more 'natural' hydrographs to maintain channel form.

Alternative 1 is not practical, given the high population south of the NVCA watershed and the desire for this population to move into the watershed.

Alternative 2 requires NVCA managers to 'sit back' and let the watercourses adjust across their floodplains for a period of time. This instability increases risk to existing infrastructure and private property and is therefore not practical.

Alternative 3 represents the current state of practice and should be maintained until such a point as alternative management strategies can be researched and put into practice.

Alternative 4 is practical and feasible and provides for the best overall approach in this watershed. However in order to achieve Alternative 4, development and SWM controls must be carefully located to areas where creeks are stable and erosion control can be effective. It is not prudent to assume that erosion control can be effective in all areas of the watershed, particularly in the Nottawasaga/Innisfil watershed, due to the nature of the bed and bank material along much of the creek lengths. Therefore it is necessary to carefully assess the entire watershed to locate areas of high potential for SWM/erosion control, with respect to potential development areas.

Cumulative Impacts

It is necessary to consider the cumulative impact of any application of SWM control on a system like the Innisfil/Nottawasaga. As development occurs and SWM control is added to the systems, there is going to be a response within the systems to the control. Given that any hydrological/erosion analysis is based on near-snapshots of water-budget/fluvial processes, the potential for overcontrol or undercontrol needs to be recognized. While a watercourse can adjust to one case of overcontrol/undercontrol, as time goes on and more SWM facilities are added, the resilience of any watercourse to accommodate alterations to flow becomes more stressed. The result may be that impacts are increased over time and will reverberate downstream as the system adjusts.

In the Nottawasaga system, all watercourses drain into the Minesing Swamp (either directly or through confluence with the main Nottawasaga stem). Therefore all cumulative impacts are going to be felt within the Minesing Swamp: it will in essence act as a bottleneck to these individual stream adjustments. In the case of undercontrol, for example, with increased sediment loading, the Minesing Swamp will become the depositional site for excess sediment in transport. This will alter water levels in the Swamp and affect habitat and hydrological processes, resulting in an adjustment at the site and downstream towards Wasaga Beach

Specific Recommendations

Invoking Alternative 4 requires a considerable amount of detailed study to a degree which is more intense than that found in a Sub-watershed Study or at a Sub-watershed level. This detailed study requires time. Therefore, we make two sets of recommendations; one to deal with the short-term, immediate pressures for development within the watersheds of the Nottawasaga, and a second to provide for the long-term health of the entire watershed during and post-development.

Short-term Recommendation:

The nature of the Innisfil System indicates that undercontrol of stormwater from potential development areas will invoke near-immediate erosion reactions at some locations. Conversely, overcontrol will, as indicated above, set in motion a channel evolution which will, over time, alter the nature of the watercourses. However this evolution caused by overcontrol will be more gradual.

Therefore, recognizing that the time required for detailed assessments may conflict with other time lines, we recommend that NVCA invoke Alternative 3 as their current management strategy. Alternative 3 will allow for some SWM discharge in accordance with the critical discharges from the erosion analysis, while allowing for infiltration to supply shallow groundwater reserves.

There is the question as to how much to pond and how much infiltration to allow for when using Alternative 3. These questions must be answered during detailed studies as development applications arise, because of the fact that each area has specific qualities which dictate how much control is needed and how much infiltration is possible. As a general rule, however, each detailed study must at least contain the following information prior to making a decision:

1. undertake a pre/post development annual water budget as per the MOE stormwater manual to develop infiltration targets
2. incorporate within the development design infiltration systems to try to meet the targets
3. within the SWM ponds, because of the high sensitivity to erosion in the watercourses, incorporate the normal water quality first flush to be released over 48 hours.

This analysis must answer these fundamental questions:

A) How much water is available in/to the system on an annual basis based on long-term precipitation trends?
B) How much water (flow) is needed to maintain the fluvial process component of the system?
C) How large should the SWM Facility be to accommodate critical discharges?
D) What is the infiltration potential and the timing of migration to watercourses?
E) How much water can be expected to infiltrate and feed shallow groundwater reserves?
F) Is there the potential to decrease the size of SWM Facilities in accordance with D) and E) above? To what capacity?
G) What are the implications for fluvial process and system maintenance of F) above?

We recognize that there may be some cumulative impacts to Alternative 3 which are yet to be fully comprehended along the Innisfil System and into the Minesing Swamp area. As further study provides critical information, NVCA will be able to react to this information and allow for a more controlled, system-healthy response to development impacts in the downstream areas.

Long-term Recommendation:

After careful consideration of the conditions of the creeks in the Nottawasaga/Innisfil watershed, we recommend that Alternative 4 be implemented as a long-term management strategy for potential development and stormwater control. We feel it is both feasible and practical to move from Alternative 3 to Alternative 4 in those areas where watercourses are more sensitive to alterations in flow regimes.

In order for Alternative 4 to be implemented, a detailed study is required to assess and select potential SWM/erosion control areas within stable sections of each creek.

We therefore further recommend a detailed study, completed by a qualified Fluvial Geomorphologist with experience in sand/silt based agricultural systems, which classifies sites along the entire Nottawasaga watershed which have:

- High stability/suitability for SWM and erosion control;
- Medium stability/ marginal suitability for SWM and erosion control;
- Low stability/poor quality and should be avoided.

These assessments would be ongoing and would be initiated in areas where development applications are in place or in areas where development has occurred and Alternative 3 has already been invoked. Once these areas have been assessed, the study would then move in a comprehensive manner across the entire Nottaswasaga watershed, from headwaters to the Minesing Swamp, dealing with high potential areas first and then filling in the gaps for the entire watershed.

Cumulative Impacts:

Further to the short-term and long-term recommendations, we also recommend that any land development and SWM Facility be assessed in accordance with the potential for cumulative impacts downstream, in particular with respect to, but not limited to, the Minesing Swamp. Each development application should include an assessment as to the potential for impacting this area which includes consideration of other existing SWM controls and those which might be in process at the time of application.

CONCLUDING STATEMENTS

JTB Environmental Systems Inc. is pleased to provide the results of the Tractive Force Analysis on the Innisfil Creek Subwatersheds. We note that the results are based on a short-term study of the watercourses and caution that their interpretation would be better served over an even longer term of study.

JTB Environmental Systems Inc. has been asked to comment on the results of the erosion modelling component of the Innisfil Creek SWS, in particular the apparent challenges facing the Hydrologic Consultants in meeting the erosion thresholds with their methodology.

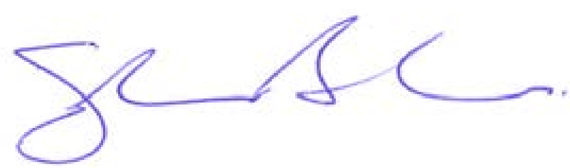
We have carefully considered the application of the method by the consultant and have also considered the letters sent between the Nottawasaga Valley Conservation Authority and Greenland International Consulting Ltd., the most recent dated 13 January 2005.

It is our opinion that the difficulties faced in matching erosion thresholds and critical discharges in this study more accurately reflects the state of practice within existing erosion model sub-routines in hydraulic models, the complexity of sediment transport dynamics, and the complexity of the watershed under study. The application of the models appears to have followed standard procedure.

It is apparent when one considers all factors in this instance that the difficulty arises not from the application of the method but in the nature of the Innisfil Creek system.

It is clear that further research needs to be completed to update erosion sub-routines in hydraulic models in order to enhance their applicability, and that watershed-specific conditions be carefully considered in these sub-routines.

Respectfully Submitted,



John T. Beebe, PhD
President and CEO
JTB Environmental Systems Inc.

