Important!

Please also note that while CH staff are agreeable to the use of this report for frequency flow rates up to the 100 year event, we require that flood plain mapping studies/analysis of the Regional Storm (i.e. Hurricane Hazel) utilize the Regional storm flood flow rates determined in the previous study completed under the auspices of the Federal-Provincial Flood Damage Reduction program (Procter and Redfern, 1986). Please also note that the specific volumetric recommendations for Stormwater Management for future land use have been superseded by the more detailed Indian Creek Subwatershed study (Philips Engineering, 2004) completed on behalf of the Town of Milton.

Disclaimer

BRONTE CREEK WATERSHED STUDY

Appendix 6

Hydrology and Stream Morphology Study

Progreston Dam, Bronte Creek

Conservation Halton

March 2002

BRONTE CREEK HYDROLOGY AND STREAM MORPHOLOGY STUDY

PLANNING & ENGINEERING INITIATIVES LTD.

April, 2003

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1.0 INTRODUCTION

It has become increasingly necessary, in this age, that the multiple use of rivers focus not only on the needs of humankind but also on those needs of all other users in the ecosystem. To this end it is important that management of rivers through the watershed and subwatershed planning process allows the regeneration of all ecosystem elements, not just those that are of short-term (or economic) gain to humans. This is resulting in the revised attitude that rivers are part of an ecosystem whose parts are in a state of dynamic balance at any moment and may change, often suddenly, from the status of dependence to one of independence. The drainage basin, channel and hydrological processes are being seen as sets of interdependencies whose interactions tend toward some equilibrium state but may divert on one path or another, depending on basin circumstances. This is very important in studies of fluvial geomorphology, primarily when one considers that a change in any one geomorphic variable in a drainage basin results in a morphological change in another part of the basin. One important change is an alteration in the degree of development in a basin, or the hydrological response of the basin and the subsequent geomorphological consequences of that change. We now recognize that changes in a watershed alter erosion potential and morphological characteristics in other parts of the watershed and into receiving basins. Increased development pressures in the Indian Creek subwatershed will have an impact on that system and the Bronte system as well. Therefore, it is important that a detailed hydrology and stream morphology study be undertaken.

1.1 Purpose and Objectives

The Bronte Creek Hydrology and Stream Morphology Study will provide important information and analysis on which to base decision-making and recommendations of the Watershed Plan. The objectives of the study include the following:

- ✓ Characterization of the primary hydrologic processes within the Bronte Creek watershed;
- ✓ Creation of a representative hydrologic model of the Bronte Creek Watershed;
- ✓ Compilation of a digital database of observed and calculated streamflow and observed rainfall records for the Bronte Creek;
- ✓ Assessment of stream morphology type and parameters for primary reaches of the Bronte Creek, including broad scale assessment of stream types which are of higher sensitivity to erosion due to land use changes;
- ✓ Compilation of representative stream reaches to be used to assess erosion sensitivity;
- ✓ Assessment of potential impacts due to proposed land use changes on the hydrologic process and flow response. This component of the assessment will be primarily focussed on proposed development

within the Indian Creek subwatershed, which has been identified as the primary area of urban expansion within the Bronte Creek watershed;

- ✓ Provide comprehensive recommendations of measures required to mitigate adverse impacts to watershed hydrology due to existing and future land uses (including erosion, low flow and storm flow response); and
- ✓ Provide recommendations for Best Management Practices, which should be considered to maintain and enhance hydrologic processes and to maintain suitable morphologic processes throughout the watershed.

1.2 Study Methodology

The study consists primarily of two parts, specifically the hydrology and the stream morphology components.

For the first component, a watershed model was developed to form the basis of the hydrologic and geomorphological analysis. The model quantified changes in the hydrologic response of the study watershed resulting from the proposed development scenarios or any stream rehabilitation/enhancement programs. For this purpose, a physically-based hydrologic model of the study watershed, for existing, future and ultimate conditions, was developed using the GAWSER (Guelph All-weather Sequential-Events Runoff) model.

For the second part, a thorough morphological assessment of the existing conditions of the Bronte Creek system and its subwatersheds, using existing digital and ortho-rectified mapping as well as stream-side assessments, was conducted. Field investigations into the existing geomorphological conditions in the study area as validation of the morphological assessment were performed. In conjunction with this, each series of reaches was characterized and categorized according to the Rosgen Classification, with field verification.

Additionally, erosion analyses were undertaken with respect to specific concerns surrounding the Indian Creek subwatershed and the downstream receiving portions of Bronte Creek. In order to complete this section of the study, information on flows, sediment budgets, energy transfers, cross-sectional and reach profiles and bankfull cross-section and planform characteristics were collected. This information was essential as background information to which future changes to the Bronte Creek system can be assessed.

The specific tasks related to the Bronte Creek Hydrology and Stream Morphology Study were as follows:

1.2.1 Hydrology

The following steps were required to set-up, calibrate/validate and apply the GAWSER model for the Bronte Creek watershed:

a. A detailed model of the watershed using GAWSER as a continuous, deterministic, physically based model to determine runoff, baseflow and surface/groundwater interactions was developed. To be consistent with modelling of watersheds with GAWSER over the last 5 to 6 years, the response units within each subcatchment element needed to be re-measured. This was accomplished with GIS tools. In the 1993 study, the channel routing cross-sections were taken from the previous Procter & Redfern (1986) floodline mapping study (HEC2 and HYMO data). These cross-sections do not have very good resolution for the low-flow channels (within the bankfull flow area) and we required new cross-section data (which was done in conjunction with the geomorphological surveys with Total Electronic Station [TES]).

b. Spot low flow measurements at nodal points and other points of interest were collected during the morphological analysis were used to characterize relative contributions from each subwatershed and the main branch. These spot flow measurements and the Halton Aquifer Management Plan Report (Halton Region, 1995) were used to adjust the model for the contributions from baseflows.

c. Validation of the GAWSER model was undertaken for the existing land use scenario.

d. Flow responses at each subwatershed outlet and other key points of interest were determined.

e. A monthly water balance based on the hydrologic model and the regional hydrogeology was developed.

f. Water balance results for each subwatershed were assessed. The expected annual runoff, infiltration, and evapotranspiration results for existing and proposed conditions were determined.

g. The impact of surfacewater taking was determined.

h. A flow frequency analysis for each node in the watershed for existing, future and ultimate watershed conditions, based on 30 years of data for 2, 5, 10, 25, 50, 100 and Regional Storm flow rates, was performed. A low flow frequency analysis for each node for existing, future and ultimate conditions was performed, based on 30 years of data for annual, minimum and average seasonal and $7Q_{20}$ flow rates.

1.2.2 Stream Morphology

The following steps were required to complete the fluvial geomorphology assessment for the Bronte Creek watershed:

a. Geomorphological assessments were completed for primary stream reaches of the Bronte Creek and the Indian Creek (1 per subwatershed, multiple locations on Indian Creek and Bronte Creek, approximately 15 to 20 in total). This assessment focused on Rosgen classification, assessment of geometric characteristics including bankfull morphometry, profile, and planform characteristics relating to meander belt width and other meander geometries. This analysis provided an indication of stability and was used for predictive purposes. Sections were specifically located at stream types and reaches which are most sensitive to land use / hydrological changes.

b. The representative stream reaches were walked. Erosion assessments were conducted for representative reaches of each primary watercourse in the study area, including information on soils, slopes, extent of erosion, types of erosion and any structures at risk. Sites were determined for additional monitoring with particular focus on the Indian Creek subwatershed and the Bronte Creek receiving basin, which received multiple assessments. Permanent erosion sites were established within the watershed.

c. Rapid Geomorphic Assessments for primary reaches of Bronte Creek and its tributaries were undertaken with respect to current stream form and sensitivity to changes in watershed hydrology. A series of spot discharge measurements were taken at each contributing basin (minimum 11 subwatersheds and the Main Branch) to determine relative contributions of base flow from each tributary and the Main Branch of Bronte Creek. A model showing relative contributions and expected conditions with respect to changing land use or hydrological conditions was presented. The spot flows were also used in the hydrologic modelling and low flow exercises.

d. Sediment (bed, bank, bedload and total suspended solids) and erosion assessments (erosion pins, monitoring) at each spot discharge sampling location were completed over the course of the study. This was necessary information to assess the proper geomorphological functioning of the system, which cannot be determined with any degree of accuracy by a rapid geomorphic assessment alone. As a matter of course, the data were collected and summarized before final analysis was undertaken.

e. Morphological assessment of channel geometries at each spot discharge sampling location required a detailed surveying using TES. The survey provided profile and stream information for meander characteristics and bankfull geometries. This was necessary information to assess the proper geomorphological functioning of the system, which cannot be determined with any degree of accuracy by a rapid geomorphic assessment alone. The data were collected and summarized before the final analysis was undertaken.

f. Reaches in the Indian Creek subwatershed and the receiving reach were selected for detailed erosion control assessment and monitoring. At these sites, detailed assessments of critical shear strengths, shear stresses relating to existing flow conditions and the propensity for further erosion in anticipation of changes in the hydrological characteristics of the watershed (usually consistent with increased development upstream) were provided. These sites were also surveyed in detail using a TES.

2.0 WATERSHED CHARACTERIZATION

2.1 General Description of Watershed

The Bronte Creek watershed drains 312.5 km^2 in south-western Ontario (see **Figure 2.1.1** for location map). Bronte Creek begins near Morriston and travels in south-easterly direction over the Niagara Escarpment. It then travels though a narrow valley before discharging into Lake Ontario. The Bronte Creek watershed is bounded to the south-east by Lake Ontario, to the west by Spencer Creek, to the northwest by the Grand River and to the northeast by Sixteen Mile Creek.

The Bronte Creek outlets through the western part of Oakville. There are several small communities within the watershed including Carlisle, Freelton, Strabane, Lowville and Progreston.

The main branch of Bronte Creek is approximately 48 kilometres long, located on a till plain and has an average channel slope of 0.005 m/m. The streambed profile for Bronte Creek is illustrated in **Figure 2.1.2**. From Morriston, the creek travels through a relatively flat channel until it reaches the Niagara Escarpment where the slope increases. At Progreston it follows a glacial spillway until it reaches the Niagara Escarpment. This spillway exhibits a broad flat floodplain, formed by melt-water during the glacial melt. The lower section of Bronte Creek flows through a deep narrow valley downstream to Bronte Harbour where it discharges into Lake Ontario.

There are 9 major tributaries to Bronte Creek. These are shown on **Figures 2.1.3a** and **2.1.3b** and will be discussed in detail in the following sections. **Figure 2.1.4** displays the quaternary geology of the watershed and is assessed further in Section 2.3.3.

The till moraine, in the upper part of Bronte Creek, and the Niagara Escarpment, in the middle of the Watershed, are the dominant factors influencing the streamflow response of the Watershed. These factors combine to produce the distinct streamflow response of Bronte Creek discussed throughout this report.

2.2 Overview of the Surfacewater Flow Cycle

This section gives a general overview of the surfacewater flow component of the hydrologic cycle to provide the reader with a basic understanding of the physical processes that characterize the streamflow in the Bronte Creek watershed. For a more complete understanding of the processes involved in surfacewater flow in a watershed, please refer to this subject (e.g., Viessman et al., 1977; Linsley et al., 1982).

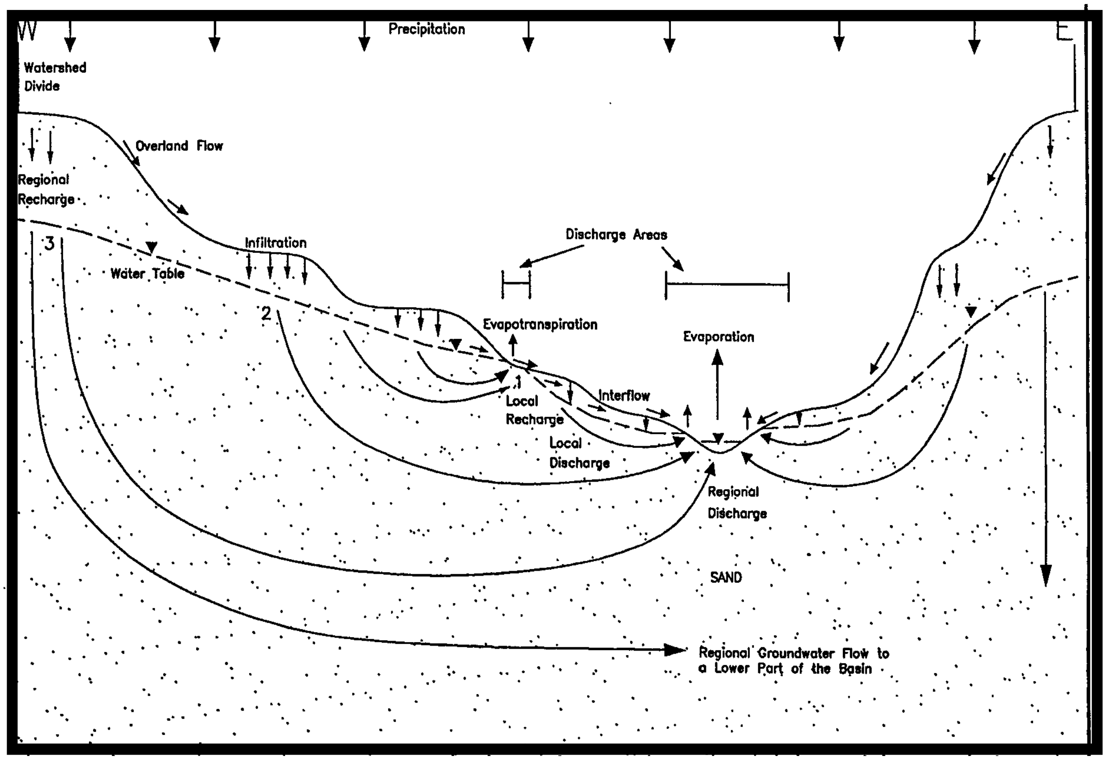
Figure 2.2.1 illustrates each part of the hydrologic cycle. The hydrologic cycle is the cycle of water movement through the earth-atmosphere system, initiated through the collection of water vapour by evaporation and transpiration from water and land surfaces (including vegetation). This water is released into the atmosphere (clouds), condenses and is deposited on land by precipitation. At the earth's surface, the precipitation is stored on the surface (e.g., lakes) or at depth (groundwater) or is evaporated or transpired to repeat the next cycle.

The hydrologic cycle begins with rain or snow (precipitation) falling to the ground. The amount and rate of precipitation that actually arrives at the ground surface is controlled by the prevailing weather system that generated the precipitation on a regional scale. At the more localized scale, topography and land use cover influence the actual precipitation amounts arriving at the ground surface.

This water (as rain, snowmelt or both) either runs off across the ground surface directly to a surface watercourse, infiltrates (percolates) into the ground to recharge groundwater storage or goes back to the atmosphere by evapotranspiration. The amount of water that actually infiltrates is controlled by the rate of precipitation input (rainfall or snowmelt), soil type (e.g., clay, silt, sand or gravel), ground surface conditions (e.g., frozen, cracking) and vegetative cover (e.g., pasture, forests). In some areas (e.g., hummocky ground), the surface topography has created large depressions, which require several metres of water to pond before overland flow occurs. Consequently, water in these depressions either percolates downward and contributes to groundwater and subsurface storage or evaporates back to the atmosphere.

Runoff water collects in stream channels that lead to larger channels or discharge to ponds, wetlands or lakes. While in these ponds or lakes, part of this water returns to the atmosphere by evaporation, or it may percolate into the ground, or spill to downstream channels. The travel time of flow in these stream channels is governed by the length, slope, roughness and cross-sectional shape of these channels. If the flow is high and rapid enough, water may overtop the channel banks, flooding the adjacent land area.

Anywhere along the length of these stream channels, discharge from groundwater storage (either regional, localized, or interflow) can contribute to the flow in the channel. These groundwater contributions to streamflow are governed by the surrounding topography, surficial geology and bedrock geology.



Source: Bronte Creek Watershed Study: Preliminary Investigation and Progress Report, Conservation Halton, January 2000.

Figure 2.2.1 Generic Illustration of the Hydrologic Cycle

2.3 Factors Influencing Surfacewater Characteristics

2.3.1 Introduction to Surfacewater Characterization

The purpose of the surfacewater characterization is to describe the dominant watershed characteristics that influence surfacewater flow.

Water in the river is the result of precipitation that has fallen on the watershed over time. Water resulting from precipitation gains entry to the river following three main paths: by directly falling on the river surface, by running over the land surface to the river (surface runoff) or by infiltrating into the ground and reappearing as groundwater discharge (springs or seeps) along the river.

It is important to note that not all of the precipitation that falls on the watershed makes it to the river. A portion of the precipitation that falls returns to the atmosphere by evaporation from open water surfaces, or is used by plants through transpiration. A portion of the water infiltrates into the ground, and may leave the watershed as groundwater and discharge to adjacent watersheds.

The path water follows in a watershed will determine to a great extent how the watershed responds to precipitation. The local climate and physiography (surficial geology, topography and land use) are dominant factors that influence how water is delivered to the streams and rivers that form a watershed. Streamflow is the response to how water is delivered to the streams and rivers forming the drainage network of a watershed. Each of these factors must to be considered when describing the surfacewater characteristics of a watershed.

2.3.2 Climate Setting

The climate of southern Ontario is characterized as having warm summers, mild winters, a long growing season, and usually reliable rainfall. The climate within southern Ontario differs somewhat from one location to another, and from one year to the next. Spatial variations are caused by the topography and varying exposure to the prevailing winds in relation to the Great Lakes. The Niagara Escarpment also affects the climate within the Bronte Creek watershed.

According to Brown et al. (1974), the Bronte Creek watershed is located in South Slopes climatic region. The mean annual precipitation for the Bronte Creek watershed is about 762 mm. The mean annual evapotranspiration is about 610 mm. The area has an annual frost free period of 140 days, with a 205 day growing season. The Bronte Creek has a mean daily temperature of -5°C in January and 21°C in July (Brown et al, 1974).

2.3.3 Physiography

At a local elevation of over 290 m, the Niagara Escarpment is the dominant physical feature in the Bronte Creek watershed, dividing the watercourse into upper and lower reaches. Formed from the erosion of gently dipping limestone and other sedimentary rocks, the Escarpment has been further shaped and partially buried by glacial fluvial and post-glacial activity.

Valleys formed from the combined erosive action of pre-glacial streams and glaciers heavily dissect the local Escarpment face. These re-entrant valleys act as conduits, channelling feeder tributaries from above the Escarpment to the main branch of Bronte Creek. Further erosion and weathering has produced several interconnecting fissures that caused large blocks of dolostone to detach from the Escarpment face. The Milton Outlier is the largest feature of this type in the watershed. The Escarpment continues to actively erode, generating a talus slope of large blocks at the base of the cliff face.

Resistant Escarpment cap rocks form a gently rolling plateau in the western reaches of the Bronte Creek watershed. Dolostone from the Amabel Formation is occasionally exposed as a limestone plain over much of this area. Thin veneers of coarse Halton Till cover portions of the plain to a depth of several metres. Close to the Escarpment, hummocky terrain which is part of the Waterdown Moraine system, buries the till and limestone plain in a complex of sand, silt and gravel outwash deposits. Drumlin fields and associated outwash deposits occupy the western portions of the watershed. The Galt Moraine is located in the north end of the watershed and is a groundwater source.

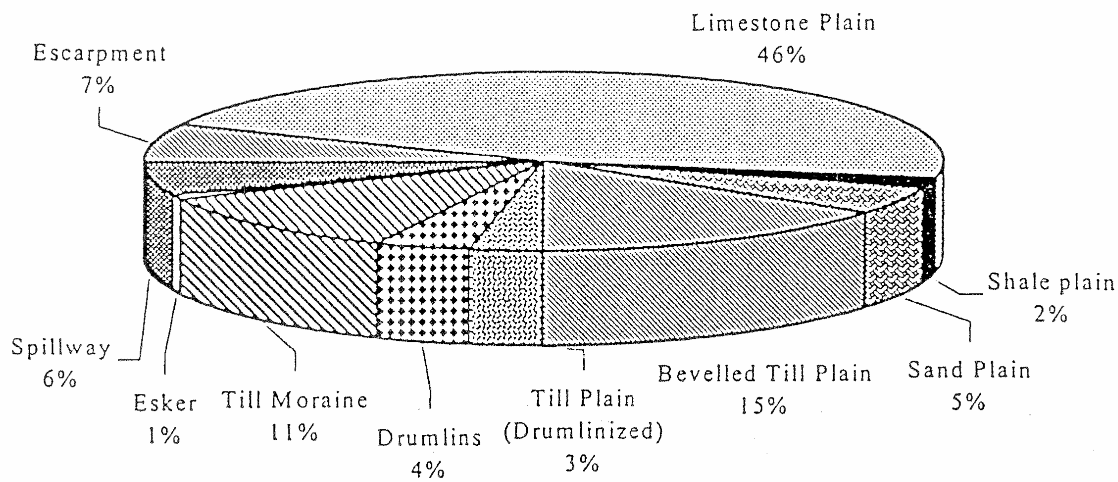


Figure 2.3.1 Physiography of the Bronte Creek Watershed

Unlike the resistant dolostone plateau, the bedrock below the Escarpment is composed of more erodable shale. The soft red shale of the Queenston Formation is well exposed in broad plain running parallel to the Lake Ontario shoreline. Numerous valleys have been incised in the bedrock by postglacial and fluvial erosion. **Figure 2.3.1** describes the relative contributions by various physiographic regions.

Thick spillway deposits of sand and gravel bury the shale closest to the Escarpment, forming part of an important aquifer system. To the east, veneer of clay-rich Halton Till covers a portion of the watershed, forming a bevelled, and occasionally, drumlinized till plain. About twelve kilometres from the Lake Ontario shoreline, a narrow band of hummocky till moraine, known as the Trafalgar moraine, forms a local watershed divide diverting the lower tributaries of the Bronte Creek into a single main channel. The lower reach of the creek is constrained within a deep, narrow shale bedrock valley that is up to 30 metres deep and as little as 100 metres wide in some locations.

2.3.4 Streamflow

Long-term monitoring of streamflow has been conducted in the Bronte Creek watershed since 1964 with the installation of the first continuous recording water level gauge near Zimmerman (02HB011) by the Water Survey of Canada (WSC). This gauge measured 78% of the flow in the Bronte Creek system. In 1977, a second gauge was installed by the WSC at Progreston (02HB016), which monitored 51% of the flow upstream of Zimmerman. The Progreston gauges were removed in 1985, whereas the Zimmerman was shutdown in 1987. A third gauge was installed at Carlisle (02HB022) in 1989, and has continued to operate ever since. This third gauge measures flows in the upper 37% of the Bronte Creek watershed.

The Progreston and Zimmerman gauges operated concurrently during the period 1977-1985. This makes it possible to ascertain flow contributions from different parts of the watershed relative to the total flow at the Zimmerman Gauge. **Figure 2.3.2** gives the mean monthly flow volumes at all three gauges for their entire period of records. Notice that the flows are highest during the spring freshet (March and April) and late autumn and lowest during the summer months.

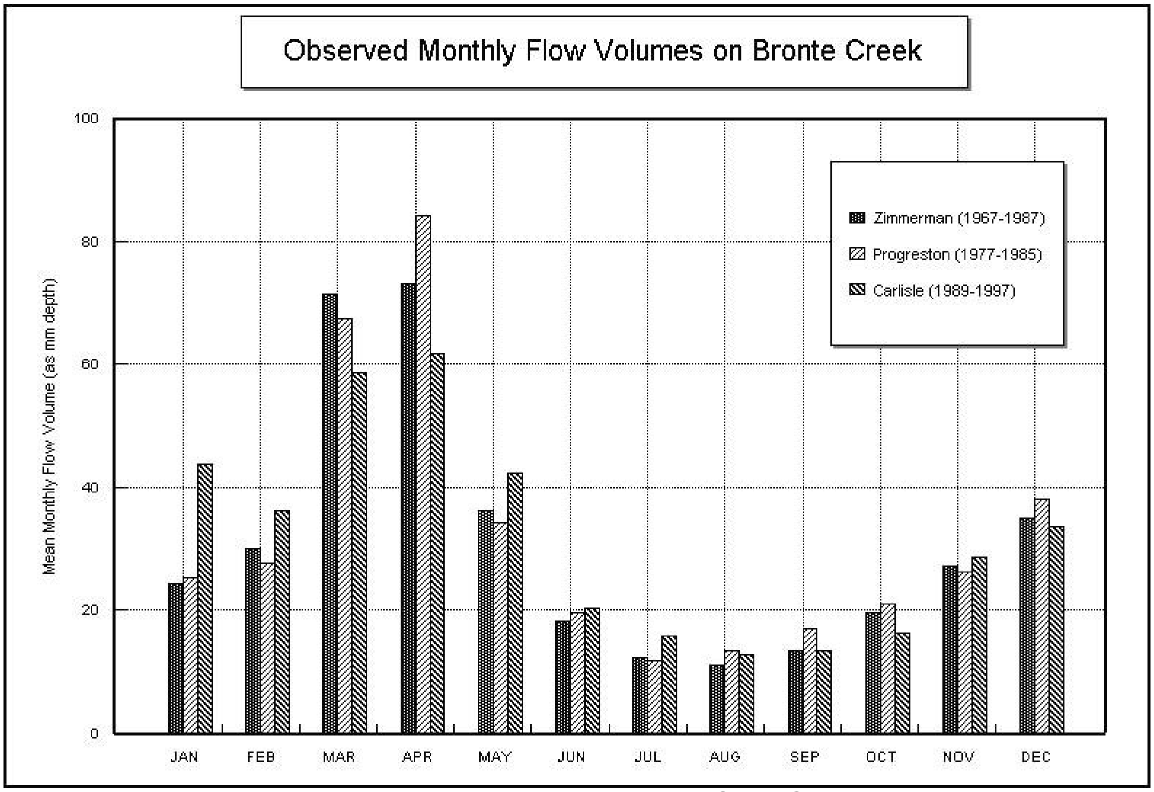


Figure 2.3.2 Mean Monthly Flow Volumes at Three Bronte Creek Gauges

The influence of topography, geology and climate on the flows along the length of Bronte Creek are evident as one looks at the relative contributions from the different parts of the watershed. For instance, in a watershed that is homogenous in terms of topography, geology and climate, one would expect the contributions from each part of the watershed relative to the total flow at the outlet to be in the same proportion as their contributing drainage areas. In this regard, the homogeneity in the Bronte Creek flows is clearly evident. For instance, the drainage area for the Progreston gauge represents 50% of the total to the Zimmerman gauge, and yet it contributes about 52% of the total flow. The slightly higher flow contributions relative to the drainage area percentages for the upper portions of the watershed are attributed to higher precipitation amounts occurring in the headwater areas. Low flow augmentation resulting from the Mountsberg Reservoir causes the summer flows at Progreston to be slightly higher than those at the Zimmerman gauge. The monthly flow pattern for the Carlisle gauge is very different from the other two gauges primarily because it is measuring flows for the 1989 to 1997 period, whereas the other gauges monitored flows before 1987.

Differences in topography and geology between the upper and middle parts of the watershed are evident in the hourly hydrographs for two specific event periods. **Figure 2.3.3** shows the observed flows at the Progreston and Zimmerman gauges for the period March 23 to April 15, 1985, while **Figure 2.3.4** presents the hydrograph plots for July 4 to 9, 1984. The influence of the reduced infiltrability for the soils in the middle part of the watershed that result in 'peaker flows' at the Zimmerman gauge can be noticed. Moreover, the streams in these areas (e.g., Limestone Creek) are much steeper than in the headwater areas causing a faster runoff response. Furthermore, the hydrograph at Progreston shows a more gradual or 'damped' response from the upstream areas. In addition, the time base for typical snowmelt event (see **Figure 2.3.3**) is much longer than for a typical rainfall event (see **Figure 2.3.4**).

Further evidence for climate influences on the streamflow response of Bronte Creek can be seen **Figure 2.3.5**, which gives the time-series of annual maximum flows at the Carlisle and Zimmerman gauges for the combined period of 1964 to 1997. Here, we see lower peak flows during the early part of the 1970s, higher flows through the late 1970s and early 1980s, and lower flows towards the end of the 1980s. The data for the Carlisle gauge in the 1990s suggests a rising trend in peak flows to 1997. In other parts of southern Ontario, flows have been greatly reduced due to severe drought conditions in the late 1990s.

As illustrated in **Figure 2.3.6**, more than 75% of the annual maximum flows in Bronte Creek occur during the 'spring freshet' in the months of March and April, when flood flows result from snowmelt or a combination of rain and snowmelt on frozen ground conditions. In recent years, more maximum flows are occurring in January and February, when early winter thaws and significant rainfalls contribute to high flows. Flood flows in the late summer and early fall period are typically caused by tropical storm systems, a period when the infiltration capacity for most soils in the area is reduced to 25 to 35% of their mid-summer values. Here, the runoff potential is at its highest without a snowpack.

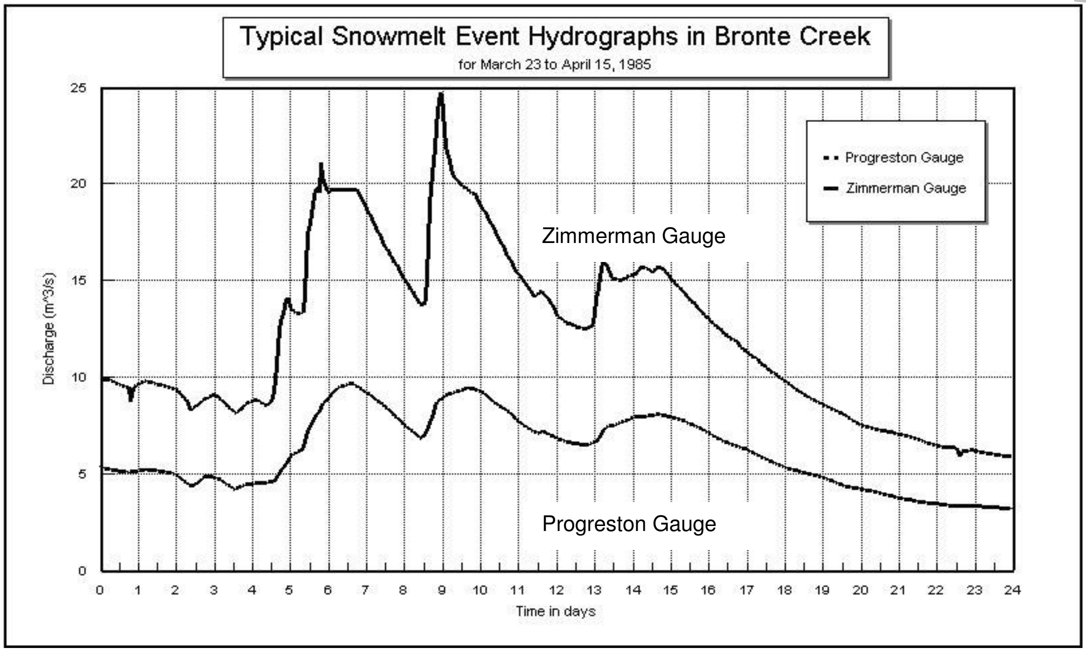


Figure 2.3.3 **Observed Hydrographs at Two Locations for March 23 to April 1985**

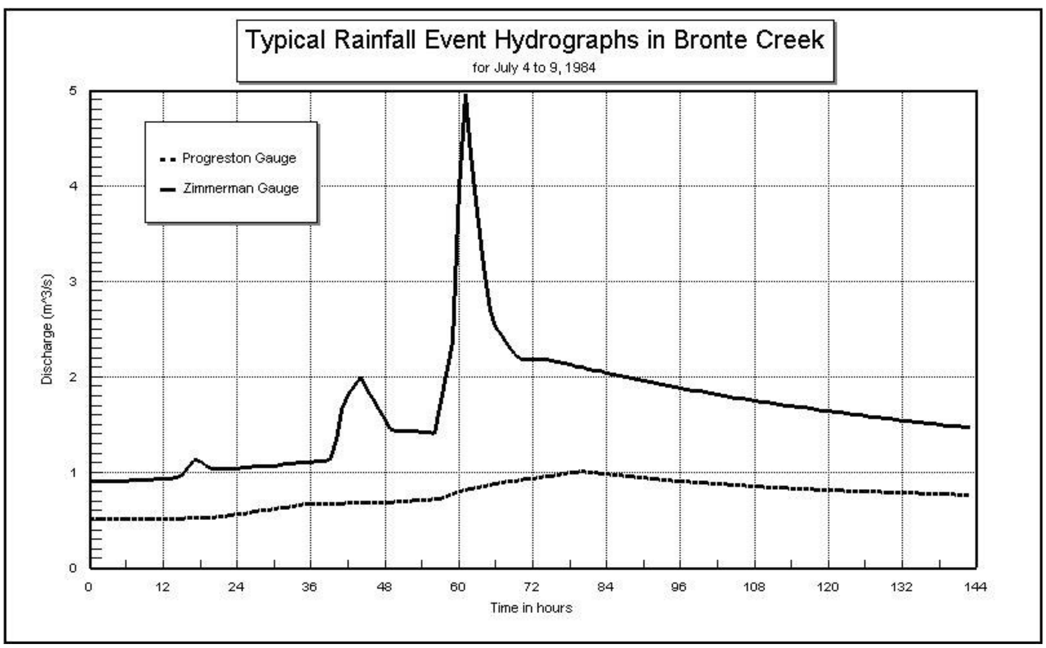


Figure 2.3.4 **Observed Hydrographs at Two Locations for July 4 to 9, 1984**

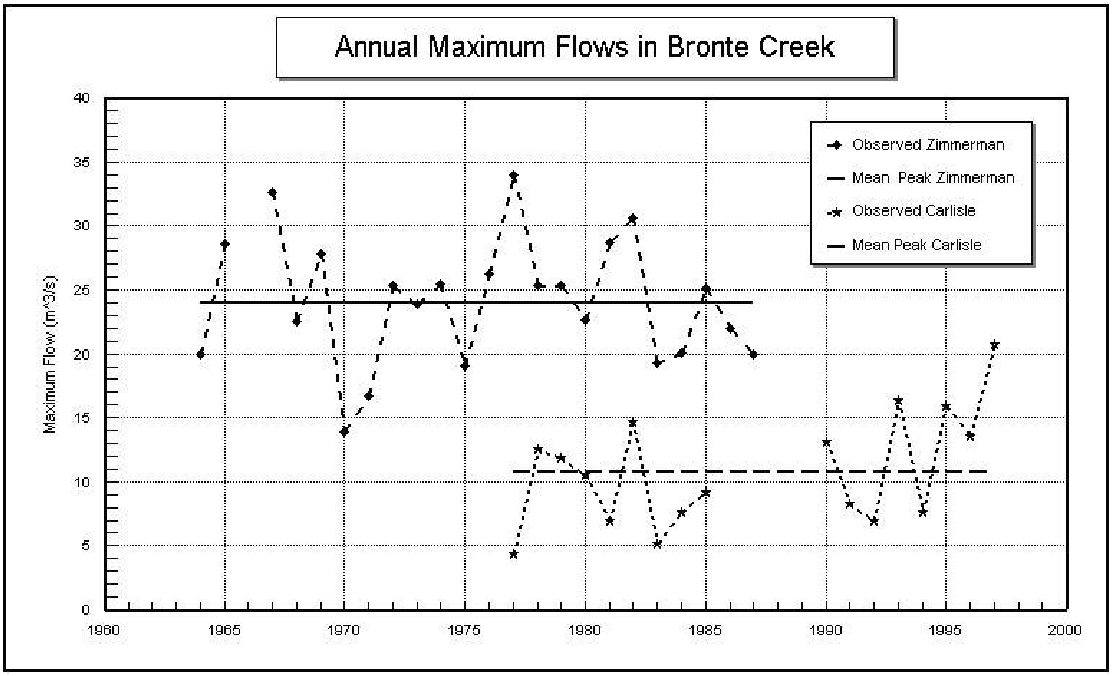


Figure 2.3.5 Time-Series of Annual Maximum Flows in Bronte Creek

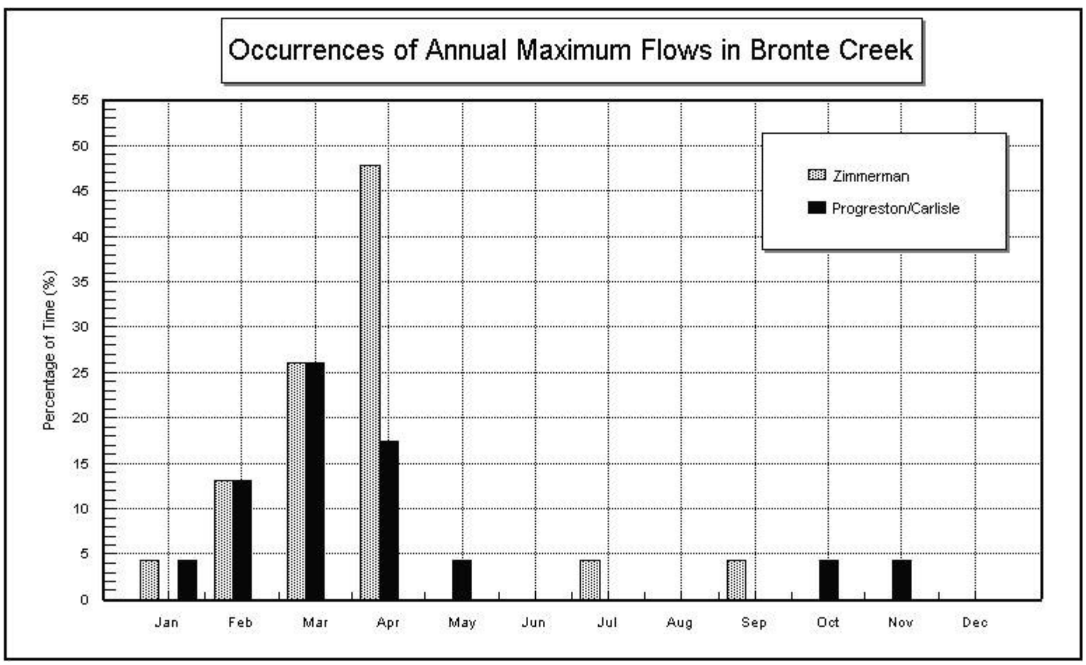


Figure 2.3.6 Occurrence of Maximum Flows by Month in Bronte Creek

A comparison of unit area flood flows for two locations within the Bronte Creek watershed is presented in **Figure 2.3.7**. Notice that the unit flood flows are much higher at Zimmerman gauge relative to Progreston/Carlisle primarily because of the reduced infiltrability and faster runoff response for the middle part of the watershed (e.g., Limestone Creek) as noted above. The higher peak flows for the Zimmerman gauge may also be caused by higher rainfall intensities due to orthographic effects introduced by the Niagara Escarpment.