APPENDIX 1: RAPID REACH ASSESSMENT FORM

APPENDIX 2: FLOW CROSS-SECTIONS

APPENDIX 3: BED MATERIAL STATISTICS

Worksheet
Worksheet for Irregular Channel

Project Description	
Project File	c:\docume~1\admini~1\mydocu~1\fluvial\innisjb.fm2
Worksheet	Innisfil Downstream Site 1
Flow Element	Irregular Channel
Method	Manning's Formula
Solve For	Discharge

Input Data		
Channel Slope	0.001000	m/m
Water Surface Elevation	-4.13	m

Elevation range: -4.17 m to 0.00 m.

Station (m)	Elevation (m)	Start Station	End Station	Roughness
0.00	0.00	0.00	23.24	0.035
0.65	-0.41			
1.35	-1.11			
2.85	-1.75			
4.04	-2.34			
5.06	-3.38			
6.74	-3.83			
8.96	-3.82			
11.45	-4.11			
13.54	-3.92			
16.33	-4.17			
17.78	-3.73			
18.67	-3.27			
18.81	-2.74			
19.91	-2.34			
21.54	-1.56			
23.24	-0.65			

Results		
Wtd. Mannings Coefficient	0.035	
Discharge	0.0008	m^3/s
Flow Area	0.01	m^2
Wetted Perimeter	0.59	m
Top Width	0.58	m
Height	0.04	m
Critical Depth	-4.15	m
Critical Slope	0.058040	m/m
Velocity	0.07	m/s
Velocity Head	0.22e-3	m
Specific Energy	-4.13	m
Froude Number	0.15	

Flow is subcritical.

Worksheet
Worksheet for Irregular Channel

Project Description	
Project File	c:\docume~1\admini~1\mydocu~1\fluvial\innisjb.fm2
Worksheet	Beeton Downstream Site 2
Flow Element	Irregular Channel
Method	Manning's Formula
Solve For	Discharge

Input Data

Channel Slope	0.002000	m/m
Water Surface Elevation	-0.92	m

Elevation range: -1.49 m to 0.83 m.

Station (m)	Elevation (m)	Start Station	End Station	Roughness
0.00	0.00	0.00	12.90	0.035
0.41	0.3e-2			
1.07	0.01			
2.49	-0.05			
3.15	-0.29			
3.66	-0.88			
3.96	-1.14			
4.88	-1.49			
5.42	-1.42			
6.40	-1.45			
7.55	-1.07			
8.55	-0.93			
8.96	-0.92			
9.79	-0.67			
9.96	-0.06			
10.13	0.18			
11.35	0.45			
12.90	0.83			

Results

Wtd. Mannings Coefficient	0.035	
Discharge	0.98	m^3/s
Flow Area	1.69	m^2
Wetted Perimeter	5.51	m
Top Width	5.28	m
Height	0.57	m
Critical Depth	-1.17	m
Critical Slope	0.021095	m/m
Velocity	0.58	m/s
Velocity Head	0.02	m
Specific Energy	-0.90	m
Froude Number	0.33	

Flow is subcritical.

Worksheet
Worksheet for Irregular Channel

Project Description	
Project File	c:\docume~1\admini~1\mydocu~1\fluvial\innisjb.fm2
Worksheet	Baily Downstream Site 3
Flow Element	Irregular Channel
Method	Manning's Formula
Solve For	Discharge

Input Data

Channel Slope	0.002000	m/m
Water Surface Elevation	-2.16	m

Elevation range: -2.18 m to 0.33 m.

Station (m)	Elevation (m)	Start Station	End Station	Roughness
0.00	0.00	0.00	12.42	0.035
0.51	0.33			
1.02	0.31			
1.62	-0.13			
2.31	-1.46			
2.69	-1.76			
3.71	-2.13			
4.43	-2.18			
5.44	-2.13			
6.42	-1.85			
8.09	-1.77			
8.66	-1.53			
8.80	-1.18			
9.98	-0.90			
11.21	-0.57			
12.42	-0.32			

Results

Wtd. Mannings Coefficient	0.035	
Discharge	0.0004	m^3/s
Flow Area	0.01	m^2
Wetted Perimeter	0.69	m
Top Width	0.69	m
Height	0.02	m
Critical Depth	-2.17	m
Critical Slope	0.069696	m/m
Velocity	0.06	m/s
Velocity Head	0.18e-3	m
Specific Energy	-2.16	m
Froude Number	0.19	

Flow is subcritical.

Worksheet
Worksheet for Irregular Channel

Project Description	
Project File	d:\innisfil\penville.fm2
Worksheet	Penville 4
Flow Element	Irregular Channel
Method	Manning's Formula
Solve For	Discharge

Input Data

Channel Slope	0.001000	m/m
Water Surface Elevation	-1.77	m

Elevation range: -2.30 m to -0.67 m.

Station (m)	Elevation (m)	Start Station	End Station	Roughness
0.00	-0.77	0.00	10.00	0.035
0.20	-0.80			
0.40	-0.83			
0.60	-0.90			
0.80	-0.93			
0.90	-0.95			
1.20	-1.02			
1.30	-1.05			
1.40	-1.09			
1.50	-1.13			
1.60	-1.17			
1.70	-1.19			
1.80	-1.23			
1.90	-1.27			
2.00	-1.32			
2.10	-1.33			
2.20	-1.42			
2.30	-1.48			
2.40	-1.66			
2.50	-1.73			
2.60	-1.79			
2.70	-1.82			
2.80	-1.89			
2.90	-2.00			
3.00	-2.08			
3.20	-2.13			
3.40	-2.21			
3.60	-2.25			
3.70	-2.25			
3.80	-2.29			
4.00	-2.30			
4.20	-2.27			
4.40	-2.24			
4.60	-2.25			
4.80	-2.26			

5.00	-2.24
5.20	-2.19
5.40	-2.16
5.60	-2.16
5.80	-2.19
6.00	-2.19
6.20	-2.21
6.40	-2.27
6.50	-2.24
6.60	-2.16
6.70	-1.84
6.80	-1.77
6.90	-1.63
7.00	-1.47
7.20	-1.41
7.40	-1.39
7.60	-1.35
7.80	-1.41
8.00	-1.42
8.10	-1.40
8.20	-1.36
8.30	-1.27
8.40	-1.09
8.50	-1.01
8.60	-0.97
8.70	-0.96
8.80	-0.95
9.00	-0.86
9.20	-0.82
9.40	-0.76
9.60	-0.75
9.80	-0.70
10.00	-0.67

Results		
Wtd. Mannings Coefficient	0.035	
Discharge	0.78	m^3/s
Flow Area	1.70	m^2
Wetted Perimeter	4.69	m
Top Width	4.23	m
Height	0.53	m
Critical Depth	-2.05	m
Critical Slope	0.023308	m/m
Velocity	0.46	m/s
Velocity Head	0.01	m
Specific Energy	-1.76	m
Froude Number	0.23	
Flow is subcritical.		

Worksheet
Worksheet for Irregular Channel

Project Description	
Project File	d:\innisfil\beeton.fm2
Worksheet	Beeton Upstream 5
Flow Element	Irregular Channel
Method	Manning's Formula
Solve For	Water Elevation

Input Data

Channel Slope 0.004000 m/m

Elevation range: -2.68 m to -0.93 m.