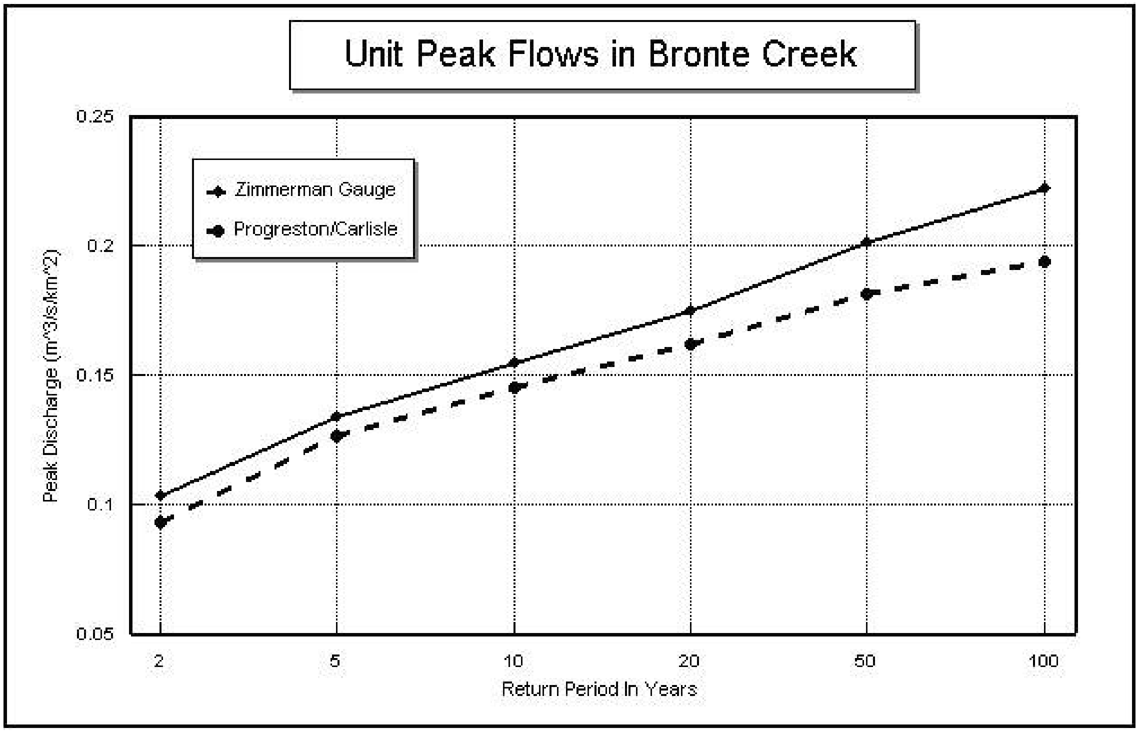


Figure 2.3.7 Unit Area Peak Flows in the Bronte Creek Watershed

Figure 2.3.8 gives the time-series of annual minimum daily flows for the Zimmerman and Carlisle gauges for the combined 1968 to 1997. This plot shows some of the same climate variability that was evident in a similar plot for annual maximum flows. The lowest minimum flows occurred in the late 1960s and early 1970s, but were higher during the late 1970s and 1980s, after Mountsberg Reservoir was built to provide some low flow augmentation as well as for flood control.

According to **Figure 2.3.9**, more than 90% of the low flows occur in the late summer and early autumn (July to September). A comparison of unit area low flows in Bronte Creek at two locations is presented in **Figure 2.3.10**. Generally, the unit 7-day low flows are much higher for the Progreston/Carlisle gauge combinations because other augmenting influence of Mountsberg Reservoir.

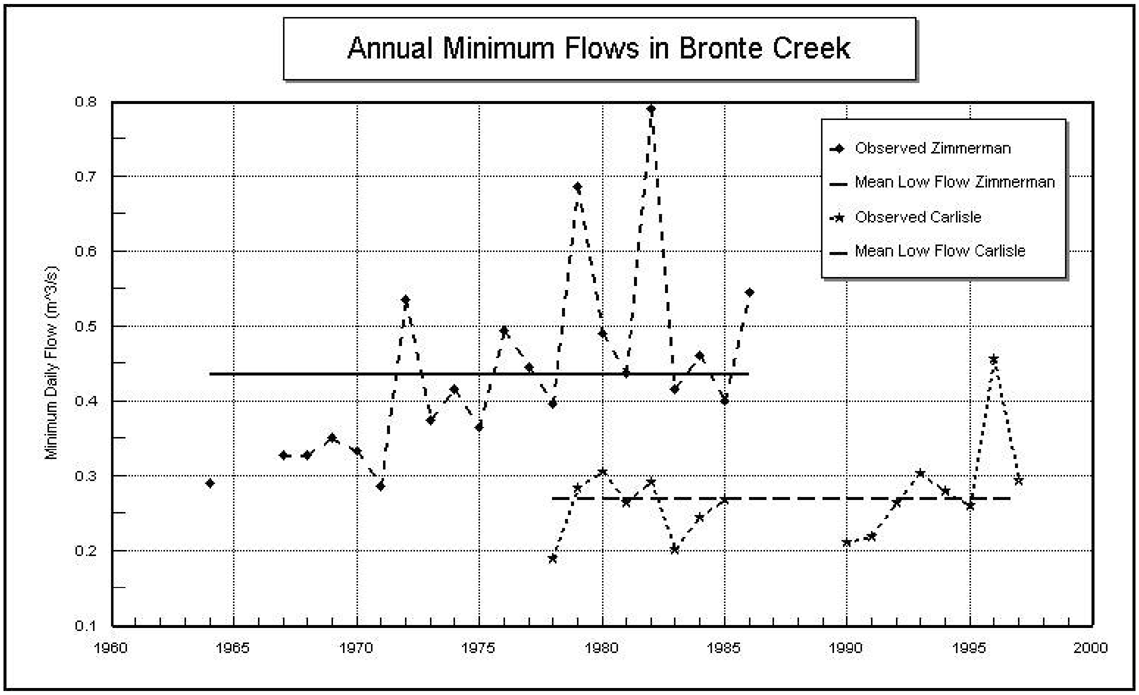


Figure 2.3.8 **Time-Series of Annual Minimum Daily Flows in Bronte Creek**

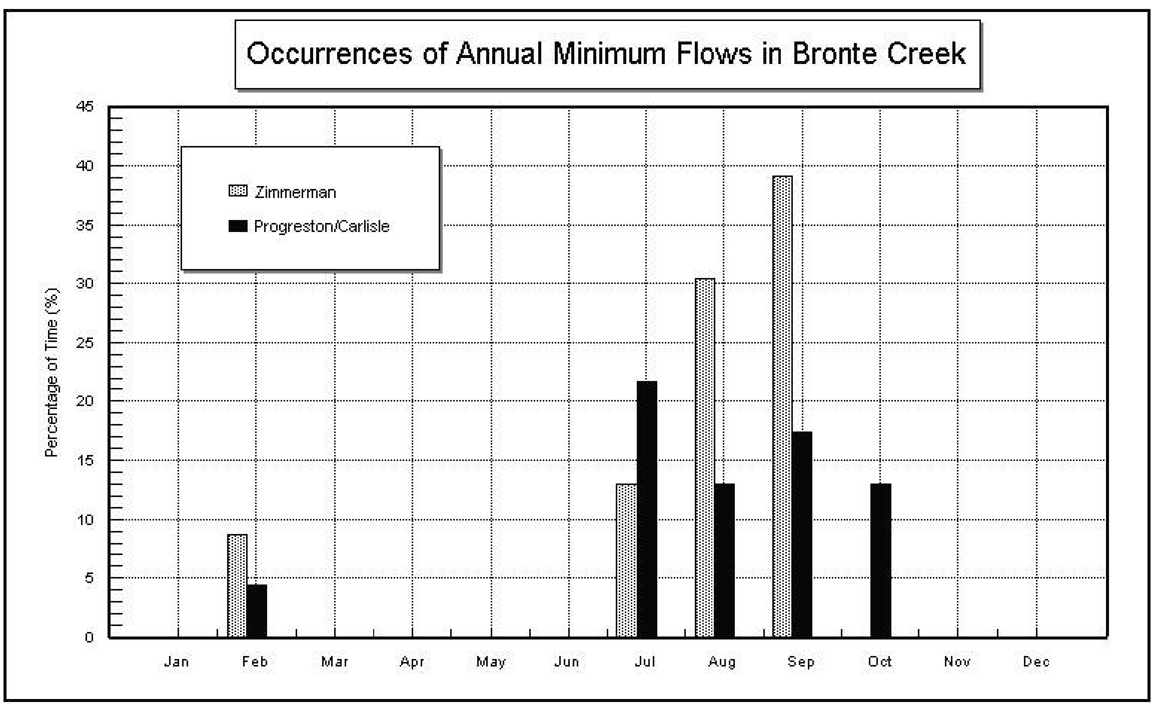


Figure 2.3.9 **Occurrence of Minimum Daily Flows by Month in Bronte Creek**

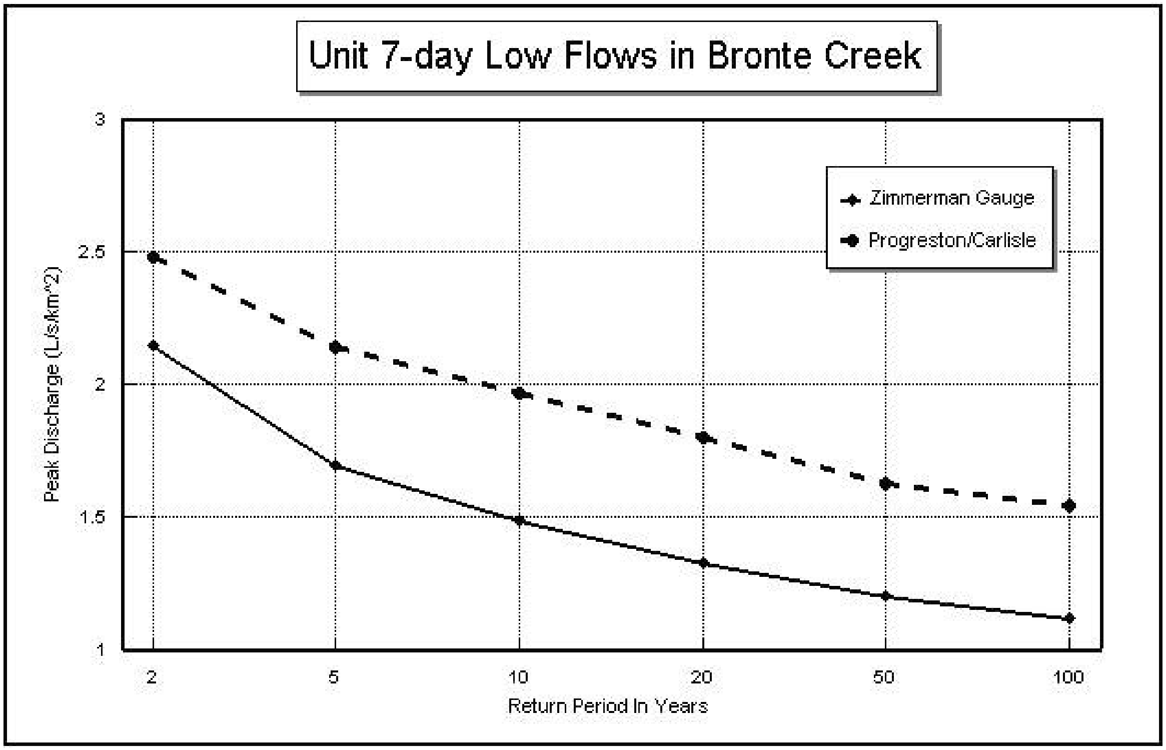


Figure 2.3.10 Comparison of Unit Area Low Flows in Bronte Creek at Two Locations

The low flow or dry weather flows can be characterized by examining the flow duration curves for all three gauges within the study area, as given in **Figure 2.3.11**. Generally, flows less than the 10% duration represent the flood flow portion of the curve. Notice how the curves tend to flatten out for durations greater than 60% as values approach the summer discharge amount (about 0.2 to 0.3 m^3/s) for the Mountsberg Reservoir. It is difficult to compare the curves for each gauge because the Zimmerman gauge flows are so much higher than the Progreston or Carlisle values. Consequently, the unit area flow curves are presented in **Figure 2.3.12**.

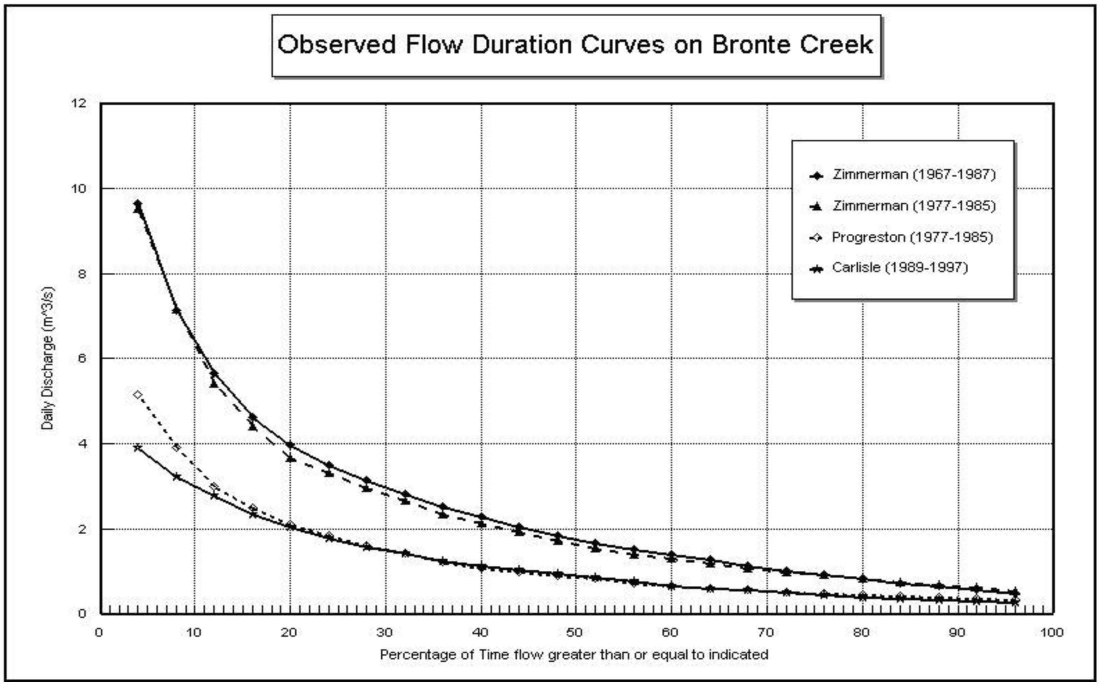


Figure 2.3.11 Flow Duration Curves on Bronte Creek

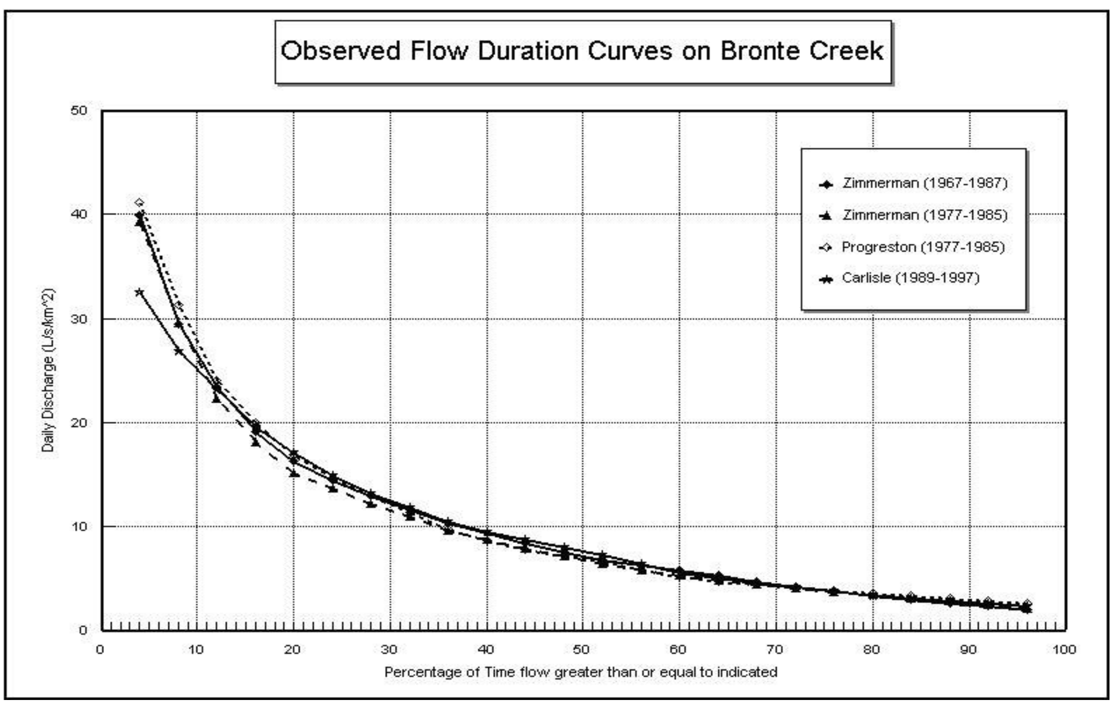


Figure 2.3.12 Comparison of Unit Area Flow duration Curves for Bronte Creek

2.3.5 Withdrawals

At present there are about 22 watertaking permits issued within the Bronte Creek watershed of which 10 are assumed to be active surfacewater permits. All of these are located downstream of the Mountsberg Reservoir. Reference should be made to **Table 2.3.1** and **Figure 2.3.13** for a description of the watertaking locations and flow rates.

Table 2.3.1 Water Withdrawals within the Bronte Creek Watershed

ID	Catch	Client Name	Surf/Ground	Pond Type	Specific Purpose	Max L/d	L/min
1	1200	Cedar Springs Community Club	Surface		Golf Course Irrigation	90920	377
2	1260	Indian Wells Golf Club	Surface	Bypass	Golf Course Irrigation	981936	2046
3	1222	Conestoga Golf and Country Club Limited	Ground		Other - Dewatering		682
4	1260	Quinton	Surface		Miscellaneous	-	
5	1340	Canada Brick Limited	Surface		Industrial	-	24
6	1180	Cedar Springs Ski Club	Surface		Snowmaking	818280	568
7	1240	Hutchinson J.F.	Surface		Field and Pasture Crops	1963872	1364
8	1340	Mikalda Farms Limited	Surface		Other - Miscellaneous	1136500	796
9	1180	Nelson Aggregate Co.	Ground	Pit or Quarry	Pits and Quarries	1363800	946
10	1180	Nelson Aggregate Co.	Ground	Pit or Quarry	Pits and Quarries	5891616	4091
11	1180	Nelson Aggregate Co.	Ground	Pit or Quarry	Pits and Quarries	1360800	946
12	1180	Nelson Aggregate Co.	Ground	Pit or Quarry	Pits and Quarries	5889600	4090
13	1240	Hochstein M.	Surface		Other - Miscellaneous	61371000	42619
14	1180	Nelson Aggregate Co.	Ground	Pit or Quarry	Pits and Quarries	5891616	4091
15	1221	McColl	Surface		Miscellaneous	-	
16	1180	Nelson Aggregate Co.	Ground	Pit or Quarry	Aggregate Washing	1363800	946
17	1260	Lowville Golf Club	Surface		Golf Course Irrigation		
18	1282	Hughes	Ground		Agricultural	-	
19	1260	Indian Wells Golf Club	Surface	On-Stream	Golf Course Irrigation	954660	1591
20	1260	Indian Wells Golf Club	Surface	Mixture of types	Golf Course Irrigation	981936	2046
21	1080	Taziar R.	Surface		Unknown	54552	500
22	1080					491422	
23	1050	Mountsberg Reservoir				0	
24	1120					454545	
25	1100					172800	
26	1080					851011	
27	1080					189840	
28	1032					850000	
29	1120					156900	

2.3.6 Groundwater

The groundwater system within the Bronte Creek watershed is a complex system due to the presence of the Niagara Escarpment, buried bedrock valleys, and various creek systems. The groundwater movement generally reflects the surficial topography and flows from north and west to Lake Ontario.

Groundwater recharge generally occurs in areas above the Escarpment while groundwater discharge zones occur at local creek systems and along the toe of the Escarpment.

Two unique areas of groundwater movement exist with the Bronte Creek Watershed, where subsurface flow does not follow the surface topography and leaves the watershed. In the Campbellville area a bedrock valley directs groundwater to the Milton area and in the southwest a very weak bedrock valley exists and redirects groundwater to the Grindstone system.

Groundwater quality and quantity into the Amabel formation above the Escarpment is generally satisfactory with most wells being drilled into bedrock. The Queenston Shales are located below the Escarpment and are inferior in water quality and quantity.

For additional information, reference should be made to the Halton Region Aquifer Management Plan (Phase 1 Report: Background Hydrogeology) as prepared by The Regional Municipality of Halton (1995).

2.4 Characterizing the Surfacewater Hydrology System

The characteristics of the surfacewater flow system in the Bronte Creek watershed are described qualitatively in this section. Upon examination of several information sources (e.g., Pleistocene geology and soil maps, land cover information, streamflow data, streambed profiles, topographic maps), 9 'sub-basins' or Zones of Uniform Meteorology (ZUMs) with tributary creeks have been identified within the Bronte Creek watershed, where the surfacewater flow characteristics are generally uniform or consistent (refer to **Figures 2.1.3a** and **2.3.1b**). Additional information is provided in **Appendix A**. These will be described in detail in the following sections. The watershed has been divided further into upper, middle and lower Bronte Creek, based on the Niagara Escarpment. **Table 2.4.1** gives a summary of the characteristics for the tributary creeks.

Table 2.4.1 Summary of Creek Characteristics				
Creek	**Catchments**	**Area km^2**	**Dominant Soil Type**	**Land Use**
Upper Bronte	1011, 1012, 1013, 1100, 1140	50.	Wentworth till	Agriculture
Strabane	1031, 1032	22.0	Gravel / Wentworth till	Agriculture
Mountsberg	1050, 1080	57.	Wentworth till	Agriculture
Flamboro	1120	9.4	Laclustrine and outwash sand	Agriculture
Kilbride	1161, 1162, 1165	44.2	Outcrop complex	Agriculture
Willoughby	1180	12.9	Halton till	Agriculture
Middle Bronte	1200, 1240	7.4	Halton till	Agriculture
Limestone	1221, 1222	40.0	Outcrop complex / Halton till	Agriculture
Lowville	1260	9.1	Halton till	Agriculture
Indian	1281, 1282, 1283, 1284, 1285, 1291, 1292, 1293	42.1	Halton till	Agriculture
Lower Bronte	1270, 1340, 1360	17.4	Halton till	Agriculture. /Urban
		312.38		

2.4.1 Upper Bronte Creek

The headwaters of the main branch of Bronte Creek are found near Morriston. From Morriston downstream to its confluence with Strabane Creek, Bronte Creek meanders through a series of wetlands associated with the Beverly Swamp Complex. Downstream through Carlisle, the creek flows through agricultural fields and disturbed floodplain areas associated with Courtcliffe Park and the Carlisle Conservation Area. Stream gradient is relatively low. Mountsberg Creek enters Bronte Creek at Courtcliffe Park within this reach.

2.4.2 Strabane Creek

Strabane Creek begins within the Beverly Swamp and flows through the hamlet of Strabane before discharging to Bronte Creek downstream of Brock Road.

2.4.3 Mountsberg Creek

The headwaters of Mountsberg Creek originate within the Badenoch-Moffat Swamp complex. Groundwater discharge emanating from the wetland complex and Galt Moraine provide coldwater conditions downstream to Mountsberg Reservoir and the Galt Moraine also provides groundwater inputs. Mountsberg Creek enters Bronte Creek near Courtcliffe Park.

2.4.4 Middle Bronte Creek

At Progreston, Bronte Creek plunges over the Niagara Escarpment and flows through a re-entrant valley feature that extends downstream to Lowville. With the exception of the Cedar Springs community, this valley is characterized by a mosaic of mature, native vegetation communities. This moderate-to-high gradient reach is fed by groundwater inputs that emanate along the valley walls. Flamboro Creek, Kilbride Creek, Willoughby Creek and Limestone Creek enter Bronte Creek within this reach.

2.4.5 Flamboro Creek

Flamboro Creek begins from a series of wetlands associated with the Lower Mountsberg Creek complex and the North Progreston Swamp. A large on-line pond, found within the Carlisle Golf and Country Club, is located at the downstream boundary of the swamp, between the CNR tracks and Carlisle Road. Below the pond, the creek re-enters a wetland system that gives way to deeply incised valley (Bronte Creek Escarpment Valley) extending downstream to Bronte Creek. Flamboro Creek enters Bronte Creek downstream of the Progreston dam.

2.4.6 Kilbride Creek

Kilbride Creek originates above the Niagara Escarpment within the Guelph Junction wetland complex. Immediately upstream of Kilbride, flows may become intermittent during drought conditions. However, groundwater inputs through the hamlet quickly restore flows through this reach. Downstream of Kilbride, the creek flows over a natural barrier associated with the Escarpment. The creek discharges to Bronte Creek immediately upstream of the Dakota Mills Dam.

2.4.7 Willoughby Creek

Willoughby Creek is fed by extensive groundwater discharge through the Medad Valley and the Bronte Creek Escarpment Valley. Although much of this relatively small subwatershed remains in a natural, wooded state, thermal impacts appear to be associated with number of on-line ponds adjacent to Cedar Springs Road. A dam located approximately 100 m upstream of the Bronte Creek confluence represents a barrier to fish passage for species entering Willoughby Creek from Bronte Creek. The creek flows into Bronte creek within the Cedar Springs Community.

2.4.7 Limestone Creek

The upstream branches of Limestone Creek arise from the Crawford Lake/Calcium Pits wetland complex above the Niagara Escarpment and from the Nassagaweya Canyon that cuts through the Escarpment between Crawford Lake and Rattlesnake Point. Upstream of Derry Road there is extensive forest cover and groundwater discharge contributes to stream flow. Downstream of Derry Road, forest cover dissipates and extensive agricultural land use predominates. Limestone Creek enters Bronte Creek upstream of No. 4 Sideroad.

2.4.8 Lower Bronte Creek

Downstream of Lowville, Bronte Creek flows within a well-defined valley feature downstream to Lake Ontario. Adjacent lands represent a mosaic of agricultural land uses and natural areas. South of the Queen Elizabeth Way, the watershed becomes predominantly urban to Lake Ontario. Downstream of the Rebecca Street road allowance, Bronte Creek enters an estuary marsh that extends downstream to Bronte Harbour. Lowville Creek, Mount Nemo Creek and Indian Creek discharge into this section of Bronte Creek.

2.4.9 Lowville Creek

Lowville Creek originates as a series of tributaries that arise along the Niagara Escarpment in the vicinity of the Conservation Halton administration office. These tributaries join downstream of Guelph Line and the main branch flows through agricultural fields and the Indian Wells Golf Course before discharging to Bronte Creek downstream of No. 4 Sideroad.

2.4.10 Indian Creek

Indian Creek arises as a number of small tributaries that emerge along the face of the Niagara Escarpment in the vicinity of Rattlesnake Point. Agricultural and settlement activities (woodland clearing, irrigation, cattle grazing, ponds\dams) within this subwatershed have resulted in degradation of the aquatic habitat. Although historically characterized as permanently flowing over much of its length, recent drought has resulted in intermittent flow conditions through the middle and lower reaches during the summer months. Indian Creek enters Bronte Creek downstream of No. 2 Sideroad.

2.4.11 Mount Nemo Creek

Mount Nemo Creek arises as a series of small tributaries that originate from the base of the Niagara Escarpment (Mount Nemo). This relatively small subwatershed is characterized by an intermittent flow regime. Mount Nemo Creek discharges to Bronte Creek immediately downstream of No. 2 Sideroad.

2.5 Characterization Summary

Specific characteristics found in the Bronte Creek watershed impose a dominant influence on the flow response in this watershed. The dominant characteristics identified include the Niagara Escarpment, limestone plain (Wentworth Till), till moraine in upper catchments, till plain (Halton Till) and limited municipal drainage.

The near absence of municipal drainage combined with the hummocky topography associated with the moraine system, have resulted in large areas with low surface drainage. In these areas, surface runoff is reduced as much of the precipitation is retained and either recharges the groundwater aquifers or evaporates.

The channel floodplain storage is a dominant factor in upper Bronte Creek. The main channel of Bronte Creek follows a broad, glacial spillway between Progreston and Lowville. The broad floodplains associated with these channels and flat channel slope results in significant channel floodplain storage. These floodplains act as large, natural reservoirs and dampen the flow response of water running off the steep moraines and drumlins in the study area that border these floodplains.

The middle part of the Bronte Creek watershed is dominated by the Niagara Escarpment. Steep slopes allow for an increased velocity of runoff velocity.

The lower part of Bronte Creek is also affected by the Niagara Escarpment as most of the lower tributaries begin in the Escarpment. These tributaries all join into one narrow deep valley for the last section of Bronte Creek before it discharges to Lake Ontario.

3.0 HYDROLOGY

3.1 Introduction

The purpose of the hydrologic analysis in this study was to provide the basis for assessment of flow conditions in the watershed and the response to rainfall events. This information can then be used for the assessment of flood potential, erosion conditions and flow variations with time.

This assessment was carried out with the use of computer modelling in conjunction with other technical analyses. Initially, an overall watershed model was developed to analyze watershed hydrology. This model used information on land use, soils, watershed topography, and the stream system to enable the prediction of flow rates in the stream during rainfall or snowmelt events. The watershed modelling also provides the basis for analyzing other stream characteristics such as low flows (base flow), water quality changes and fisheries habitat. The flow information generated by the watershed model has been used in subsequent sections of this study.

3.2 Information Sources

3.2.1 Meteorological Information

Long-term monitoring of meteorological quantities has occurred in the region surrounding Bronte Creek for more than 100 years. Historical data are primarily available from Environment Canada's Atmospheric Environment Service (AES). **Table 3.2.1** gives further details about the observing program for stations whose records have been reviewed in previous studies (e.g., Schroeter and Boyd, 1998; Schroeter & Associates, 1999; Schroeter et al., 2000b). All of the meteorological data assembled and processed during the Grand River Water Management Strategy Project, were used directly in the Bronte Creek Watershed Study. Aside from the three Indian Creek gauges (see Section 3.2.3), the only new meteorological data were provided by Conservation Halton.

In total there are 39 years of data available from AES. In particular, three long-term data sets have been edited to remove 'missing values'. These three data sets are for the Guelph OAC/Arboretum/Guelph Dam combination, Hamilton RBG and Pearson Airport. These data sets were provided by the Grand River Water Management Strategy and Climate Change Study. A 20 year dataset for Milton Kelso was available from a Golf Course Study by Burnside. As part of this study, the Hamilton RGB data set and the daily measurements provided by the GRCA for the AES station in Millgrove were used to create a fourth 39 year 'cleaned-up dataset'. These long-term datasets were all used for the long-term simulation outlined in Section 3.3.4. All the other AES data that were available were gathered during the 1993 study (Schroeter & Associates, 1993). The mean annual precipitation amount for these 39-year runs is 852 mm annually (see **Appendix A**).

To validate or confirm the parameter setting in the model, there were only 8 years of data that could be used, because that was the period of time when the two flow gauges stations, Progreston and Zimmerman, were open at the same time. The same 39 year data sets were used to drive these simulations, but only the 8 year portion from 1977 to 1985 were used. For the 8-year continuous simulation period the mean annual precipitation was 999 mm.

Table 3.2.1 Observing Climate Stations Available for Study

Station Name	Station Code	Owner	Available Period Of Record*	Data Collected
Burlington Eliz., GDN	6151057	AES	1961-1977	P,RG
Burlington Fire HQ's	6151059	AES	1970-1983	T,P,RG
Burlington TS	6151064	AES	1951-1992	T,P
Georgetown	6152691	AES	1960-1966	P,T
Georgetown WWTP	6152695	AES	1962-1999	P,T
Guelph Arboretum	6143069	AES	1975-1995	P,T,RG
Guelph OAC	6143083	AES	1960-1973	P,T,RG,E
Guelph Lake Dam	GRCA003	GRCA	1988-1999	P,T,RG
Hamilton RBG	6153300	AES	1960-1999	P,T,RG
Hornby IHD	6153545	AES	1967-1978	P,T,RG,E
Kelso CA		HRCA	1989-Present	T,P,RG
Millgrove	6155183	AES	1951-1999	P,T
Milton Kelso	6155187	AES	1966-1987	P,T,RG
Mountsberg	6145516	AES	1976-1985	P,RG
Mountsberg CA		HRCA	1989-Present	RG
Oakville SE WPCP	615N745	AES	1970-1992	T,P,RG
Toronto Pearson Int'l A	6158733	AES	1960-1999	P,T,RG

Notes: P – daily precipitation (rain and snow)
E - Pan evaporation estimates
T - daily maximum and minimum air temperature
RG - Recording raingauge (tipping bucket)

3.2.2 Snow Cover Patterns

Detailed information about snow accumulation characteristics according to different landscape units in south-western Ontario have been reported by Schroeter and Whiteley (1986), Schroeter (1988) and Burkart et al. (1991). Information about snow cover patterns is used directly in the step-up of the hydrologic model. See **Appendix A** for details.

3.2.3 Streamflow Data

Continuous streamflow measurements have been available within the Bronte Creek watershed at three gauge sites maintained by the Water Survey of Canada (WSC). As part of a landfill site monitoring project, Gartner Lee installed a gauge on the east branch of Indian Creek near the outlet of Subcatchment 1291. Additional streamflow measurements were collected during the course of the present study at two gauges within the Indian Creek watershed for the period April to September 2001 as shown in **Figure 2.1.3**. Moreover, operation of the old WSC Zimmerman gauge has been re-established by Halton Region and Conservation Halton in April 2001. **Table 3.2.2** summarizes the flow data available for this study. Additional information is provided in **Appendix D**.

The two WSC gauges, Progreston and Zimmerman, operated simultaneously for the period June 1977 to August 1985, and so daily flows were extracted from WSC's HYDAT CD-ROM to confirm the monthly parameter adjustment factors. However, for testing the model in event mode, open-water hourly flows were available for these two gauges from previous work (Schroeter & Associates, 1993) for 1982 to 1985 only. Hourly flows were later obtained from five gauges for the period April to September 2001, but the data from these gauges were not available for model testing here because there were insufficient events monitored due to the extremely dry weather (no rain). For those events that have been monitored during this period, the measurements require additional processing and quality assurance testing.

Table 3.2.2 Streamflow Data Available from Gauges within Bronte Creek

Station Name	WSC Station ID	Operational Period
Bronte Creek at Carlisle	02HB022	August 1989 to present
Bronte Creek at Progreston	02HB016	June 1977 to August 1985
Bronte Creek near Zimmerman	02HB011	October 1963 to May 1987
		Re-established April 2001
Indian Creek, East Branch (outlet of 1291)		Established by Gartner Lee
Indian Creek, East Branch (at node 6292)		April 2001 – Sept. 2001
Indian Creek, West Branch (at node 6284)		April 2001 – Sept. 2001

3.3 Hydrologic Modelling

3.3.1 Introduction

The analysis of existing hydrologic conditions in Bronte Creek was handled using the GAWSER (Guelph All-Weather Sequential-Events Runoff) model, a deterministic watershed model based on the HYMO format. It has been applied widely in Ontario for planning, design, real-time flood forecasting, and evaluating the effects of physical changes in the drainage basin (Schroeter & Associates, 1996; Schroeter and Boyd, 1998).

In 1992, the GAWSER program was adapted for continuous simulation work (in particular water balance assessments), and since then water quality routines (primarily sediment transport and in-stream temperatures) have been added as well. Since 1987, GAWSER has been applied in more than 50 watershed studies (including Laurel Creek, Blair/Bechtel/Bauman, Mill Creek and Eramosa River), and forms the primary flood forecasting tool at 10 Conservation Authorities in Ontario. The program has been tested and validated in event simulation mode with observed streamflow data from more than 104 gauges for 1500 gauge-events. In continuous simulation mode, the program has been validated with long-term streamflow data from more than 32 gauges comprising 300 gauge-years. For urban runoff modelling (required in most post-development scenarios), GAWSER has been validated with discharge measurements from more than 10 gauges representing 46 gauge-events. In short, GAWSER represents the state-of-the-art in hydrologic modelling in Ontario, capable of answering the complex questions about the hydrologic response of a watershed required in detailed watershed planning studies. By far, GAWSER has the most comprehensive snow accumulation, re-distribution and ablation/melt routines of any model currently available for use in Ontario.

There are two principal reasons for remodelling the hydrology of the watershed. The first is to update the watershed model, taking into account the development that has taken place since the previous model was completed and to consider areas of potential future development (e.g., Indian Creek) in greater detail. The second reason is to take advantage of the vast improvements to the GAWSER model within the last 7 to 8 years, particularly its application for continuous simulation, and its groundwater-surfacewater interactions.

Existing hydrology models, developed as part of past studies, were reviewed and used as a basis for modelling in this Study. In addition, topographic mapping, servicing plans, aerial photography, land use maps, quaternary geology maps, meteorological and flow data were also used in the analysis of the hydrologic conditions and in the preparation of the watershed model.

In 1992-1993, the GAWSER model was set-up for all 17 watersheds within the area comprising Conservation Halton, including the Bronte Creek watershed. The purpose of the 1993 study was to provide real-time flood forecasting procedures for the HRCA using an existing deterministic hydrologic software package.

The 1992-1993 GAWSER model of the Bronte Creek watershed comprised 18 subcatchment elements. It was initially calibrated and validated with streamflow data from 6 events (March-April 1982, June 1982, August 1982, April 1984, September 1986 and April 1987), three of which had significant snowmelt components. Later it was further tested in real-time data for August 1992 (Hurricane Andrew), December 1992-January 1993, and March 1994.

The updated model is composed of 32 subcatchment elements. The updated soil group/land cover types (response units) were included in the new model. The Quaternary Geology maps, for the area, were used to determine the soil groups. A detailed description of the GAWSER model and its application to this Study is covered in **Appendix A.**

3.3.2 Model Set-up

As shown on **Figure 3.3.1**, Bronte Creek has been divided into 32 subcatchment elements for hydrologic modelling purposes. These subcatchments were chosen to have stream crossings at all flow monitoring stations, to provide sufficient distributed flow inputs to the floodplain mapping (backwater curve) calculations, and to reflect the spatial variations in soil type, as well as present and future land use. Other subcatchments were delineated to improve modelling results based upon: i) large changes in longitudinal slope of major tributary streams within the subwatershed, ii) the need to have subcatchment shapes such that a single overland flow path length is representative, iii) the degree of imperviousness (e.g., can it be classed rural or urban), and iv) to isolate the drainage area contributing to large wetland or depression storage areas (kettles).

The subcatchment boundaries were marked by hand on 1:50,000 map sheet, from which drainage areas and stream lengths were measured. These boundaries were overlaid on the surficial geology (quaternary) maps, from which soil types and land cover areas were determined.