Station (m)	Elevation (m)	Start Station	End Station	Roughness
0.00	-1.39	0.00	8.00	0.035
0.20	-1.40			
0.40	-1.43			
0.60	-1.44			
0.80	-1.39			
1.00	-1.39			
1.20	-1.42			
1.40	-1.44			
1.60	-1.45			
1.70	-1.49			
1.80	-1.54			
1.90	-1.56			
2.00	-1.60			
2.10	-1.73			
2.20	-1.98			
2.30	-2.04			
2.40	-2.08			
2.50	-2.06			
2.60	-2.10			
2.80	-2.12			
3.00	-2.15			
3.20	-2.16			
3.40	-2.19			
3.60	-2.27			
3.70	-2.29			
3.80	-2.37			
3.90	-2.41			
4.00	-2.44			
4.10	-2.51			
4.20	-2.57			
4.30	-2.58			
4.40	-2.58			
4.50	-2.62			
4.60	-2.65			
4.70	-2.67			
4.80	-2.67			

4.90	-2.68
5.00	-2.67
5.10	-2.65
5.20	-2.63
5.30	-2.62
5.40	-2.61
5.50	-2.57
5.60	-2.55
5.70	-2.50
5.80	-2.44
5.90	-2.35
6.00	-2.30
6.10	-2.00
6.20	-1.96
6.30	-1.93
6.40	-1.91
6.50	-1.87
6.60	-1.81
6.70	-1.75
6.80	-1.60
6.90	-1.09
7.00	-1.04
7.10	-1.03
7.20	-1.00
7.40	-0.97
7.60	-0.95
7.80	-0.95
8.00	-0.93

Discharge	0.03	m³/s

Results		
Wtd. Mannings Coefficient	0.035	
Water Surface Elevation	-2.55	m
Flow Area	0.10	m²
Wetted Perimeter	1.43	m
Top Width	1.39	m
Height	0.13	m
Critical Depth	-2.60	m
Critical Slope	0.034382	m/m
Velocity	0.30	m/s
Velocity Head	0.47e-2	m
Specific Energy	-2.55	m
Froude Number	0.36	
Flow is subcritical.		

Worksheet
Worksheet for Irregular Channel

Project Description	
Project File	d:\innisfil\innisfil.fm2
Worksheet	Innisfil Upstream 6
Flow Element	Irregular Channel
Method	Manning's Formula
Solve For	Water Elevation

Input Data

Channel Slope 0.003000 m/m

Elevation range: -2.87 m to -0.68 m.

Station (m)	Elevation (m)	Start Station	End Station	Roughness
0.00	-0.99	0.00	15.00	0.035
0.20	-1.00			
0.40	-1.04			
0.60	-1.12			
0.80	-1.18			
0.90	-1.26			
1.00	-1.30			
1.10	-1.40			
1.20	-2.04			
1.30	-2.10			
1.40	-2.27			
1.50	-2.38			
1.60	-2.40			
1.70	-2.48			
1.80	-2.48			
2.00	-2.46			
2.60	-2.66			
2.70	-2.68			
2.80	-2.67			
3.00	-2.48			
3.10	-2.57			
3.30	-2.70			
3.40	-2.76			
3.50	-2.73			
3.60	-2.73			
3.70	-2.83			
3.80	-2.84			
3.90	-2.87			
4.00	-2.87			
4.10	-2.85			
4.20	-2.86			
4.30	-2.86			
4.40	-2.85			
4.50	-2.80			
4.60	-2.80			
4.70	-2.75			

4.80	-2.73
4.90	-2.71
5.00	-2.69
5.10	-2.67
5.20	-2.54
5.30	-2.54
5.40	-2.54
5.50	-2.57
5.60	-2.63
5.70	-2.62
5.80	-2.60
5.90	-2.65
6.00	-2.65
6.20	-2.52
6.40	-2.64
6.60	-2.60
6.80	-2.58
7.00	-2.60
7.20	-2.54
7.40	-2.65
7.60	-2.61
7.80	-2.60
8.00	-2.60
8.10	-2.55
8.20	-2.54
8.30	-2.54
8.40	-2.52
8.50	-2.45
8.60	-2.41
8.70	-2.26
8.80	-2.25
8.90	-2.20
9.00	-2.19
9.10	-2.15
9.20	-2.08
9.30	-2.10
9.40	-2.11
9.50	-2.08
9.60	-2.07
9.70	-2.04
9.80	-2.02
10.00	-1.93
10.20	-1.47
10.40	-1.42
10.60	-1.42
10.80	-1.41
11.00	-1.44
11.20	-1.44
11.40	-1.41
11.60	-1.41

11.80	-1.44
12.00	-1.42
12.20	-1.36
12.40	-1.35
12.60	-1.31
12.80	-1.20
13.00	-1.18
13.20	-1.10
13.40	-1.03
13.60	-1.00
13.80	-0.98
14.00	-0.94
14.20	-0.91
14.40	-0.86
14.60	-0.73
14.80	-0.73
15.00	-0.68

Discharge	13.80	m^3/s

Results		
Wtd. Mannings Coefficient	0.035	
Water Surface Elevation	-1.45	m
Flow Area	9.59	m^2
Wetted Perimeter	10.87	m
Top Width	9.17	m
Height	1.42	m
Critical Depth	-1.90	m
Critical Slope	0.016252	m/m
Velocity	1.44	m/s
Velocity Head	0.11	m
Specific Energy	-1.34	m
Froude Number	0.45	
Flow is subcritical.		

Worksheet
Worksheet for Irregular Channel

Project Description	
Project File	c:\docume~1\admini~1\mydocu~1\fluvial\innisjb.fm2
Worksheet	Cookstown Site 7
Flow Element	Irregular Channel
Method	Manning's Formula
Solve For	Discharge

Input Data

Channel Slope	0.002600	m/m
Water Surface Elevation	-2.10	m

Elevation range: -2.11 m to 1.18 m.

Station (m)	Elevation (m)	Start Station	End Station	Roughness
0.00	0.00	0.00	15.80	0.035
0.21	0.01			
0.98	-0.09			
2.42	-0.41			
2.95	-0.59			
3.75	-1.16			
4.24	-1.52			
4.48	-1.52			
5.02	-1.72			
5.71	-1.78			
6.80	-2.04			
8.35	-2.11			
9.84	-1.97			
10.63	-1.73			
11.53	-1.48			
11.62	-1.48			
11.83	-0.55			
12.16	-0.14			
13.04	-0.05			
13.82	0.17			
14.79	0.38			
14.97	0.99			
15.80	1.18			

Results		
Wtd. Mannings Coefficient	0.035	
Discharge	0.73e-4	m^3/s
Flow Area	0.17e-2	m^2
Wetted Perimeter	0.34	m
Top Width	0.34	m
Height	0.01	m
Critical Depth	-2.10	m
Critical Slope	0.087626	m/m
Velocity	0.04	m/s

Velocity Head	0.92e-4	m
Specific Energy	-2.10	m
Froude Number	0.19	
Flow is subcritical.		

Worksheet
Worksheet for Irregular Channel

Project Description	
Project File	d:\innisfil\bailey.fm2
Worksheet	Bailey Upstream 8
Flow Element	Irregular Channel
Method	Manning's Formula
Solve For	Water Elevation

Input Data

Channel Slope 0.003000 m/m

Elevation range: -3.19 m to -0.61 m.