The total drainage area of Bronte Creek was found to be 312.5 km^2, with a mean subcatchment size of 10 km^2, and 24 channel routing reaches having an average length of 3200 m. One reservoir element (Mountsberg Reservoir) with significant storage has been identified and considered in the model. A more detailed study of Indian Creek has been requested which is why it has more subcatchment elements and channel reaches than the other areas considered.

The results of comparing the measured drainage areas with those published in previous studies for several key locations are summarized in **Table 3.3.1**.

Table 3.3.1 Comparison of Drainage Area Estimates for the Study Subwatersheds				
Location	**WSC**	**FDRP**	**1993**	**This Study**
Mountsberg Reservoir		37	40	37
Carlisle Gauge	117	115	120	116
Progreston Gauge	124	122	127	122
Zimmerman Gauge	235	235	233	245
Lake Ontario Outlet		310	304	313

To account for the wide variation in runoff generation response attributed to the different land cover features and soil types (e.g., source areas), the subcatchment elements were further subdivided into nine 'hydrologic response units' (HRUs); one impervious and eight pervious. These HRUs are defined in **Table 3.3.2**. Additional information on response units is found in **Appendix A**.

Open areas have low vegetal growth, like pastures, cropped fields, fallow and grasses. They are grouped together because they change from year-to-year. 'Low vegetative cover' is a more stable term for long-term modelling. The open water response unit (2) permitted a reasonable accounting of the evapotranspiration from these areas.

Table 3.3.2 Hydrologic Response Unit (HRUs) Definitions Applied to Bronte Creek	
Response Unit Value	**Description**
1	Impervious and bedrock
2	Open Water
3	Peat, Muck and Stream Deposits
4	Halton Till: Clay of silt till
5	Wentworth Till: Stoney, sandy, silt till
6	Lacustrine and Outwash Sand
7	Gravel
8	High Vegetation, Low infiltration (Includes Soil Types 3 and 4)
9	High Vegetation, High Infiltration (Includes Soil Types 5 to 7)

Soil type areas for each subcatchment were measured from the quaternary geology map of the area, the same information used in the hydrogeologic investigations. Forest cover information was taken from the 1:50,000 scale topographic map for the area. The drainage characteristics (e.g., hydraulic conductivity, soil-water contents, depression storage depths) for the various response units were taken directly from published information (e.g., Watt et al., 1989) and other studies involving applications of the GAWSER model (e.g., Schroeter & Boyd, 1998; Totten Sims Hubicki, 1998; Schroeter et al., 2000a). The elevation-area relationship for the Mountsberg reservoir was taken from data provided by Conservation Halton.

For rural subcatchments, impervious areas include roads and adjoining shoulders, lanes, ditches and stream channels. The total impervious area in a given subcatchment can be determined by measuring the length of the roads and streams from topographic maps, and multiplying by a representative width. In previous applications of GAWSER in southern Ontario, the imperviousness of rural watersheds usually represents about 1.5 to 3% of the area (Schroeter & Associates, 1996). The values used here (see **Table 3.3.3**) are comparable.

For subcatchments containing reservoirs or lakes with surface areas greater than 3% of the drainage area, the impervious total includes the surface area of the reservoir (or lake) under normal operating conditions. Subcatchments containing exposed bedrock had these areas included in their impervious totals.

The classification scheme for response units outlined here has been utilized in several recent hydrology studies (e.g., 16&18, 1999, Schroeter and Boyd, 1998; Schroeter & Associates, 1998; CH2M-Hill, 1996). Stream channel data is presented in **Appendix A**.

Table 3.3.3 summarizes the subcatchment characteristics for the Bronte Creek watershed. On the whole, 30% of the Bronte Creek watershed is forested. The upper part of the Bronte Creek watershed is comprised of 45% Wentworth Till, which is a stoney, sandy, silt till. The middle part of the Bronte Creek watershed is mainly composed of gravel, and outwash sand. The lower part of Bronte Creek is 85% Halton Till which is a clay or silt till.

Table 3.3.3 Subcatchment Characteristics for Existing Conditions in the Bronte Creek Watershed

Subcatchment	Area (km^2)	Length (m)	Width (m)	Imp RU1 %	RU 2 %	RU 3 %	RU 4 %	RU 5 %	RU 6 %	RU 7 %	RU 8 %	RU 9 %	FTB
1011	21.50	11000	3656	2	0	6.5	0.0	65.2	0.0	1.6	4.7	19.9	2.0
1012	8.35	5000	1667	2	0	22.4	0.0	40.8	0.0	1.8	24.7	8.2	2.0
1013	6.65	2000	667	2	0	17.1	0.0	26.0	0.0	26.4	13.0	15.6	2.0
1031	9.81	4500	1500	2.8	0	39.1	0.0	33.9	0.0	24.2	0.0	0.0	2.0
1032	12.20	1525	763	2.8	0	8.8	0.0	35.0	6.0	21.4	7.7	18.2	2.0
1050	37.09	12000	3536	2	6.2	10.8	0.0	43.2	1.9	0.0	10.5	25.5	2.0
1080	20.59	1030	515	2.6	0	19.3	0.0	25.7	2.3	15.2	26.6	8.3	2.0
1100	5.37	1074	537	5.6	0	0	0.0	8.4	62.9	14.2	0.0	8.9	2.0
1120	9.43	6000	2000	4.2	0	12.1	0.0	0.0	23.7	12.0	33.1	14.8	2.0
1140	8.19	1170	585	2	0	1	6.9	0.0	31.6	28.8	1.1	28.5	2.0
1161	25.69	9000	3000	2	0	21.2	0.0	32.7	0.7	5.3	21.8	16.2	2.0
1162	8.63	5900	1470	2	0	43	0.0	16	1.0	5.0	25	8.0	2.0
1165	10.03	669	334	0.5	0	30.6	0.9	2.2	9.3	14.7	34.4	7.4	2.0
1180	12.93	5000	2500	2	0	6.2	58.7	0.0	4.4	6.5	17.4	4.7	2.0
1200	3.55	710	355	2	0	0.9	39.1	0.0	0.0	8.1	28.4	21.5	2.0
1221	28.11	6000	4000	1.1	0	13.5	15.7	4.1	0.0	9.8	46.3	9.4	2.0
1222	11.91	1489	744	2	0	5.7	72.9	0.0	0.0	7.5	11.5	0.6	2.0
1240	3.86	429	286	2	0	18.6	60.2	0.0	0.0	0.0	19.2	0.0	2.0
1260	9.10	4500	2250	2	0	2.9	67.5	0.0	0.0	0.0	27.7	0.0	2.0
1281	6.91	4000	2000	2	0	1.9	86.5	0.0	0.0	0.0	9.6	0.0	2.0
1282	3.73	1243	622	2	0	3.5	79.4	0.0	0.0	0.0	15.1	0.0	2.0
1283	3.42	3500	1400	2	0	6.7	77.1	0.0	0.0	0.0	14.2	0.0	2.0

Table 3.3.3 Subcatchment Characteristics for Existing Conditions in the Bronte Creek Watershed													
Subcatchment	**Area (km^2)**	**Length (m)**	**Width (m)**	**Imp RU1 %**	**RU 2 %**	**RU 3 %**	**RU 4 %**	**RU 5 %**	**RU 6 %**	**RU 7 %**	**RU 8 %**	**RU 9 %**	**FTB**
1284	3.72	930	465	2	0	0	87.3	0.0	0.0	0.0	10.7	0.0	2.0
1285	6.23	1558	779	2	0	0	94.2	0.0	0.0	0.0	3.8	0.0	2.0
1291	2.43	3500	1167	2	0	0	98.0	0.0	0.0	0.0	0.0	0.0	2.0
1292	1.42	1014	676	2	0	0	89.1	0.0	0.0	0.0	8.9	0.0	2.0
1293	0.94	940	627	2	0	0	97.9	0.0	0.0	0.0	0.1	0.0	2.0
1301	4.93	822	548	2	0	1.2	93.2	0.0	0.0	0.0	3.5	0.0	2.0
1302	3.59	898	598	2	0	8.7	76.2	0.0	0.0	0.0	13.2	0.0	2.0
1315	1.34	200	355	2	0	26.9	46.9	0.0	0.0	0.0	24.2	0.0	2.0
1320	4.79	3000	1500	2	0	2.9	61.5	0.0	0.0	0.0	33.7	0.0	2.0
1340	8.95	471	314	2	0	6.5	57.6	0.0	1.1	0.0	31.6	1.3	2.0
1360	7.16	895	597	0.1	0	31.2	39.0	0.0	6.5	0.0	11.6	1.6	1.2

Note: Definitions for response units (RU's) provided in **Appendix A**.

In **Table 3.3.3**, length represents the longest distance of flow to the main channel. Width represents the overland flow to the off channel. RU 1 to RU 9 show the percentage of the catchment which is covered by that response unit, as described above. FTB is the base time factor used for the linear reservoir plus lag and route method of overland flow routing. FTB is typically 2 for rural subwatersheds that are less than 60 km^2 (Schroeter & Associates, 1996).

Appendix A (Section 2) gives additional information and details regarding the set-up of the existing conditions hydrologic model for Bronte Creek. This additional information includes the following:

- Response Unit Drainage Characteristics
- Subcatchment Characteristics
- Stream Channel Data
- Treatment of Detention Ponds and Marshes
- Treatment of Special Groundwater Seepage and Discharge
- Sensitivity Analysis
- Schematic Representation

3.3.3 Model Validation

Full details of the model validation exercise are given in **Appendix A** (Section 3). Overall, the agreement between observed and simulated flows was acceptable for this kind of study.

3.3.4 Continuous Simulations

The hydrologic model was applied for the period June 1, 1977 to September 22, 1985 when both the Progreston and Zimmerman gauges were in operation. The initial or starting conditions (e.g., initial snowpack, soil-water contents, and river flows) were estimated in the same manner as outlined in **Appendix A**, with one exception. Because the model was started on June 1, 1977, the initial snowpack depth and water contents can be assumed to be zero.

A first check on the results for the eight-year simulation is a water balance table produced automatically by the GAWSER program. **Table 3.3.4** gives the mean annual water balance quantities and how they are distributed by month throughout the year for Bronte Creek at the Zimmerman gauge. These quantities represent the aerial average of the entire drainage area upstream of the Zimmerman gauge.

The individual quantities in **Table 3.3.4** can be expressed in a water balance

[3.3.1] Precip = ET + Runoff + Baseflow + Losses

where 'Precip' represents the total precipitation (rainfall plus snowfall), ET is the combined evapotranspiration and sublimation total, 'Runoff' is the mean annual runoff, 'Baseflow' is the portion of the infiltrated water that returns to the stream, and 'Losses' signifies the amount of infiltrated water that does not return to the receiving stream. The 'Losses' total also includes water stored in the system, and is sometimes referred to as the 'net storage' term. For instance, the positive totals for 'Losses' during the winter months (e.g., December to March) represents snow on the ground, whereas the negative values during the summer months (e.g., July to August) denotes water pulled from soil-water storage. 'Total Flow' is the sum of 'Runoff ' and 'Baseflow'. **Table 3.3.4** can be reproduced for any point of interest in the watershed model. Water balance quantities for other points of interest will be shown in Section 5.2.

Table 3.3.4 Water Balance Summary For Hydrograph Bronte Creek Near Zimmerman
Period: 1977/06/01 to 1985/09/22 Area: 243.8 km^2

Month	Water Balance Quantities (mm) Precip.	ET	Runoff	Infiltration (Baseflow)	(Losses)	Total Flow
Jan	44.2	8.8	6.5	20.6	8.3	27.0
Feb	55.3	7.3	13.9	14.4	19.8	28.2
Mar	66.1	9.9	28.9	19.0	8.2	47.9
Apr	81.9	48.7	35.8	36.0	-38.6	71.8
May	85.4	86.0	4.7	30.1	-35.4	34.8
Jun	84.5	104.1	3.3	15.9	-38.8	19.2
Jul	88.7	96.5	5.2	5.8	-18.7	10.9
Aug	138.5	98.3	8.9	6.7	24.7	15.6
Sep	105.3	66.9	8.5	11.3	18.7	19.7
Oct	72.3	39.5	7.8	16.1	8.9	23.9
Nov	82.8	20.3	9.4	18.3	34.8	27.7
Dec	93.7	8.3	14.4	23.6	47.4	38.0
Total	998.6	594.6	147.1	217.6	39.2	364.8

From **Table 3.3.4**, one can see that the mean annual precipitation for the 1977-1985 water year period is about 999 mm, which is about 18% higher that than the long-term normal value for the area. The average annual evapotranspiration (plus sublimation) total is about 594 mm, or 8% higher than normal for this part of southern Ontario according to Brown et al. (1980) and OMNR (1984). This higher than normal evapotranspiration estimate is not unusual, because the precipitation amount is much higher as well. The mean annual runoff total is about 147 mm, of which 53% is generated during the months of February to April. The mean annual total streamflow is 365 mm, of which 60% appears as baseflow. Although not shown, the observed mean annual streamflow volume for the same time period is 378 mm, which is only 4% higher than the simulated value listed in **Table 3.3.4**. For the same modelling period, the simulated total streamflow for the Progreston gauge is within 1% of the measured volume.

Upon examination of **Table 3.3.4**, one can see that on the average 44% of total annual runoff volume occurs in March and April. The negative values for the 'losses' suggest that water is being pulled from soil-water storage in order to satisfy the evapotranspiration potential. Notice that for June, the mean precipitation is 84.5 mm, whereas the actual ET amount is 104 mm. Since 19.2 mm of water leaves the watershed as runoff plus baseflow, then the deficit created by having less precipitation than ET means that water must come from soil-water storage.

Figures 3.3.2 and **3.3.3** show the measured and modelled mean monthly volumes at the Progreston and Zimmerman gauges. In general, the distribution of monthly volumes has been preserved, meaning that high and low volume months follow the pattern we would expect. March and April are the highest months because of the spring freshet, whereas July and August are the lowest, as they should be. There are some discrepancies between individual months (e.g., March, August) which are attributed to two possible reasons: a) unrepresentative precipitation (mostly rainfall), and b) inaccurate flow measurements in the period just prior to ice cover breakup. Both reasons are plausible, although the first one is most likely for the summer months, whereas the second is more than possible during the winter months. Recall, that the presence of the Niagara Escarpment complicates the weather patterns, making representative precipitation amounts from within and outside the watershed difficult to assess. For low flow months (e.g., June to August), actual discharges from the Mountsberg reservoir would further improve the simulation results at Progreston and Zimmerman. At present, the same elevation-outflow table is applied for each year for the Mountsberg reservoir. Overall, the agreement between the observed and simulated monthly volume plots are very encouraging, notwithstanding the complexities cited earlier.

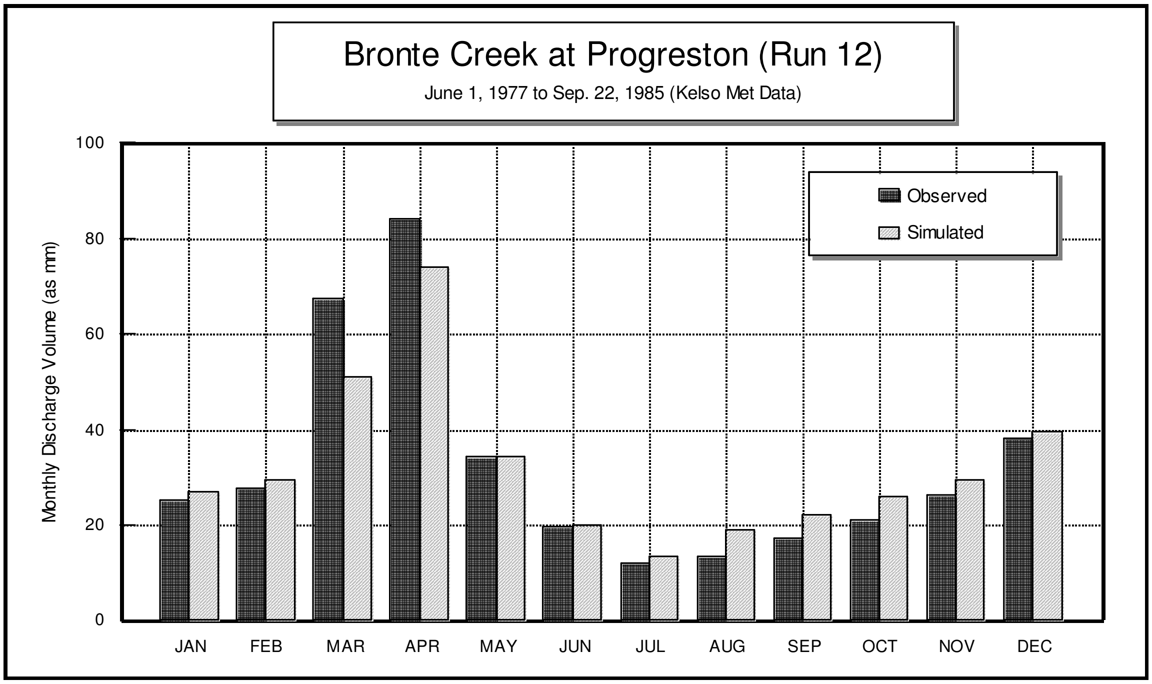


Figure 3.3.2 Observed and Simulated Monthly Flow Volumes at Progreston

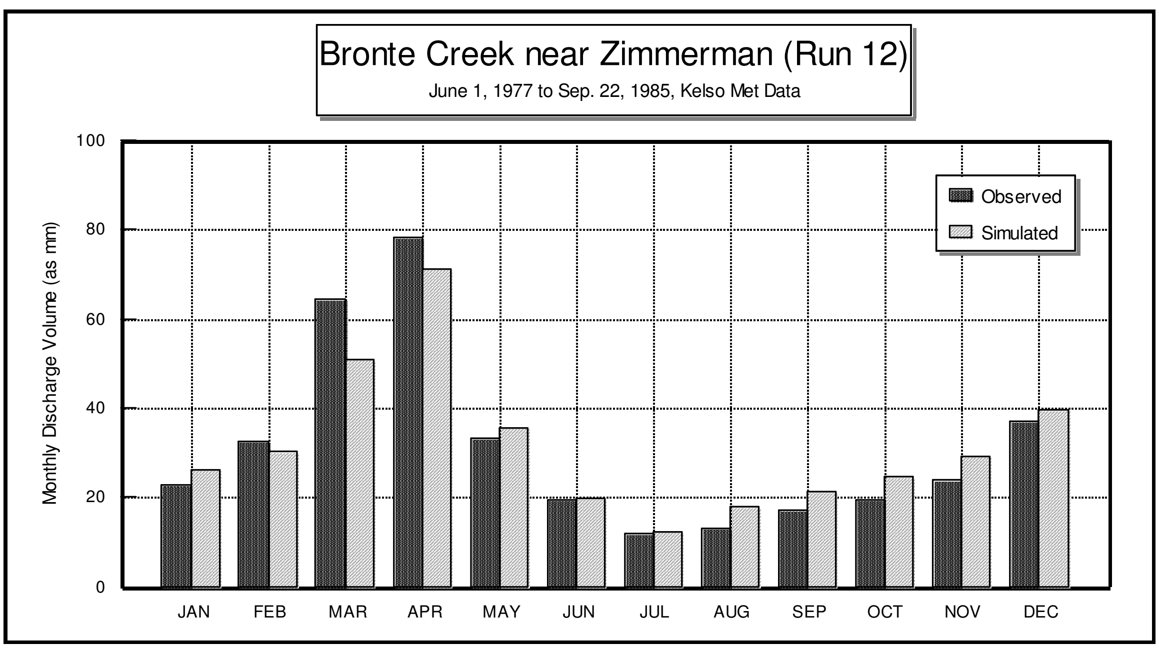


Figure 3.3.3 Observed and Simulated Monthly Flow Volumes at Zimmerman

Another check on model performance for continuous simulation is given by the flow duration curves exhibited in **Figure 3.3.4**. In general, the agreement between observed and simulated curves is very good throughout, but is subject to the same input difficulties noted earlier (e.g., flow data under ice cover conditions, representative precipitation patterns, and actual operations of Mountsberg reservoir. Moreover, a better handle on the actual water taking procedures for a number of users upstream of Zimmerman (e.g., Carlisle Golf Course) would help improve the agreement between measured and modelled flows for the 30 to 70% duration times.