Station (m)	Elevation (m)	Start Station	End Station	Roughness
0.00	-0.63	0.00	13.00	0.035
0.20	-0.64			
0.40	-0.69			
0.60	-0.81			
0.70	-0.88			
0.80	-0.93			
0.90	-1.01			
1.00	-1.05			
1.10	-1.15			
1.20	-1.39			
1.30	-1.50			
1.40	-1.59			
1.50	-1.69			
1.60	-1.75			
1.70	-1.86			
1.80	-1.95			
1.90	-2.07			
2.00	-2.12			
2.10	-2.21			
2.20	-2.31			
2.30	-2.40			
2.40	-2.56			
2.50	-2.59			
2.60	-2.66			
2.70	-2.75			
2.80	-2.82			
2.90	-2.81			
3.00	-2.86			
3.10	-2.89			
3.20	-2.91			
3.30	-2.98			
3.40	-3.00			
3.50	-3.02			
3.60	-3.03			
3.70	-3.05			
3.80	-3.06			

4.00	-3.13
4.20	-3.14
4.40	-3.17
4.60	-3.17
4.80	-3.19
5.00	-3.17
5.20	-3.13
5.40	-3.11
5.60	-3.09
5.80	-3.07
6.00	-3.07
6.20	-3.06
6.40	-3.04
6.60	-3.04
6.80	-3.06
7.00	-3.05
7.20	-3.01
7.40	-3.00
7.60	-2.95
7.80	-2.93
8.00	-2.91
8.20	-2.82
8.30	-2.66
8.40	-2.58
8.60	-2.47
8.70	-2.39
8.80	-2.42
8.90	-2.42
9.00	-2.39
9.10	-2.35
9.20	-2.28
9.30	-2.26
9.40	-2.20
9.50	-2.21
9.60	-2.17
9.70	-2.13
9.80	-2.13
9.90	-2.14
10.00	-2.14
10.20	-2.13
10.40	-2.12
10.60	-2.10
10.80	-2.04
11.00	-1.90
11.10	-1.77
11.20	-1.73
11.30	-1.63
11.40	-1.51
11.50	-1.44
11.60	-1.39

11.70	-1.31
11.80	-1.24
12.00	-1.15
12.10	-1.08
12.20	-1.06
12.30	-1.01
12.40	-0.96
12.50	-0.88
12.60	-0.80
12.70	-0.67
12.80	-0.66
12.90	-0.63
13.00	-0.61

Discharge	0.11	m³/s

Results		
Wtd. Mannings Coefficient	0.035	
Water Surface Elevation	-3.00	m
Flow Area	0.36	m²
Wetted Perimeter	4.04	m
Top Width	4.00	m
Height	0.20	m
Critical Depth	-3.07	m
Critical Slope	0.030589	m/m
Velocity	0.31	m/s
Velocity Head	0.49e-2	m
Specific Energy	-3.00	m
Froude Number	0.33	

Flow is subcritical.

SAMPLE STATISTICS

SAMPLE IDENTITY: **Bailey DS** ANALYST & DATE: , 5/29/2003

SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

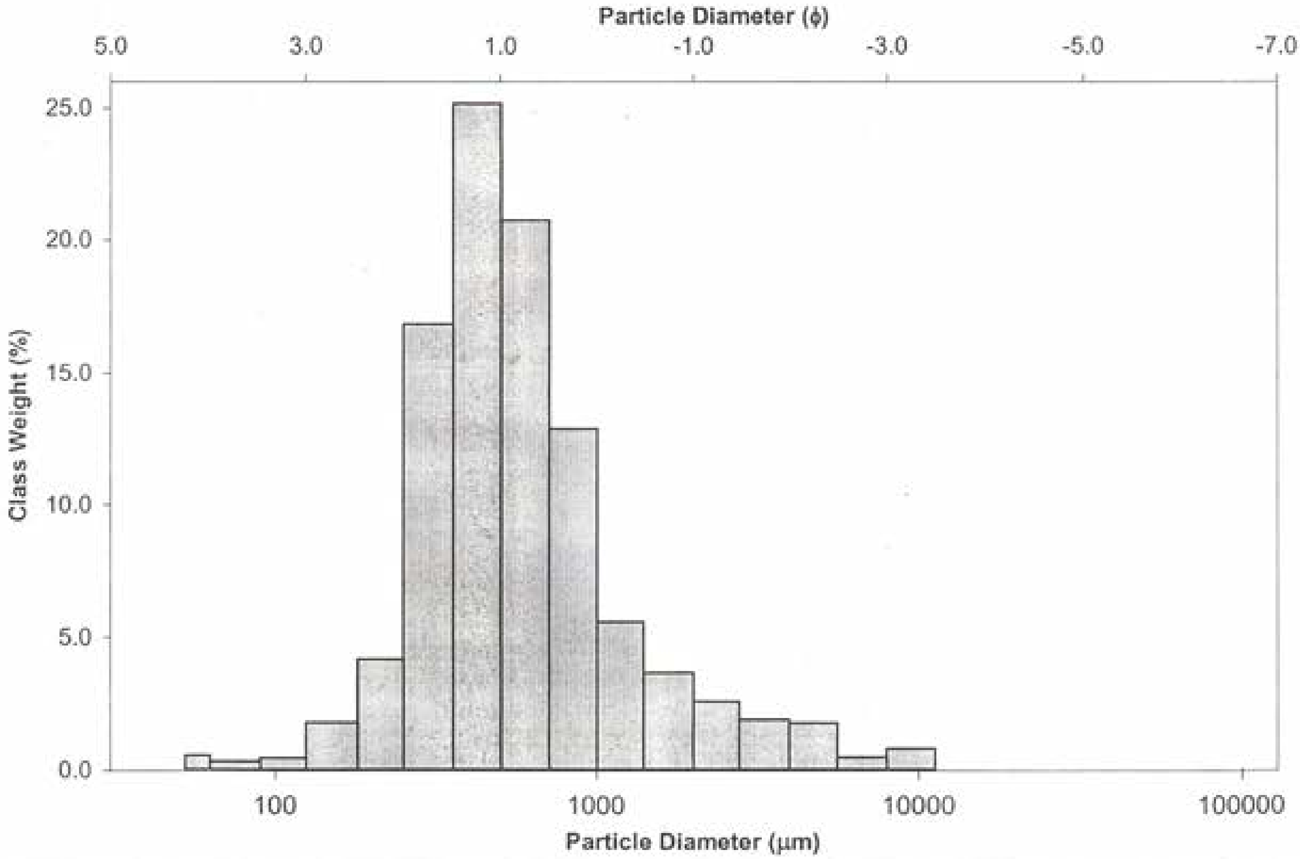
	μm	φ
MODE 1:	427.5	1.247
MODE 2:		
MODE 3:		
D_{10}:	266.6	-0.645
MEDIAN or D_{50}:	506.3	0.982
D_{90}:	1563.5	1.907
(D_{90} / D_{10}):	5.865	-2.958
$(D_{90} - D_{10})$:	1296.9	2.552
(D_{75} / D_{25}):	2.228	4.607
$(D_{75} - D_{25})$:	441.4	1.156

GRAIN SIZE DISTRIBUTION

GRAVEL:	7.4%	COARSE SAND:	34.1%
SAND:	92.4%	MEDIUM SAND:	42.4%
MUD:	0.3%	FINE SAND:	5.9%
		V FINE SAND:	0.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.3%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.8%	MEDIUM SILT:	0.0%
FINE GRAVEL:	2.2%	FINE SILT:	0.0%
V FINE GRAVEL:	4.4%	V FINE SILT:	0.0%
V COARSE SAND:	9.3%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	853.9	574.8	0.799	541.4	0.885	Coarse Sand
SORTING (σ):	1173.6	2.135	1.094	2.007	1.005	Poorly Sorted
SKEWNESS (Sk):	4.641	0.987	-0.987	0.245	-0.245	Coarse Skewed
KURTOSIS (K):	29.32	4.905	4.905	1.306	1.306	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **Bailey US**

ANALYST & DATE: , 5/30/2003

SAMPLE TYPE: Polymodal, Very Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Medium Gravel

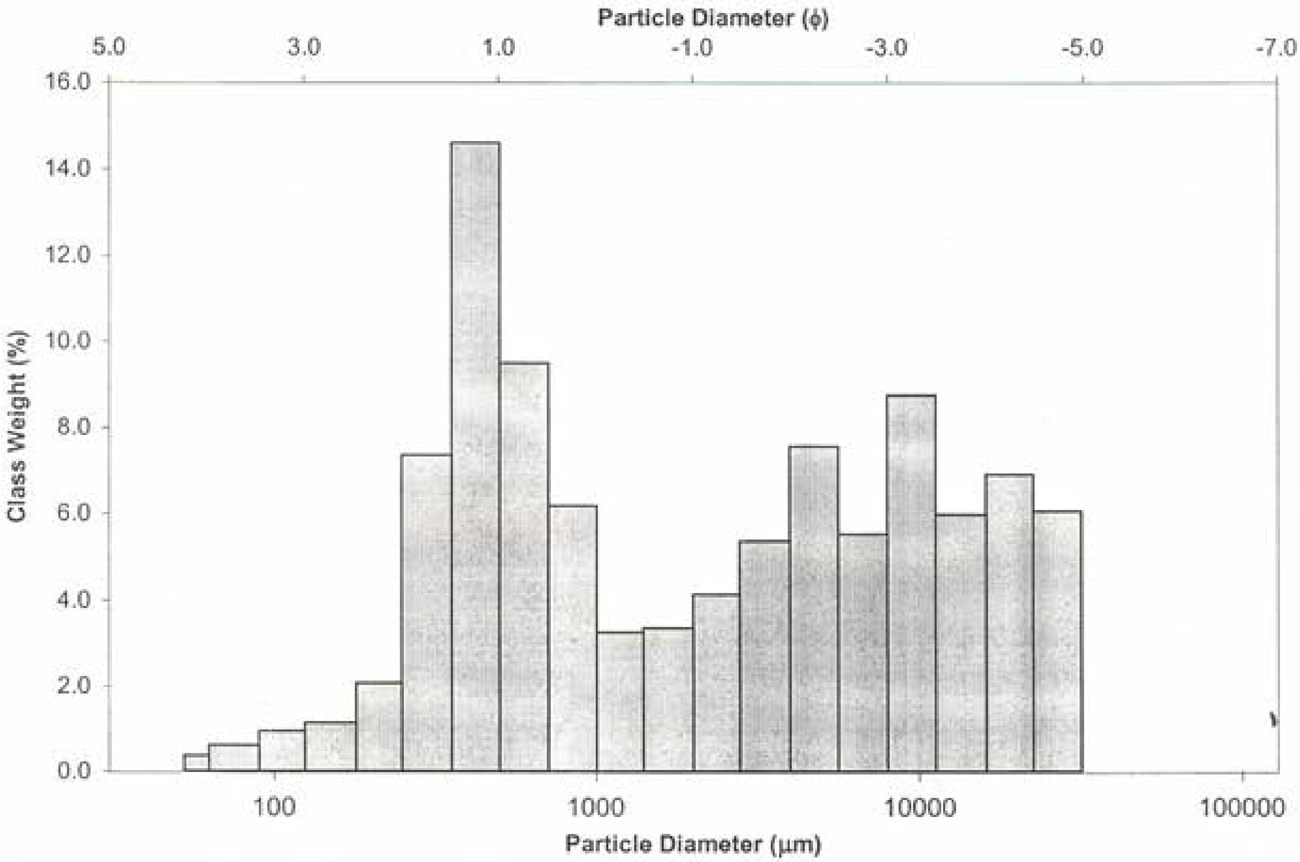
	μm	ϕ
MODE 1:	427.5	1.247
MODE 2:	9600.0	-3.243
MODE 3:	4800.0	-2.243
D_{10}:	317.9	-4.200
MEDIAN or D_{50}:	2073.7	-1.052
D_{90}:	18384.9	1.654
(D_{90} / D_{10}):	57.84	-0.394
$(D_{90} - D_{10})$:	18067.0	5.854
(D_{75} / D_{25}):	18.57	-0.339
$(D_{75} - D_{25})$:	8386.4	4.215

GRAIN SIZE DISTRIBUTION

GRAVEL:	50.4%	COARSE SAND:	15.9%
SAND:	49.4%	MEDIUM SAND:	22.1%
MUD:	0.2%	FINE SAND:	3.2%
		V FINE SAND:	1.5%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.2%
COARSE GRAVEL:	12.8%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	14.8%	MEDIUM SILT:	0.0%
FINE GRAVEL:	13.2%	FINE SILT:	0.0%
V FINE GRAVEL:	9.6%	V FINE SILT:	0.0%
V COARSE SAND:	6.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	5932.2	2074.0	-1.052	2201.7	-1.139	Very Fine Gravel
SORTING (σ):	7646.6	4.863	2.282	4.825	2.270	Very Poorly Sorted
SKEWNESS (Sk):	1.501	0.052	-0.052	0.062	-0.062	Symmetrical
KURTOSIS (K):	4.242	1.699	1.699	0.638	0.638	Very Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **Beeton DS**

ANALYST & DATE: , 6/2/2003

SAMPLE TYPE: Polymodal, Very Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Medium Gravel

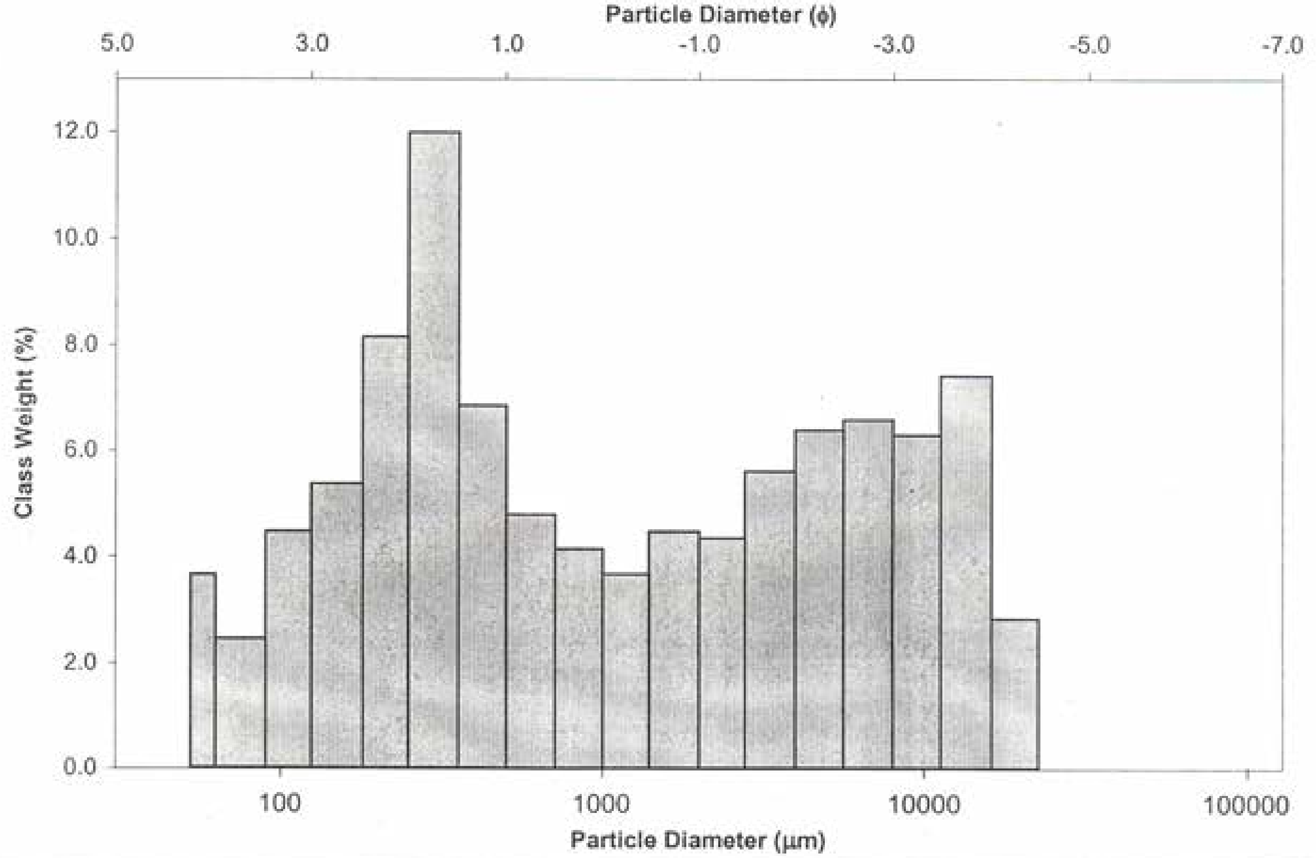
	μm	φ
MODE 1:	302.5	1.747
MODE 2:	13600.0	-3.743
MODE 3:	6800.0	-2.743
D_{10}:	134.7	-3.528
MEDIAN or D_{50}:	912.6	0.132
D_{90}:	11535.6	2.892
(D_{90} / D_{10}):	85.65	-0.820
$(D_{90} - D_{10})$:	11400.9	6.420
(D_{75} / D_{25}):	19.69	-0.792
$(D_{75} - D_{25})$:	5007.4	4.300