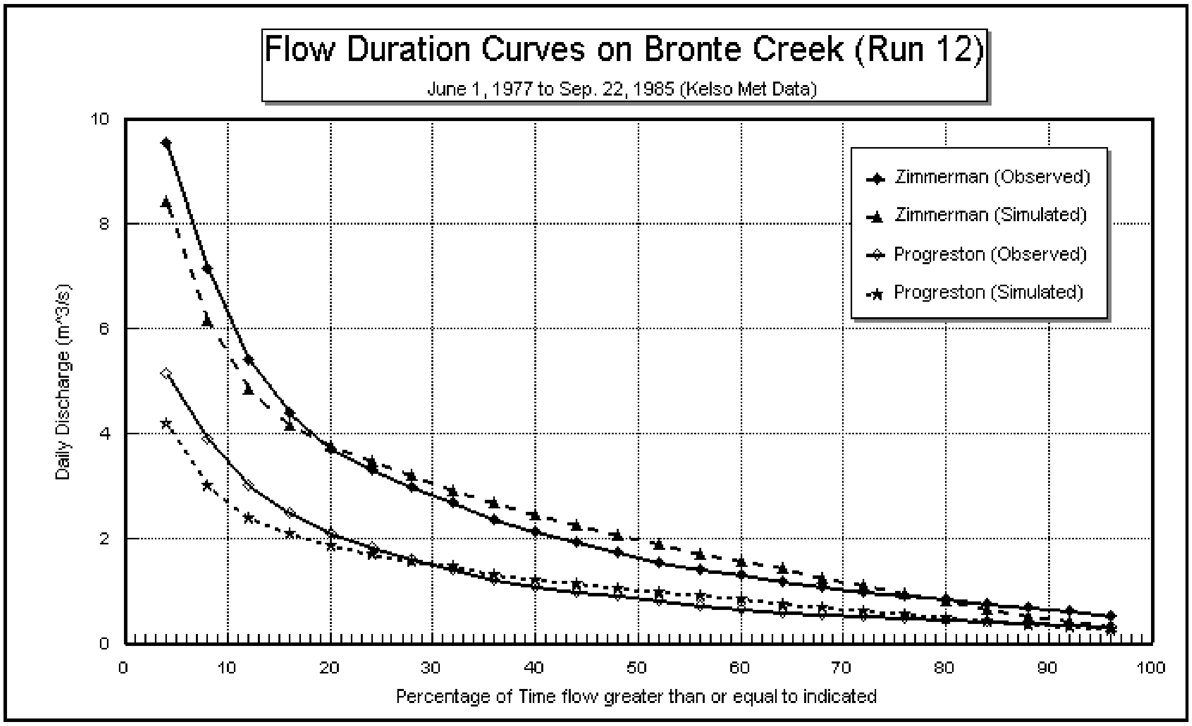


Figure 3.3.4 **Observed and Simulated Flow Duration Curves at Progreston and Zimmerman**

Finally, **Table 3.3.5** provides the flood flows at key points for existing conditions.

Table 3.3.5 Summary of Flood Flow Estimates: Return Period Storm Events for Existing Conditions

No.	Point of Interest	Area km^2	Peak Flows (m³/s) 1:2 yr	1:05	1:10	1:20	1:25	1:50	1:100
6013	Bronte Ck u/s Strabane Ck	36.5	2.9	3.76	4.32	4.82	4.97	5.45	5.9
2031	Strabane Creek Outlet	29.85	2.05	2.67	3.06	3.41	3.51	3.83	4.12
6031	Bronte Ck d/s Strabane Ck	46.31	4.22	5.46	6.23	6.93	7.13	7.81	8.43
6032	Bronte Ck u/s Mountsberg Ck	58.51	5.17	6.74	7.71	8.68	8.94	9.82	10.6
1050	Mountsberg Reservoir Inflow	37.1	1.72	2.18	2.46	2.72	2.79	3.02	3.22
5300	Mountsberg Reservoir	37.1	1.51	1.91	2.16	2.39	2.45	2.65	2.83
6080	Mountsberg Creek Outlet	57.7	8.98	11.7	13.6	15.5	16	18	19.8
2090	Bronte Ck at Carlisle	116.2	10.9	14.4	16.7	19.1	19.8	22.1	24.3
6100	Bronte Ck at Progreston	121.6	11.1	14.8	17.1	19.7	20.4	22.7	25.1
1120	Flamboro Ck Outlet	9.43	0.702	0.97	1.19	1.45	1.52	1.78	2.01
6120	Bronte Ck d/s Flamboro Ck	131	11.7	15.6	18.1	20.9	21.7	24.3	26.8
6165	Kilbride Creek Outlet	44.33	5.18	6.77	8	9.27	9.69	11	12.3
6160	Bronte Ck d/s Kilbride Ck	183.5	15.3	20.4	23.7	27.4	28.4	31.8	35.1
1180	Willoughby Creek	12.9	1.69	2.19	2.51	2.81	2.89	3.16	3.42
6180	Bronte Ck d/s Willoughby Ck	196.4	16.8	22.3	25.9	29.8	31	34.6	38.1
6222	Limestone Creek Outlet	40	10.2	13	14.8	16.3	16.7	18.1	19.5
6225	Bronte Ck d/s Limestone Ck	240	22.4	29.5	34.2	39.4	40.9	45.5	50.3
6240	Bronte Ck near Zimmerman	243.8	24.9	32.5	37.4	42.4	43.9	48.9	53.8
1260	Lowville Creek Outlet	9.1	2.83	3.66	4.22	4.73	4.87	5.34	5.77
6260	Bronte Ck d/s Lowville Ck	252.9	27.7	36	41.5	47	48.6	54	59.3
6302	Indian Ck outlet at Bronte	37.32	28.1	36.1	40.9	45.1	46.2	49.7	53.1
6310	Bronte Ck d/s Indian Creek	290.3	55.3	72	82.2	92	94.7	104	112
1320	Mount Nemo Creek outlet	4.79	2.23	2.89	3.34	3.77	3.89	4.29	4.64
6320	Bronte Ck d/s Mount Nemo Ck	296.4	57.9	75.3	86.1	96.4	99.2	109	118
1340	Bronte Subcatchment 1340	8.95	11.8	14.7	17	19.1	19.7	21.7	23.5
6340	Bronte Ck d/s Sub 1340	305.3	59.4	77.2	88.6	99.1	102	112	121
2360	Bronte Ck at QEW	305.3	59.1	76.9	88.2	98.7	102	111	120
2380	Bronte Ck at Lake Ontario	312.5	60.2	78.3	90	101	104	113	123

3.3.5 Event Modelling

The model parameter adjustment table (see **Appendix A)** established in previous GAWSER applications, and confirmed in the 8-year continuous simulations reported in the previous section, was applied directly in the event modelling. This meant that no model parameter adjust factors were modified during the event modelling exercise, with two exceptions. First, the initial soil-water content factors for the two soil layers (e.g., FIMCI, FIMCII) had to be adjusted for each specific event. Because a start-up period (about 3 to 5 days) was incorporated as part of the event, these factors were relatively easy to determine. For snowmelt events (e.g., February 2000), the initial soil-water contents were set at field capacity (e.g., FIMCI=FIMCII=1.0) in most instances. The second factor requiring adjustment for snowmelt events only is the initial snowpack water content factors (FIWE). These factors were estimated from snow course information (or by calibration from measured streamflows when no snow course data were available, i.e. December 1982).

The event modelling results are summarized in terms of observed and simulated hydrograph volumes and peak discharges in **Table 3.3.6**. A comparison of observed and simulated times to peak and times to centroid are not provided here, because of the time shift difficulties resulting from using rainfall data outside the watershed and the presence of the Niagara Escarpment caused the numeric values of the departure statistics to indicate a somewhat distorted picture of the model's performance with regard to hydrograph timing. In order to show the overall agreement between measured and modelled discharge for historic events in the Bronte Creek watershed, observed and simulated hydrographs for two representative events at both gauges are plotted in **Figures 3.3.5, 3.3.6** and **3.3.7**.

A complete synopsis of the event modelling, in terms of a comparison between observed and simulated values for key hydrograph statistics (e.g., volume, peak flow, time to peak) and the Nash-Sutcliffe model efficiency, R2, are given in **Table 3.3.6**, together with the 'goodness of fit' index or GFI. The average values for each statistic shown at the bottom of **Table 3.3.6** were computed as 'flow-weighted' means. This was done so that a small volume event (e.g., August 1982, August 1985) did not bias the overall statistics. Notice that the mean GFI for the Zimmerman gauge is 74, with the lowest value being zero for two rather small volume events (July 1982, August 1985), and the highest value is 86.6 (March 1984). For the Progreston gauge, the mean GFI is 76.7, where the lowest value is also zero (June 1982), and the highest is 84.1 (January 1983). These mean GFI values suggest that the overall agreement between the observed and simulated results are considered good (see Section 3.3.8 for definitions of 'poor', 'fair', 'good', 'very good', and 'excellent'). Some GFI values for individual events are very good (March 1982, December 1982, March 1984), while others are poor (June 1982, August 1982, August 1985) for mostly low volume rainfall events. These results are considered entirely acceptable for most hydrologic modelling exercises like flood plain mapping and watershed management planning.

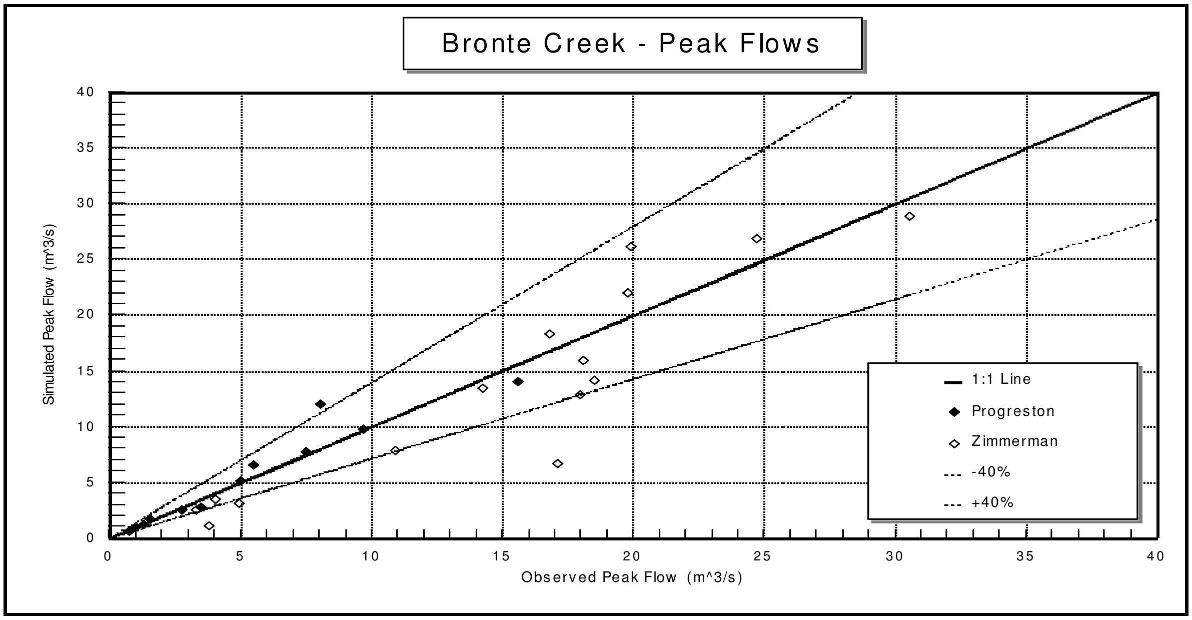
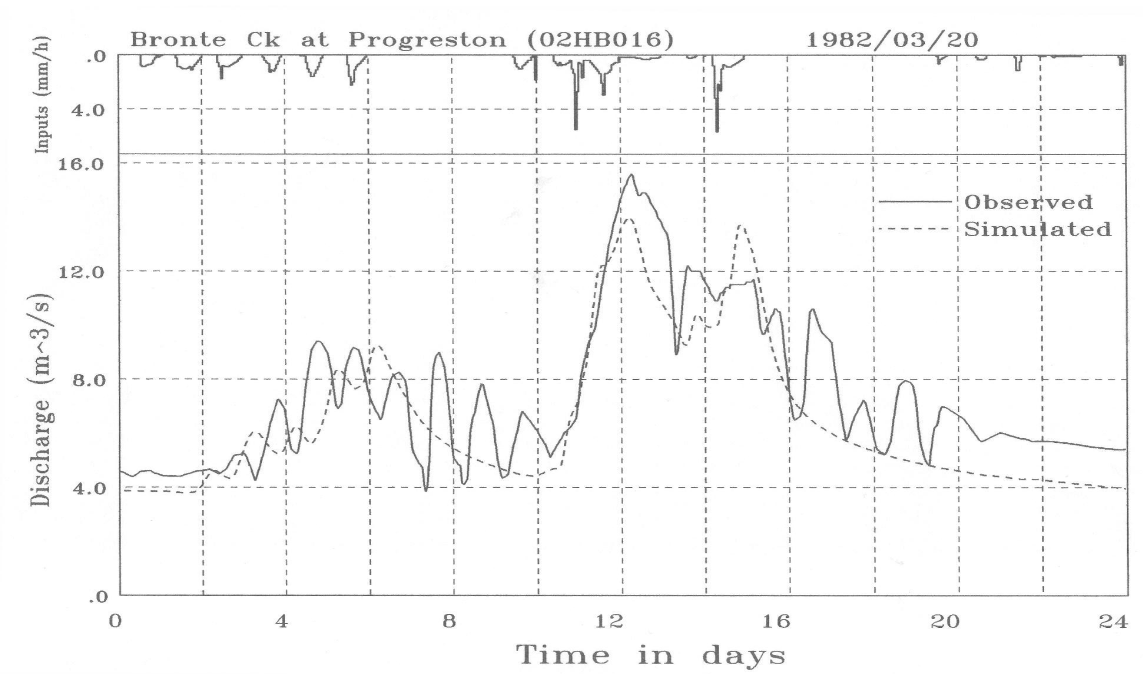


Figure 3.3.5 Comparison of Observed and Simulated Hydrograph Peak Flows for Event Modelling



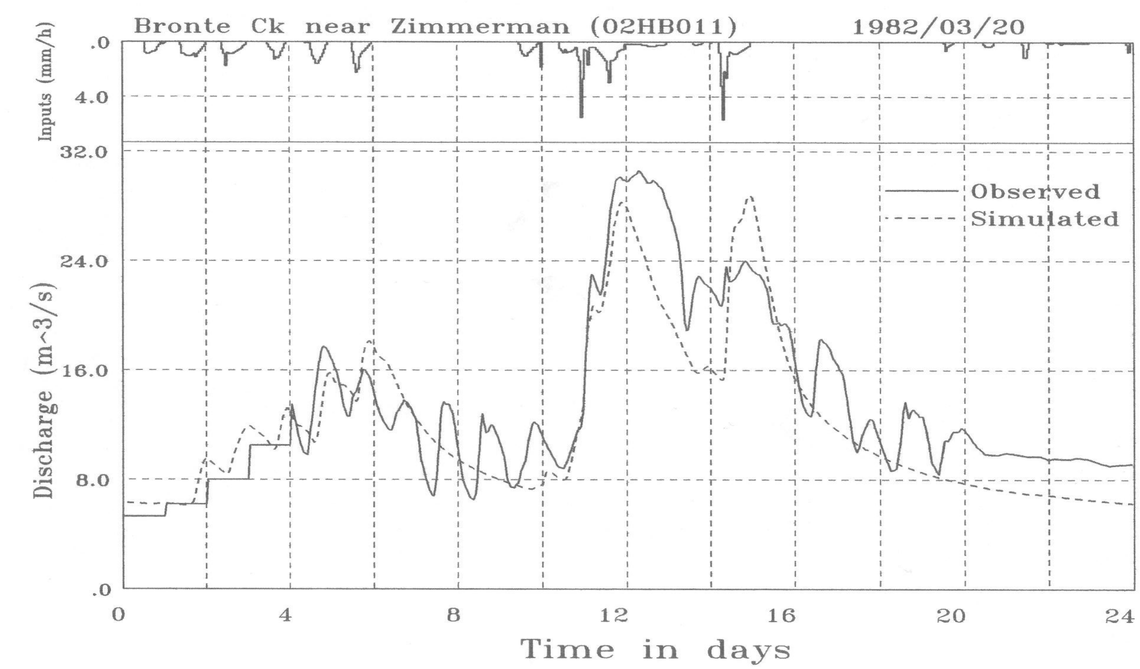


Figure 3.3.6 Observed and Simulated Hydrographs for the March 20 to April 12, 1982 Event

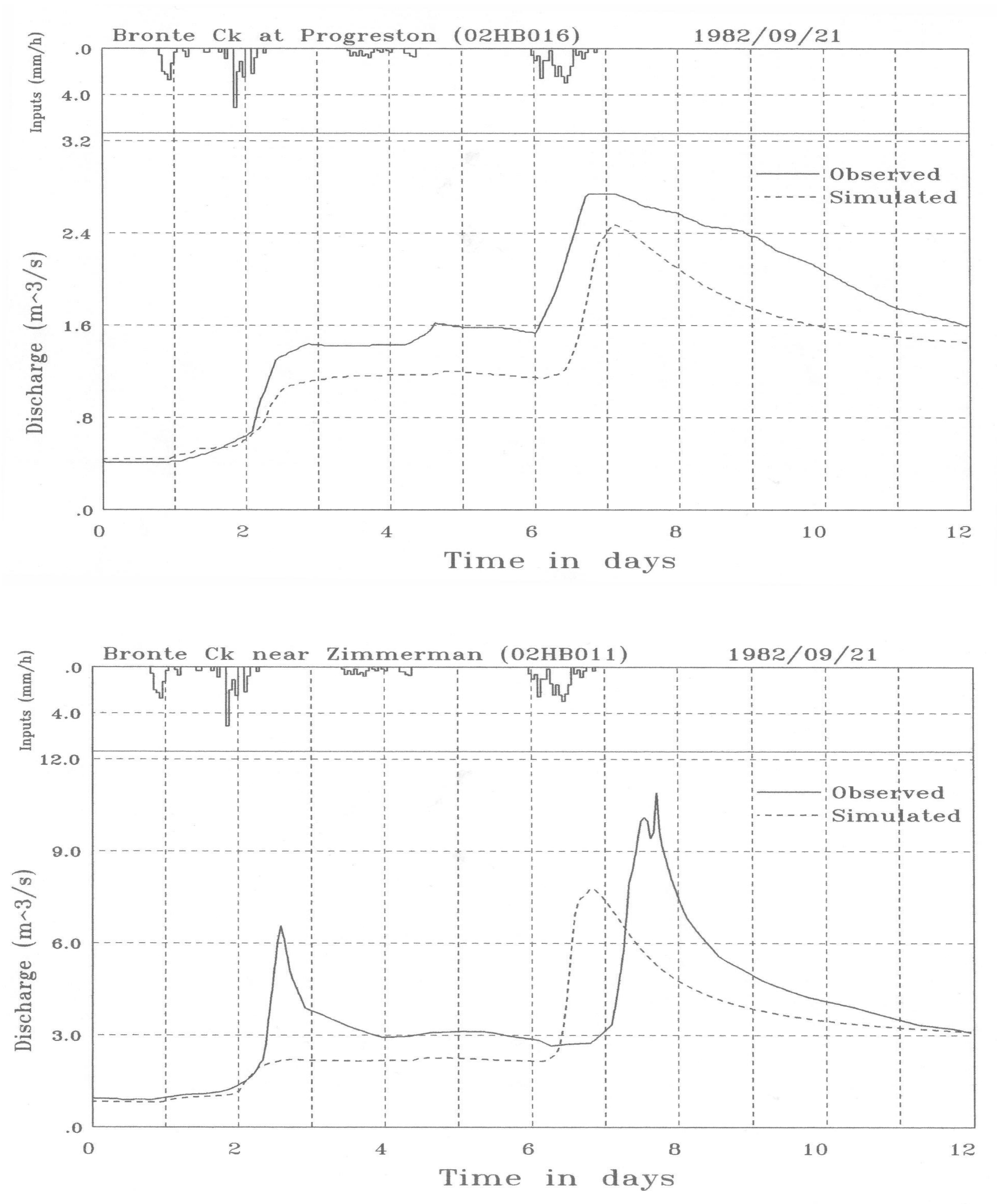


Figure 3.3.7 Observed and Simulated Hydrographs for the Sept. 21 to Oct. 1, 1982 Event

Table 3.3.6 Summary of Event Modelling Results

Event	Gauge Name	Area (km^2)	Differences in Hydrograph Stats %Vol	%Peak	TP(h)	TCC(h)	Model Efficiency	Good Fit Index
Mar 1982	Progres	121.6	-12.3	-10.3	-1.000	-9.290	0.69	80.8
	Zimmer	243.8	-9.7	-5.9	64.000	-17.080	0.73	83.6
Jun 1982	Progres	121.6	2.9	-9.8	19.000	-1.260	-2.35	0.0
	Zimmer	243.8	-11.4	-24.3	35.000	-0.400	-0.55	21.5
Aug 1982	Progres	121.6	10.7	-21.6	15.000	11.370	-0.10	42.7
	Zimmer	243.8	4.5	-61.6	10.000	14.810	-1.46	0.0
Sep 1982	Progres	121.6	-20.0	-9.9	9.000	-1.080	0.59	74.4
	Zimmer	243.8	-17.0	-28.6	-21.000	4.780	0.09	48.7
Dec 1982	Progres	121.6	-9.6	1.9	-20.000	-6.700	0.46	72.5
	Zimmer	243.8	-1.8	-12.2	10.000	-5.450	0.73	84.7
Jan 1983	Progres	121.6	-4.1	19.2	10.000	1.610	0.76	84.1
	Zimmer	243.8	-17.4	-23.8	15.000	-4.050	0.52	69.0
Apr 1983	Progres	121.6	-16.2	0.8	-20.000	4.330	0.38	67.5
	Zimmer	243.8	-3.4	-6.3	3.000	7.490	0.67	82.9
Mar 1984	Progres	121.6	-4.4	49.3	-13.000	12.360	0.66	73.5
	Zimmer	243.8	-6.8	11.1	-2.000	5.700	0.79	86.6
Jun 1984	Progres	121.6	11.5	0.6	-2.000	7.940	0.62	79.7
	Zimmer	243.8	8.8	-17.3	9.000	12.230	0.54	73.3
Jul 1984	Progres	121.6	-5.4	-11.9	23.000	1.020	0.48	72.5
	Zimmer	243.8	14.6	-37.1	3.000	5.260	0.53	67.6
Mar 1985	Progres	121.6	-8.5	-0.1	57.000	-4.860	0.67	82.5
	Zimmer	243.8	-13.2	8.5	8.000	-8.160	0.64	78.7
Aug 1985	Progres	121.6	13.2	-24.3	10.000	2.990	0.05	48.7
	Zimmer	243.8	-5.8	-74.1	11.000	11.550	-4.79	0.0
Nov 1985	Zimmer	243.8	11.5	8.9	14.000	-13.720	0.64	78.9
Sep 1986	Zimmer	243.8	-26.8	-28.9	3.000	8.480	-0.54	18.0
Apr 1987	Zimmer	243.8	-8.6	31.2	1.000	-25.350	0.74	79.7
Average:	Progres		-8.7	6.3	9.790	-1.522	0.59	76.7
	Zimmer		-7.9	0.3	16.108	-7.700	0.54	74.0

With regard to hydrograph volumes, the model predictions were very good at the two gauges. For the Zimmerman gauge, the hydrograph volumes for the majority of the events (14 out of 15, or 93%) were simulated to within +20% of the measured values. For the Progreston gauge, the modelled hydrograph volumes for all 12 events were within +20% of the observed volumes.

Upon examination of the bottom of **Figure 3.3.5**, the model simulations of the peak flows at both gauges are considered good overall. Notice that 25 of a total 27 (or 92%) modelled peak flows are within +40% of the observed values. There does not appear to be a systematic high or low bias in the predicated peak flows, because they are fairly evenly distributed on either side of the 1:1 or perfect fit line.

Comparisons of observed and simulated hydrographs for two illustrative events (one snowmelt, one rainfall-only) are plotted in **Figures 3.3.6** and **3.3.7**. The agreement between measured and modelled flows is very good in most cases, but very poor in others. Recall, that for a number of events, there were uncertainties/difficulties in estimating the correct rainfall pattern and spatially distributed volumes, initial snowpack conditions, and missing hourly flow data for comparative purposes. Moreover, for the Progreston gauge in particular, the outflow characteristics entered into the model for Mountsberg reservoir may have introduced additional uncertainties into the modelling results.

Measured and modelled hydrographs for March 20 to April 12, 1982 are shown in **Figure 3.3.6**. As can be seen, this is not a single event, but rather a series of snowmelt events that occurred over a 24-day period. Some of these snowmelt events were accompanied by rainfall (e.g., March 31 to April 1, 1982). The GFI values were 80.8 for the Progreston gauge, and 83.6 for the Zimmerman gauge, suggesting very good simulation results. This ‘event’ illustrates two important aspects of the modelling. First, it clearly shows how well the model predicts flows in a continuous simulation mode. The fact that the time of rise for the two largest events (March 24 to 26th, and April 1 to 4) are modelled correctly at both gauges is quite remarkable, because it demonstrates how well the model tracks the water balance through the soil profile to the stream. In general, the baseflow recessions between each event are modelled exceptionally well. Moreover, the correct timing of the Zimmerman flows, in particular, proves that we have an exceptionally good channel routing algorithm, and that the channel inputs (e.g., cross-sections, channel length and slope, roughness value) have been estimated correctly. Secondly, this ‘event’ also illustrates the difficulty in obtaining representative rainfall data, and how it influences the results. Notice how the event on Day 17 and 18 is not well simulated at all. The hydrograph shapes suggests that another event or events occurred between April 6 and 10, 1982.

Figure 3.3.7 presents the observed and simulated hydrographs for the September 21 to October 1982 event (or series of events). Here, the GFI values are much lower with 74.4 being computed for the Progreston gauge, and 48.7 for Zimmerman. Generally, the hydrograph shapes are preserved, but then the unrepresentative rainfall patterns make a good simulation difficult. For the Zimmerman gauge, the missed first hydrograph peak (September 22 and 23) obviously indicates a problem with the rainfall pattern and volumes, while the modelled flows for the second event are almost a day early. Again, the representativeness of the rainfall data can be questioned, but the very late observed hydrograph response for the Zimmerman gauge could suggest an error in reporting the correct timing of the measured flows.

In summary, the event modelling results are entirely satisfactory for the purpose of this study. The monthly model parameter adjustment factors were validated during the continuous simulations using flow data for the entire eight-year period at two gauges. In this study we tested the model in event mode for 15 events, a rather severe test considering that most previous hydrologic modelling exercises checked model performance with data from only 3 to 5 events (e.g., GRCA, 1988, Triton 1991).

3.3.6 Comparison of Flood Flows

To help establish the ‘reasonableness’ of the estimated flood flows, a comparison of the flood flows generated for Bronte Creek using the event and continuous modelling are given in **Table 3.3.7** together with estimates from the Index Flood Method (Moin and Shaw, 1985), and those from the FDRP (Proctor & Redfern, 1986 study).

Appendix A provides a complete comparative analysis of the flood flows. To summarize, the discrepancies between this study and the FDRP study results, primarily in the peak flows from the 100-year event, is a result of a better understanding of hydrologic systems, utilization of improved modelling capabilities, and confirmation of calculated flows against observed data.

In general, there is enough agreement between the different methods to ‘bound’ the actual results, which suggests that the formulated model predicts flood flows in the Bronte Creek watershed reasonably well. Regional storm analysis will be undertaken by Conservation Halton at a later date.

Hyd. No.	Location	Area (km2)	2yr Event Model	2yr. Cont. Model	2yr. Index Flood Method	2yr. FDRP Study	100yr. Event Model	100yr. Cont. Model	100yr. Index Flood Method	100yr. FDRP Study
6013	Bronte Creek u/s of Strabane Ck	36.5	2.90	2.39	4.89		5.90	4.99	11.8	
2031	Strabane Creek Outlet	29.9	2.05	0.950	4.26		4.12	4.87	10.3	
6032	Bronte Ck u/s of Mountsberg Ck	58.5	5.17	4.15	6.79		10.6	8.64	16.4	
1050	Mountsberg Reservoir Inflow	37.1	1.72	1.70	4.95		3.22	3.25	11.9	
5300	Mountsberg Creek Outflow	37.1	1.51	1.37			2.83	3.08		
6080	Mountsberg Creek Outlet	57.7	8.98	5.27	6.73	0.6	19.8	15.7	16.2	5.9
2090	Bronte Creek at Carlisle	116.2	10.9	7.95	11.0		24.3	20.5	26.4	
6100	Bronte Creek at Progreston	121.16	11.1	8.34	11.3	5.4	25.1	21.4	27.2	33.9
1120	Flamboro Creek Outlet	9.43	0.702	0.540	1.91		2.01	1.85	4.6	
6165	Kilbride Creek Outlet	44.3	5.18	3.48	5.60	2.4	12.3	9.91	13.5	22.1
6160	Bronte Creek d/s Kilbride Creek	183.5	15.3	11.9	15.1		35.1	30.3	36.3	
6222	Limestone Creek Outlet	40.0	10.2	6.01	5.21	5.4	19.5	14.2	12.6	34.7
6240	Bronte Creek near Zimmerman	243.8	24.9	18.4	18.3	30.5	53.8	45.8	44.2	173.3
6285	West Branch Indian Creek Outlet	24.0	15.8	9.14	3.65		30.8	22.9	8.81	
6293	East Branch Indian Creek Outlet	4.79	4.02	2.43	1.19		7.65	5.95	2.87	
6302	Indian Creek at Bronte Creek	37.3	25.2	14.0	4.97	13.1	49.4	34.5	12.0	54.9
6310	Bronte Creek d/s Indian Creek	290.3	55.3	33.3	20.71		112	80.8	49.9	
2380	Bronte Creek at Lake Ontario	312.5	60.2	35.9	21.8		123	85.9	52.5	

Table 3.3.7 Comparison of Flood Flow Estimates for Bronte Creek

4.0 FLUVIAL GEOMORPHOLOGY

4.1 Introduction

The fundamental goal of fluvial ecosystem assessment, maintenance, restoration and monitoring is to maintain a condition that resembles its natural pre-disturbed 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 human use, environmental services, and the ecosystem itself. 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.

This study consists of a geomorphological assessment of the Bronte Creek Watershed and its tributary streams. In order to complete this assignment, it was necessary to assess the existing conditions of the entire system, using existing digital and ortho-rectified mapping as well as stream-side assessments. We conducted field investigations into the existing geomorphological conditions in the study area as validation of the morphological assessment, which was a desktop exercise.

Part of the stream-side assessment of the study area included the classification of study reaches according to the Rosgen Classification. While we do not feel the Rosgen Classification is singularly appropriate in assessing streams for potential rehabilitation, we have added the information as an additional tool for assessment. We caution that recent studies on Mill Creek, Groff Mill Creek, Laurel Creek, Henry Sturm Greenway and Etobicoke Creek clearly highlight the limitation of the Rosgen-type classifications in stream assessments and other studies (for instance, channel designs).

Through the morphological assessment a number of candidate reaches were selected for further stream-side evaluation. Each site underwent a detailed assessment as to its general characteristics, flow and sediment properties, erosion potential and shear stress analysis. Emphasis was spent on the Indian Creek Watershed as this watershed has been designated an area of concern within this study by Conservation Halton.

Finally, assessment of the impacts of flow and land-use changes in the watershed (in particular Indian Creek), as well as flow duration exceedance and low flow analysis, was undertaken. Recommendations for future rehabilitation and/or additional studies are presented.

4.2 Desktop Analysis of Stream Systems

Channel geometric relationships (sinuosity, meander geometries, etc.) are helpful in determining baseline information for monitoring purposes and for comparing the candidate streams with other channels in the same physiographic regions.

1. **Available Mapping:** Desktop analysis of stream characteristics from a planform perspective were undertaken as the initial component of this study. The purpose of this component was to determine areas of concern from a planform perspective and to identify candidate reaches for stream-side assessments. To complete this component we used mapping provided by Conservation Halton (Bronte Creek Hydrology, March, 2001: approx 1:30,000); and air photos (most recent flight: 1:8000 approx) provided by Conservation Halton.
2. **Methodology:** An analysis of channel morphological characteristics is informative in that it provides details about the system which can be correlated against other stream systems in the area. This comparison allows one to compare dissimilar systems to a certain degree, which may allow for predictive relationships to be formed even though there may be inadequate data. Stream channels were assessed according to standardized cartographic

procedures to determine channel length, sinuosity, average meander belt width, and average radius of curvature. Each channel segment was manually measured and recorded. The results are found in **Table 4.2.1**.

3. **Results:** Results from the desktop mapping exercise are presented in **Table 4.2.1**. However, the table refers to main branch lengths and does not include all tributaries.

Table 4.2.1 Desktop Mapping Results

Stream Channel Segment	Channel Length (km)	Sinuosity Index	Average Meander Belt Width (m)	Average Radius of Curvature (m)
Bronte Creek:	**53.629**	**1.244**	**19.61**	**39.43**
Mouth to Indian Creek	16.339	1.346	40.44	83.19
Indian to Limestone Creek	2.629	1.384	19.81	41.51
Limestone to Kilbride Creek	6.956	1.132	19.41	45.32
Kilbride to Flamboro Creek	2.629	1.182	16.18	28.87
Flamboro to Mountsberg Creek	4.125	1.200	14.15	21.01
Mountsberg to Strabane Creek	3.155	1.322	15.16	26.98
Strabane to Headwaters	17.796	1.142	12.13	29.11
Indian Creek:	**14.722**	**1.295**	**17.38**	**45.88**
Bronte to Main Channel Trib Split	7.240	1.468	14.56	56.29
Trib Split to Headwaters	7.482	1.121	20.22	35.47
Limestone Creek:	**13.840**	**1.152**	**16.70**	**28.43**
Bronte to Main Branch Split	5.549	1.225	13.21	25.19
Main Branch Split to Headwaters	8.291	1.078	20.19	31.68
Kilbride Creek	**17.715**	**1.153**	**14.36**	**26.55**
Mt. Nemo Creek	**3.437**	**1.416**	**12.21**	**29.30**
Lowville Creek	**6.067**	**1.163**	**6.74**	**18.96**
Willoughby Creek	**4.854**	**1.083**	**13.48**	**32.36**
Flamboro Creek:	**5.598**	**1.136**	**12.94**	**29.67**
Bronte to Main Branch Split	1.456	1.213	12.13	31.22
East Branch Split	3.348	1.060	10.51	18.99
West Branch Split	4.142	1.070	16.17	38.80
Mountsberg Creek:	**25.763**	**1.276**	**11.12**	**25.98**
Bronte to Reservoir	12.578	1.103	14.15	31.88
Reservoir to Headwaters	13.185	1.449	8.09	20.08
Strabane Creek	**7.078**	**1.315**	**10.11**	**23.37**

Note: Average meander belt width and average radius of curvature for meanders is based on the averaging of 10 bends in each of the candidate reaches.

Results show that sinuosity of the channels ranges from a low value of 1.060 to a high of 1.468. Average meander belt width ranges from a low of 8.09m (which is extremely low for streams in this physiographic region and indicates a complex of external controls) to a high of 40.44m. Average radius of curvature ranges from a low of 18.99m to a high of 83.19m. It is important to recognize that this data is for information purposes only and is used to generally characterize the main stream channels. It is in no way to be utilized to base site-specific management decisions or apply channel design templates against. Further site-specific data collection would be necessary for those purposes. These results indicate general morphological characteristics which have been used in addition to visual assessment of mapping and air photos to select candidate reaches for detailed geomorphic analysis.

4. **Reaches Identified for Geomorphic Assessment:** Results from the desktop mapping and visualization exercise identified 28 sites within the Bronte Creek Watershed which have a likelihood of high erosion potential (see **Figure 4.2.1**). Note that each site is a reach of undetermined length, and in the case of confluent junctions includes both Bronte Creek and the confluent stream. This information is based on stream morphological assessments using general relationships relating to:

- Changes in stream pattern in the absence of external control.
- Increases / decreases in meander beltwidth.
- Rapid changes in sinuosity (either increasing or decreasing).
- Locations where stream curvature is outside thresholds for stability.
- Locations where subwatershed stream channels are confluent.
- Confluent junctions which meet at inappropriate angles.
- Entrance points / exit points from major reservoirs.

The distribution of sites is as follows (see Bronte Creek Erosion Potential Map, **Figure 4.2.1**):

Mt Nemo Creek:	1 site (confluent with Bronte)
Indian Creek:	4 sites (1 confluent with Bronte)
Lowville Creek:	1 site (confluent with Bronte)
Limestone Creek:	3 sites (1 confluent with Bronte)
Willoughby Creek:	1 site (confluent with Bronte)
Kilbride Creek:	3 sites (1 confluent with Bronte)
Flamboro Creek:	2 sites (1 confluent with Bronte)
Mountsberg Creek:	5 sites (1 confluent with Bronte)
Strabane Creek:	2 sites (1 confluent with Bronte)
Bronte Creek:	6 sites (not including confluent junctions with other creeks)

These reaches were visited and confirmed as to their suitability for this study, given the Terms of Reference. From these 28 reaches within the Bronte Creek Watershed, a number of sites were identified as requiring inclusion in the field component of the study. The breakdown of sites (a total of 53 sites) for final geomorphological assessment was as follows (see **Figure 4.2.2**):

Bronte Creek:	17 sites
Indian Creek:	13 sites (10 on main branch, one each on three tributaries)
Limestone Creek:	7 sites (6 on main branch, one tributary)
Kilbride Creek:	5 sites
Lowville Creek:	2 sites
Mount Nemo Creek:	1 site
Flamboro Creek:	1 site
Willoughby Creek:	1 site
Mountsberg Creek:	4 sites
Strabane Creek:	2 sites

A general convention was used in the selection of sites was that each subwatershed of Bronte Creek contained a site immediately upstream of the confluence of Bronte Creek. A site was included on the main branch of Bronte Creek immediately downstream of each subwatershed junction. Other sites were selected because they were representative of the creek overall, whether they were classified as an eroding site or not.