GRAIN SIZE DISTRIBUTION

GRAVEL:	40.5%	COARSE SAND:	9.2%
SAND:	57.7%	MEDIUM SAND:	19.4%
MUD:	1.8%	FINE SAND:	13.7%
		V FINE SAND:	7.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.8%
COARSE GRAVEL:	2.8%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	14.1%	MEDIUM SILT:	0.0%
FINE GRAVEL:	13.3%	FINE SILT:	0.0%
V FINE GRAVEL:	10.2%	V FINE SILT:	0.0%
V COARSE SAND:	8.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	3582.5	1107.9	-0.148	1135.1	-0.183	Very Coarse Sand
SORTING (σ):	4867.1	5.341	2.417	5.530	2.467	Very Poorly Sorted
SKEWNESS (Sk):	1.589	0.095	-0.095	0.135	-0.135	Coarse Skewed
KURTOSIS (K):	4.656	1.693	1.693	0.693	0.693	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **Beeton US**

ANALYST & DATE: , 5/30/2003

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

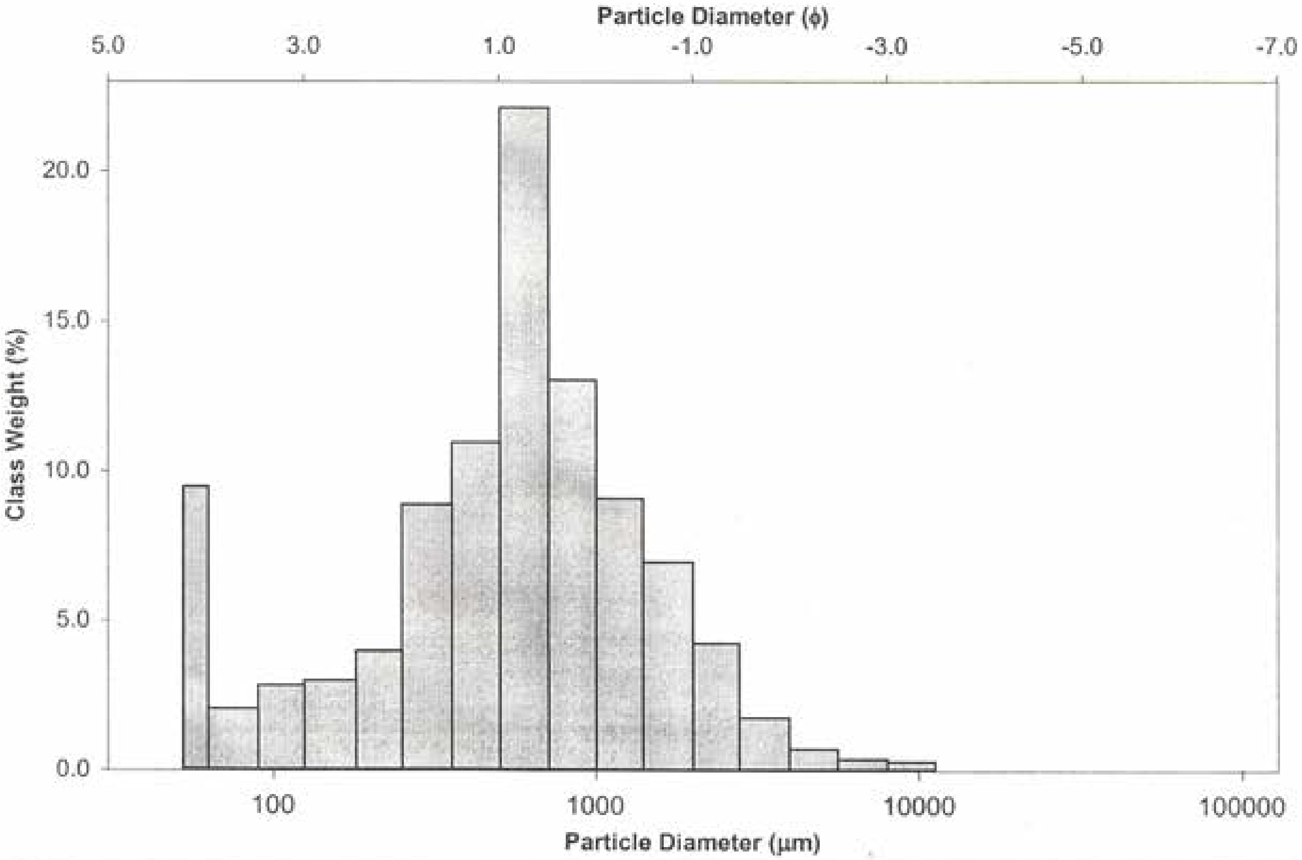
	μm	φ
MODE 1:	605.0	0.747
MODE 2:	58.00	4.113
MODE 3:		
D_{10}:	124.7	-0.832
MEDIAN or D_{50}:	595.0	0.749
D_{90}:	1780.0	3.003
(D_{90} / D_{10}):	14.27	-3.610
$(D_{90} - D_{10})$:	1655.2	3.835
(D_{75} / D_{25}):	2.964	72.84
$(D_{75} - D_{25})$:	652.7	1.568

GRAIN SIZE DISTRIBUTION

GRAVEL:	7.5%	COARSE SAND:	37.4%
SAND:	87.7%	MEDIUM SAND:	21.0%
MUD:	4.8%	FINE SAND:	7.3%
		V FINE SAND:	5.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	4.8%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.3%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.1%	FINE SILT:	0.0%
V FINE GRAVEL:	6.2%	V FINE SILT:	0.0%
V COARSE SAND:	16.9%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	850.5	544.0	0.878	565.7	0.822	Coarse Sand
SORTING (σ):	941.4	2.660	1.411	2.725	1.446	Poorly Sorted
SKEWNESS (Sk):	4.050	-0.407	0.407	-0.156	0.156	Fine Skewed
KURTOSIS (K):	28.98	3.248	3.248	1.378	1.378	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **Cookstown**

ANALYST & DATE: , 5/30/2003

SAMPLE TYPE: Trimodal, Very Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Coarse Gravelly Medium Sand

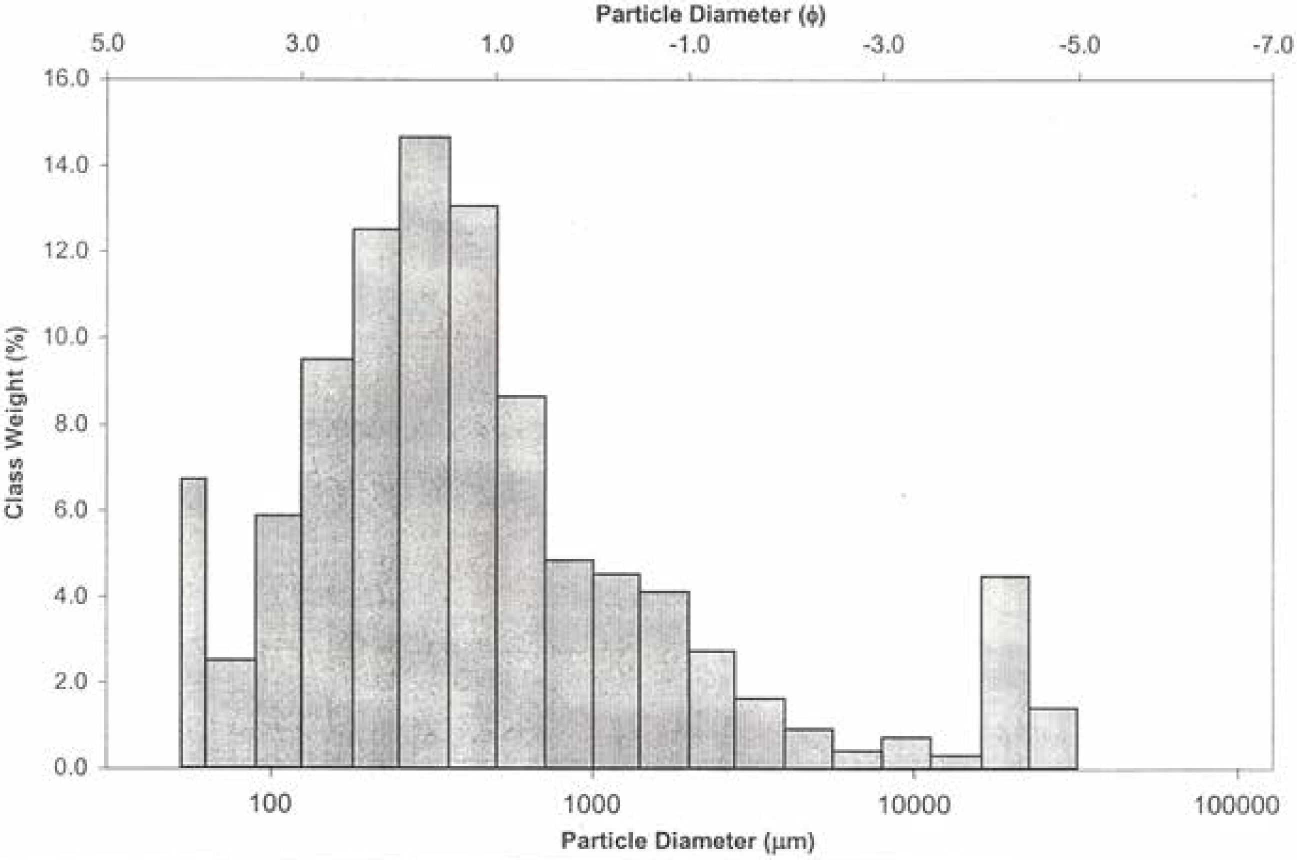
	μm	φ
MODE 1:	302.5	1.747
MODE 2:	58.00	4.113
MODE 3:	19200.0	-4.243
D_{10}:	111.6	-1.508
MEDIAN or D_{50}:	351.5	1.508
D_{90}:	2843.8	3.164
(D_{90} / D_{10}):	25.49	-2.098
$(D_{90} - D_{10})$:	2732.3	4.672
(D_{75} / D_{25}):	4.194	7.689
$(D_{75} - D_{25})$:	614.6	2.068

GRAIN SIZE DISTRIBUTION

GRAVEL:	12.8%	COARSE SAND:	14.2%
SAND:	83.8%	MEDIUM SAND:	29.1%
MUD:	3.3%	FINE SAND:	22.9%
		V FINE SAND:	8.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	3.3%
COARSE GRAVEL:	6.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	1.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.3%	FINE SILT:	0.0%
V FINE GRAVEL:	4.5%	V FINE SILT:	0.0%
V COARSE SAND:	9.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1953.1	472.4	1.082	427.9	1.225	Medium Sand
SORTING (σ):	5062.3	4.005	2.002	4.116	2.041	Very Poorly Sorted
SKEWNESS (Sk):	3.558	1.190	-1.190	0.343	-0.343	Very Coarse Skewed
KURTOSIS (K):	14.75	4.247	4.247	1.547	1.547	Very Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **Inisfil DS** ANALYST & DATE: , 6/2/2003

SAMPLE TYPE: Unimodal, Moderately Sorted TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Medium Sand

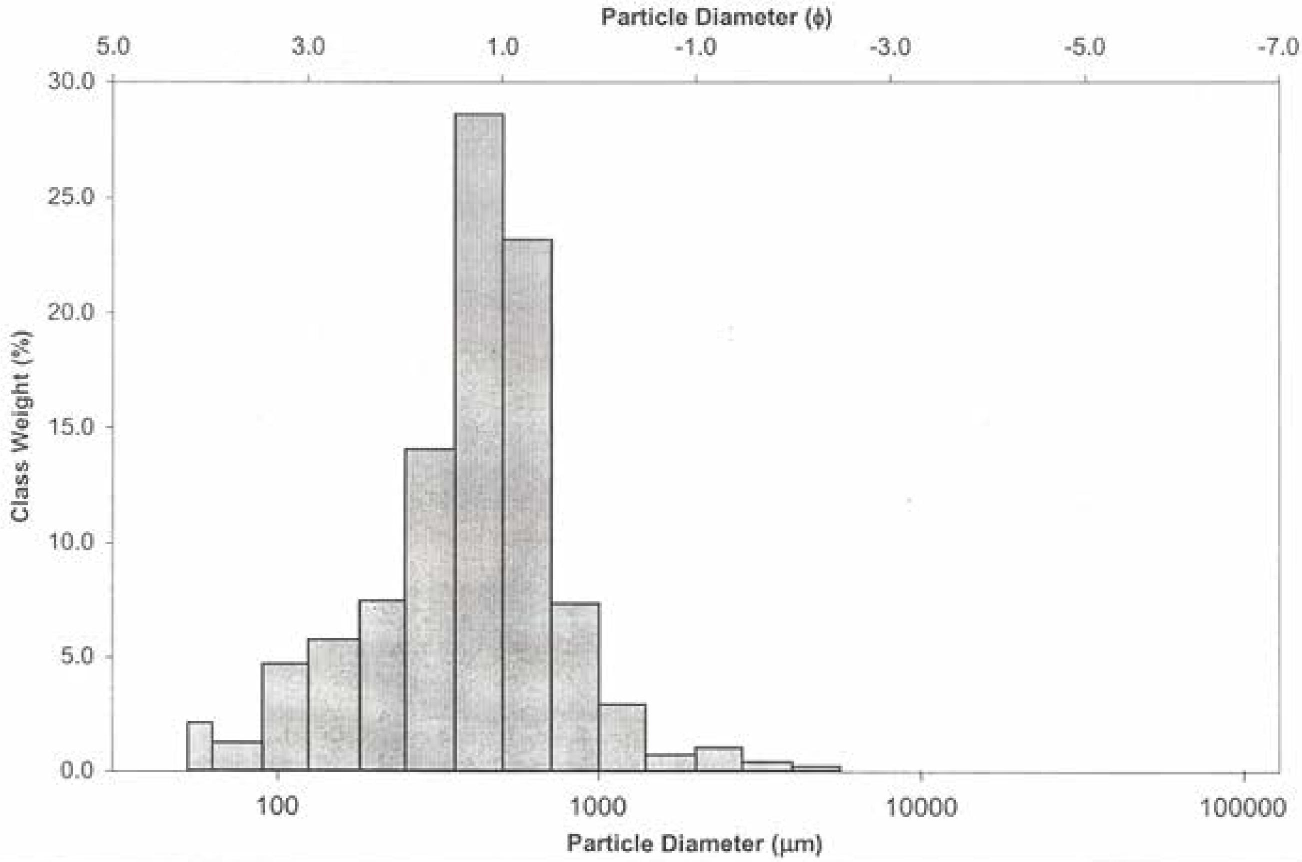
	μm	φ
MODE 1:	427.5	1.247
MODE 2:		
MODE 3:		
D_{10}:	151.1	0.323
MEDIAN or D_{50}:	426.0	1.231
D_{90}:	799.6	2.726
(D_{90} / D_{10}):	5.292	8.449
$(D_{90} - D_{10})$:	648.5	2.404
(D_{75} / D_{25}):	2.104	2.418
$(D_{75} - D_{25})$:	310.5	1.073

GRAIN SIZE DISTRIBUTION

GRAVEL:	1.6%	COARSE SAND:	31.3%
SAND:	97.4%	MEDIUM SAND:	43.4%
MUD:	1.0%	FINE SAND:	13.3%
		V FINE SAND:	5.8%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.2%	FINE SILT:	0.0%
V FINE GRAVEL:	1.4%	V FINE SILT:	0.0%
V COARSE SAND:	3.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	499.1	395.2	1.340	390.4	1.357	Medium Sand
SORTING (σ):	412.6	1.945	0.960	1.884	0.914	Moderately Sorted
SKEWNESS (Sk):	4.623	-0.270	0.270	-0.219	0.219	Fine Skewed
KURTOSIS (K):	36.61	4.057	4.057	1.228	1.228	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **Inisfil US** ANALYST & DATE: , 6/2/2003

SAMPLE TYPE: Unimodal, Moderately Well Sorted TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Coarse Sand

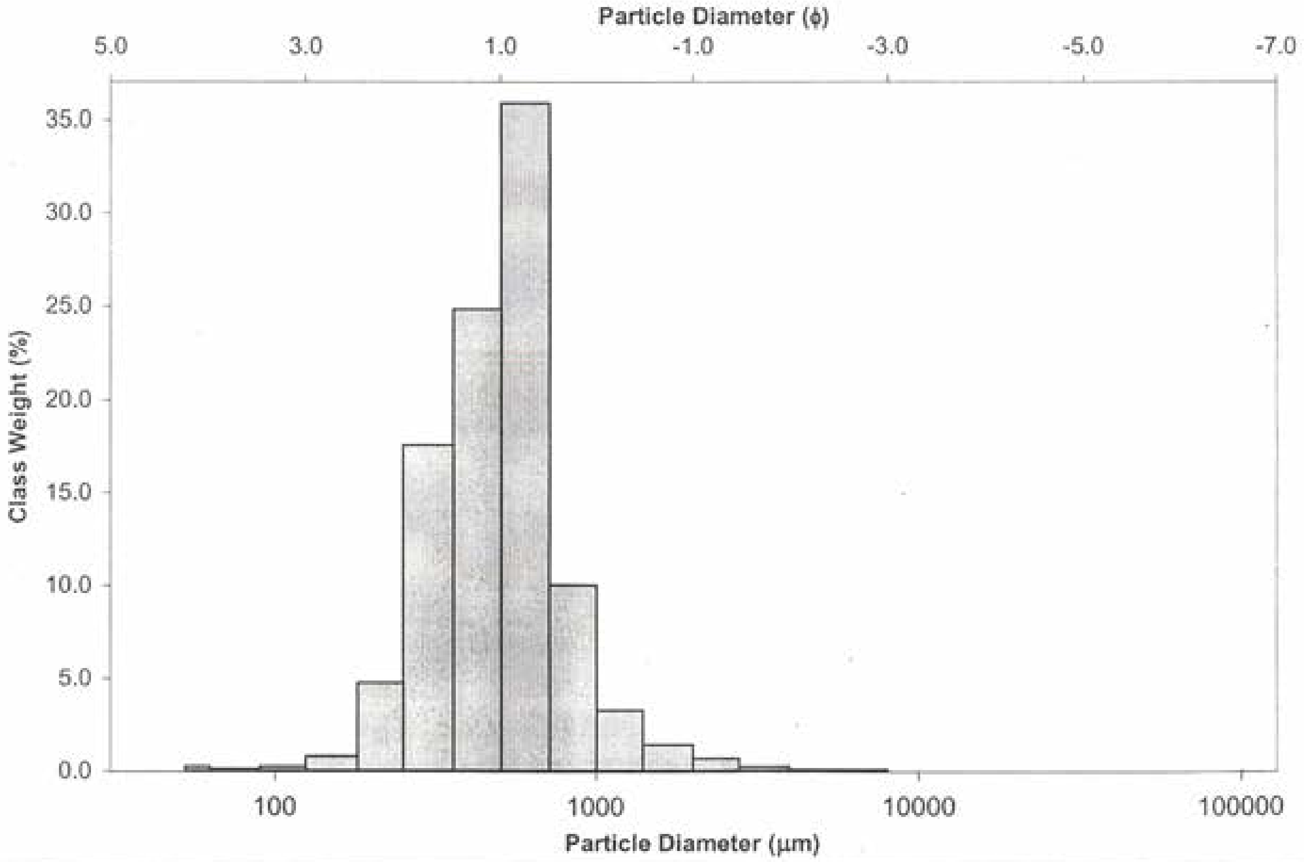
	μm	φ
MODE 1:	605.0	0.747
MODE 2:		
MODE 3:		
D_{10}:	272.5	0.231
MEDIAN or D_{50}:	508.8	0.975
D_{90}:	852.2	1.876
(D_{90} / D_{10}):	3.127	8.127
$(D_{90} - D_{10})$:	579.7	1.645
(D_{75} / D_{25}):	1.784	2.328
$(D_{75} - D_{25})$:	284.2	0.835

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.8%	COARSE SAND:	46.5%
SAND:	99.1%	MEDIUM SAND:	42.6%
MUD:	0.1%	FINE SAND:	5.3%
		V FINE SAND:	0.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.8%	V FINE SILT:	0.0%
V COARSE SAND:	4.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	561.2	492.5	1.022	479.1	1.062	Medium Sand
SORTING (σ):	335.6	1.591	0.670	1.539	0.622	Moderately Well Sorted
SKEWNESS (Sk):	4.970	0.234	-0.234	-0.122	0.122	Fine Skewed
KURTOSIS (K):	58.10	4.805	4.805	1.041	1.041	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **Penville**

ANALYST & DATE: , 5/30/2003

SAMPLE TYPE: Polymodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Fine Gravel

	μm	ϕ
MODE 1:	427.5	1.247
MODE 2:	4800.0	-2.243
MODE 3:	1700.0	-0.743
D_{10}:	246.8	-2.977
MEDIAN or D_{50}:	753.3	0.409
D_{90}:	7874.7	2.018
(D_{90} / D_{10}):	31.90	-0.678
$(D_{90} - D_{10})$:	7627.8	4.996
(D_{75} / D_{25}):	7.161	-0.882
$(D_{75} - D_{25})$:	2448.4	2.840

GRAIN SIZE DISTRIBUTION

GRAVEL:	30.5%	COARSE SAND:	21.3%
SAND:	69.3%	MEDIUM SAND:	26.6%
MUD:	0.3%	FINE SAND:	7.0%
		V FINE SAND:	2.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.3%
COARSE GRAVEL:	4.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	5.9%	MEDIUM SILT:	0.0%
FINE GRAVEL:	9.9%	FINE SILT:	0.0%
V FINE GRAVEL:	10.7%	V FINE SILT:	0.0%
V COARSE SAND:	11.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	2800.5	1047.3	-0.067	1050.7	-0.071	Very Coarse Sand
SORTING (σ):	4793.4	3.828	1.937	3.838	1.940	Poorly Sorted
SKEWNESS (Sk):	3.002	0.491	-0.491	0.339	-0.339	Very Coarse Skewed
KURTOSIS (K):	12.69	2.521	2.521	0.902	0.902	Mesokurtic

GRAIN SIZE DISTRIBUTION