At each of the 53 sites, detailed information was collected on flows, channel form, bankfull capacity, sediment analysis, TSS, erosion assessment and Rosgen classification. Photos of each site were collected. Summary sheets containing characteristics of each site are located in **Appendix B3**. A detailed geomorphic assessment sheet was also completed on each site which was used to indicate erosive sensitivity.

4.3 Stream Morphology

Fluvial geomorphological assessments of creek systems require an investigation of flow regimes, sediment transport, bed material particle size distributions, erosion monitoring and stability investigations, as well as geometric characteristics of the entire stream system. The combination of this data allows for preparation of alternatives to the existing condition which follow proper fluvial geomorphological functioning of watercourses.

Flow data is collected using transect profiles to determine cross-sectional form and flow velocity metres to determine speed. The resulting product is the discharge of the creek through the transect.

Samples of bed materials are collected, dried, weighed, fractioned, and re-weighed to determine particle size distributions. This information provides information relevant to sediment transport and channel stability.

Sediment transport samples are collected at each site. This helps identify whether a reach is erosive or aggrading, and is an indication of stability (high rates of transport reflect instability, low rates indicate either stability or lack of available sediment for transport).

Erosion pins at each bank along each site give an indication of bank retreat over the course of a study. Pins are introduced to the banks and measured as to their protrusion. They are then simply re-measured each visit and the change in protrusion indicates removal of material.

1. **Study Sites:** Each of the study sites selected in Part 1 of the project were assessed according to the Terms of Reference for this project. Site visits were conducted from late April until the end of July, 2001. In all, each site was visited a minimum of two times, Indian Creek and Lower Bronte Creek sites were visited four times over this period.
2. **Morphological Assessment:** ***Site Characteristics and Rosgen Classification:*** The results of the site characterization for each of the 53 sites visited over the study period are summarized in **Appendix B1**. Site photos are included with data summary sheets and are included in the **Appendix B3**. Information on cross-sectional form, discharge and other stream measurements are also included in the data summary sheets in **Appendix B3**. There are a variety of stream management issues throughout the watershed, however the most important ones relate to the condition of Indian Creek. These will be highlighted in other sections of this Report.

4.3.1 Subwatershed Summary with Respect to Existing Morphological Issues

Each subwatershed was assessed as to potential morphological issues on a subwatershed scale. While this assessment is general, it is to be utilized in context with other results in this report (e.g., Erosion sensitivity analysis). The Bronte Creek system as a whole is functioning well outside of areas of concern noted in other sections of this report, and will continue to do so as long as there are no further development pressures on the main stem. Generally, the issues as assessed are:

Indian Creek (IC1 - IC13)

Indian Creek is the one subwatershed which is undergoing the most alteration and is certainly requiring the most immediate attention. Briefly, the issues include a lack of riparian buffer zone along a majority of the channel (IC3 - IC10); potential impacts of water-taking during times of low flow (especially considering the creek was dry for a large period of time this summer); access to the stream by cattle and the subsequent impacts (bank collapse, water quality, etc.)(IC1, IC2); and a need to match hydrograph shape in this system, in particular when development in the upper basin occurs. The issue of hydrograph shape is discussed later in this report and will not be repeated here. Clearly Indian Creek is in a state of flux and requires considerable intervention if it is to be saved from further degradation.

Management Targets

- Riparian buffer establishment.
- Cattle access.
- Limiting water-taking until further comprehensive analysis is completed.
- Match pre-and post-development rising limbs on the flow hydrograph.

Kilbride Creek (KC1 - KC5)

For the most part the areas that were observed on Kilbride Creek are not a concern from a fluvial perspective. One area of concern is where Kilbride Creek is forced to make a hard turn and run alongside Derry Road. The initial concern is that of increased sediment and contaminants making their way in to the creek from the road, especially during seasons in which ploughing of the road takes place. The distance that has been maintained between the roadway itself and the waterway would seem to be too narrow. At the same location the landowner has stated that she has noted increased erosion since recent construction on Derry Road. It is of recommendation to observe this area for any further erosion, so as to avoid any loss of the buffer zone or roadway. As for the rest of the creek there are a few locations in which the buffer zone has been lost to manicured lawns, it would be beneficial to the creek if these could be put back to a woody buffer zone.

Management Targets

- Assess rates of erosion and sediment accumulation along the Derry Road section.
- Public education regarding lawn cutting to the edge of the creek—use a direct mailing to local landowners as an Information Sheet.
- Establish riparian buffers wherever possible.

Limestone Creek (LC1 - LC6, LCT1)

Limestone Creek is in relatively good shape overall, with the exception of cattle grazing in the lower reaches and the subsequent issues relating to this. There is little sediment accumulation of fines and the shear stress analysis indicates the creek is able to move fine material off the bed at channel-full discharges. If there are any management issues on this creek they would be associated with a decreased riparian buffer which has the potential to cause channel alterations.

At the mouth of Limestone the floodplain is being used for cattle grazing. Here the cattle are able to walk right up to the waters edge (LC1). This has resulted in a reduction in buffer zone width as well as having contributed to significant slumping of the banks. There are fields across the stream that are accessed by crossing through the stream, presumably by both cattle and vehicles, this should stop as it will disturb the banks further as well as the bed and any habitat that exists nearby in the stream. Further up the stream the primary concern shifts to maintaining a woody buffer zone along side the stream (LC2-LC6). This will further aid in keeping the stream cool and filtering out contaminants as well as keeping bank migration within acceptable ranges.

Management Targets

- Restrict cattle access to the stream.
- Restrict vehicular access to the stream.
- Public education regarding these two issues—contact the landowners directly to discuss the implications of this behaviour.

Strabane Creek (SC1, SC2)

The main body of Strabane Creek lies within a swamp that appears to be at equilibrium. No alteration or need for concern exists within this portion. Upstream of the swamps there is an area of large pools that seem to be maintained for the purpose of a bird sanctuary. These as well seem to be old enough that they too have reached equilibrium but could be of interest for creating habitat.

Management Targets

- No specific targets or interventions needed.
- Continue assessment of system at regular intervals (monitor through creek walks, roadside assessments).

Willoughby Creek (WC1)

Willoughby Creek would appear to be functioning well with respect to fluvial processes. Of concern would be the dammed pond just upstream of the mouth. The area below the pond has reached an equilibrium in which it appears to be stable but removing the pond could introduce the possibility of creating more coldwater habitat.

Management Targets

- No specific targets or interventions needed.
- Continue assessment of system at regular intervals (monitor through creek walks, roadside assessments).

Mount Nemo Creek (MN1)

There is evidence of deep bank undercutting and debris transport but only under high flow (MN1). In the summer months the water levels drop to a level that does not have the competency to move or erode away the larger particles within the channel. Erosion and habitat creation would not be of concern on Mount Nemo Creek.

Management Targets

- No specific targets or interventions needed.
- Continue assessment of system at regular intervals (monitor through creek walks, roadside assessments).

Mountsberg Creek (MB 1A, MB 1B, MB3, MB4)

Upstream in the Mountsberg Creek system the main issue of concern is related to the effects of raising and lowering of the levels of the Mountsberg Reservoir. Since the operation of the reservoir is responsible for increasing and decreasing discharge at the outlet (into Mountsberg Creek), it is vitally important that the channel system of Mountsberg Creek be stable and not impacted by human activity in any way. This requires that a developed riparian system be in place which allows the creek system to adjust to unnatural rates of rising and lowering of flows in the channel, and precludes the cutting of any riparian vegetation whatsoever in this section of the creek. Any alteration to the natural landscape in this region could result in excessive erosion at the site and subsequent sedimentation downstream.

As a general guideline, the operation of the reservoir levels should be carefully considered. For example, raising or lowering the levels at a rapid rate will cause erosion and sedimentation in Mountsberg Creek, both upstream and downstream of the reservoir. From a streamside perspective, vegetation should not be cut within at least 30 metres of the creek channel. This will allow the creek to naturally adjust to raising and lowering water levels.

Field investigations indicate that there are no significant concerns currently related to the operation of the reservoir, in summary the field situation appears relatively stable. There are however indications that local land use practices may be contributing to potential accelerated erosion in the downstream reaches; these practices are specific to a local landowner cutting grass to the edge of the creek. This results in a decrease in bank strength through a loss of rooting opportunity (a binding mechanism), which increases potential erosion.

One consideration would be to remove the west branch (an alternative made to Mountsberg Creek within Courtcliffe Park) of the channel at Courtcliffe Park. The East Branch appears to be more sound in its functionality. The concrete pools in the West Branch would only act to warm the water. Upstream of the mouth the creek passes through areas of dense forest. In these areas extreme amounts of woody debris have built up. These areas are going to be subject to limited sediment transport resulting in sediment build up. It would be recommended to remove some of the debris, however, not all as some may be necessary for bank and pool stability (MB 1A, MB 1B).

Management Targets

- No specific targets or interventions needed, other than monitor proposed work at the Courtcliffe Park site, and monitor wood debris accumulations for potential bank blowouts and sediment accumulation.
- Continue assessment of system at regular intervals (monitor through creek walks, roadside assessments).

Lowville Creek (LO1, LO2)

Lowville Creek appears to be functioning well, although there does appear to be some bank instability at various locations (i.e. Lowville Sites 1 and 2). Other issues for concern relate to inadequate buffer widths at the Lowville 1 site.

Management Targets

- No specific targets or interventions needed.

- Continue assessment of system at regular intervals (monitor through creek walks, roadside assessments).

Flamboro Creek (FC1)

Overall stability at base flow and instability in some banks appear to be the main cause of concern in this watershed (FC1). While there are no specific issues, and the system appears to be functioning well within the expectations of a creek this size. As a smaller system, it is sensitive to minor changes within its basin and care should be taken if any alterations to existing land use characteristics are to be considered.

Management Targets

- No specific targets or interventions needed.
- Continue assessment of system at regular intervals (monitor through creek walks, roadside assessments).

4.3.2 Flow Monitoring

In any investigation of channel processes it is essential to collect information on flows at a station and along the channel, the purpose being to determine the discharge relationships of the system and to relate that information to sediment transport. When possible, a record of continuous flow provides a clear picture of discharge relationships during input events and more importantly for this study, gives an accurate depiction of low flow volumes.

At each site, measurements of channel width, depth, and fluid speed were made and recorded. Prior to any measurements, a transect line was stretched across the creek between fixed survey stakes. The upstream left bank water edge was marked with tape and all measurements were taken relative to that mark.

Width was determined by stretching a tape across the creek along the transect. If there was any undercutting, that was measured as well. In cases where the bank edge was not well defined, care was taken to ensure that an accurate measurement was taken. Channel depths were measured at the upstream left bank and every 20 cm along the transect, up to and including the right bank.

Prior to fluid speeds (i.e., magnitude) being taken, the cross-section was divided up into 5 panels, using the equal-width method (Water Survey of Canada, 1986). The mid-points of these panels were determined through measurement (all measurements being taken from the upstream left side of the cross-section) and were coded P1 to P5. The exact location of the panel mid-point was marked on the transect so it could be referenced without re-measurement. Depths of all panels were recorded to the nearest millimetre, the same way channel profile depths were measured.

Each site was sampled as to existing flow conditions at each visit. **Table 4.3.1** summarizes the discharge and channel variables at the initial site visit. **Table 4.3.2** summarizes bankfull characteristics based on evaluations of channel form using Manning's n to satisfy high flow conditions. While it would have been beneficial to access high flows as they occurred, attempts to do so early in the study period were hampered by safety concerns in the rapid flow.

For the most part, bankfull dimensions are what we would expect to find, with greater stream capacity in the downstream reaches and decreasing capacity in the upstream areas. Locations where dimensions do not follow this general pattern are representative of external controls, that is, there may be increases in channel capacity due to inputs from tributaries or stormwater inputs where the channel has enlarged its form to accommodate the energy input from these contributing areas. Away from the immediate input area, the channel would then revert to a more natural capacity and form, as it is not in direct contact with higher energy inputs. Examples where this occurs include Indian Creek Sites 5 and 7, and Bronte Creek Site 10.

Velocities, which accompany the discharges shown in **Table 4.3.2**, are not in the range which would be competent for transporting bed particles greater than 1.00 mm in size. This does not mean that sediment larger than 1.00 mm is not in the creek, it simply indicates that average velocities associated with these discharges limits sediment transport. This requires careful interpretation. Clearly these systems are not significantly aggrading at each of the study reaches, in fact it appears from all data combined that the system is fully operational and is transporting sediment, very efficiently through its course, except for the larger till materials found on Indian Creek. Therefore there are other factors to take into account regarding the range of recorded discharges and sediment transport.

Table 4.3.1 Flow Conditions During Initial Site Visits, Spring, 2001

Creek, Site	Top Width (m)	Wetted Perimeter (m)	Flow Area (m^2)	Flow Depth (m)	Mean Velocity ($m\ sec^{-1}$)	Discharge ($m^3\ sec^{-1}$)
Bronte 1	10.29	10.53	1.77	0.31	1.42	2.52
Bronte 2	15.06	15.39	4.70	0.52	0.40	1.90
Bronte 3	10.83	10.95	2.11	0.39	0.76	1.61
Bronte 4	13.45	13.56	3.58	0.39	0.56	2.00
Bronte 5	16.21	16.31	3.47	0.35	0.41	1.42
Bronte 6	13.00	13.14	4.17	0.47	0.27	1.14
Bronte 7	12.19	12.40	2.91	0.29	0.43	1.26
Bronte 8	11.22	11.97	4.60	0.62	0.53	2.46
Bronte 9	14.11	14.32	2.86	0.28	0.47	1.35
Bronte 10	9.13	9.54	2.46	0.42	0.51	1.25
Bronte 11	8.31	8.55	1.98	0.35	0.50	0.99
Bronte 12	8.79	9.18	2.28	0.41	0.40	0.90
Bronte 13	16.35	16.60	7.52	0.76	0.08	0.58
Bronte 14	6.85	7.36	4.02	0.92	0.13	0.54
Bronte 15	5.94	6.19	2.57	0.72	0.17	0.43
Bronte 16	9.60	9.76	1.95	0.29	0.09	0.18
Bronte 17	7.20	7.63	2.28	0.67	0.06	0.13
Indian 1	11.18	11.56	3.47	0.61	0.41	1.43

Table 4.3.1 Flow Conditions During Initial Site Visits, Spring, 2001						
Creek, Site	**Top Width (m)**	**Wetted Perimeter (m)**	**Flow Area (m^2)**	**Flow Depth (m)**	**Mean Velocity ($m\ sec^{-1}$)**	**Discharge ($m^3\ sec^{-1}$)**
Indian 2	8.66	8.94	3.36	0.60	0.34	1.14
Indian 3	3.31	3.41	0.52	0.22	0.11	0.06
Indian 4	6.46	6.53	1.07	0.28	0.19	0.20
Indian 5	6.48	6.95	1.72	0.57	0.10	0.18
Indian 6	7.72	8.03	2.76	0.54	0.05	0.15
Indian 7	8.03	8.37	3.05	0.49	0.08	0.24
Indian 8	4.98	5.17	1.61	0.41	0.11	0.18
Indian 9	0.88	0.97	0.09	0.13	0.08	0.01
Indian 10	4.16	4.34	0.69	0.27	0.12	0.08
Indian Trib 1	1.77	1.80	0.12	0.11	0.17	0.02
Indian Trib 2	2.64	2.97	0.51	0.32	0.23	0.12
Indian Trib 3	3.18	3.61	1.32	0.65	0.13	0.17
Limestone 1	4.28	4.71	1.24	0.40	0.39	0.48
Limestone 2	4.41	5.02	2.17	0.74	0.23	0.49
Limestone 3	4.52	4.68	1.22	0.38	0.33	0.40
Limestone 4	4.25	4.60	1.66	0.67	0.19	0.32
Limestone 5	4.84	5.24	1.27	0.36	0.32	0.41
Limestone 6	3.36	3.67	1.07	0.43	0.34	0.36
Limestone Trib	2.18	2.44	0.55	0.33	0.11	0.06
Lowville 1	3.79	3.85	0.56	0.21	0.09	0.05
Lowville 2	2.65	2.79	0.48	0.31	0.17	0.08
Mountsberg 1A	6.86	7.01	1.22	0.29	0.09	0.11
Mountsberg 1B	6.55	6.84	2.34	0.49	0.12	0.29
Mountsberg 3	5.17	5.35	1.36	0.46	0.07	0.03
Mountsberg 4	5.89	6.01	1.53	0.45	0.06	0.09
Kilbride 1	6.75	7.00	0.78	0.21	0.15	0.12
Kilbride 2	4.15	4.22	0.63	0.22	0.13	0.08
Kilbride 3	4.61	4.72	1.04	0.34	0.07	0.07
Kilbride 4	2.89	3.20	0.70	0.31	0.14	0.10
Kilbride 5	4.37	4.43	0.63	0.24	0.15	0.10
Mt. Nemo 1	2.92	3.05	0.32	0.27	0.09	0.03
Willoughby 1	3.21	3.23	0.25	0.13	0.28	0.07
Flamboro 1	2.90	2.96	0.32	0.18	0.19	0.06
Strabane 1	5.08	5.29	1.35	0.46	0.06	0.08
Strabane 2	Unavailable					

Table 4.3.2 Bankfull Flow Characteristics Determined Using Manning's "n" for Each Site						
Creek, Site	**Bankfull Discharge (m^3 sec^{-1})**	**Bankfull Width**	**Bankfull Flow Area (m^2)**	**Bankfull Wetted Perimeter (m)**	**Bankfull Depth (m)**	**Bankfull Velocity (m sec^{-1})**
Bronte 1	4.09	10.58	2.40	10.85	0.37	1.71
Bronte 2	3.55	16.01	7.01	16.42	0.67	0.51
Bronte 3	2.93	11.83	3.14	11.97	0.48	0.94
Bronte 4	4.56	15.31	6.19	15.46	0.57	0.74
Bronte 5	3.49	18.65	6.31	18.79	0.51	0.55
Bronte 6	2.66	13.77	7.13	14.08	0.69	0.37
Bronte 7	3.27	12.78	5.28	13.15	0.48	0.62
Bronte 8	2.92	11.59	5.17	12.39	0.67	0.56
Bronte 9	2.87	14.82	4.60	15.08	0.40	0.62
Bronte 10	4.11	11.87	5.58	12.41	0.72	0.74
Bronte 11	2.24	9.72	3.44	9.99	0.51	0.65
Bronte 12	1.24	9.10	2.81	9.55	0.47	0.44
Bronte 13	1.72	17.40	14.90	18.01	120	0.12
Bronte 14	1.04	8.64	6.58	9.39	1.27	0.16
Bronte 15	0.60	6.93	3.34	7.24	0.84	0.18
Bronte 16	0.36	10.30	3.03	10.50	0.40	0.12
Bronte 17	0.18	7.94	2.92	8.39	0.76	0.06
Indian 1	2.60	15.67	5.68	16.21	0.76	0.46
Indian 2	2.34	8.95	5.30	9.47	0.82	0.44
Indian 3	0.21	4.60	1.28	4.81	0.41	0.17
Indian 4	0.48	8.22	2.01	8.34	0.41	0.24
Indian 5	0.78	7.18	4.11	8.09	0.97	0.18
Indian 6	0.32	8.19	4.52	8.68	0.76	0.07
Indian 7	0.75	8.75	6.38	9.56	0.89	0.12
Indian 8	0.27	5.44	2.12	5.70	0.51	0.13
Indian 9	0.31	10.01	2.24	10.81	0.73	0.14
Indian 10	0.19	4.81	1.22	5.11	0.39	0.15
Indian Trib 1	0.13	2.35	0.41	2.44	0.25	0.32
Indian Trib 2	0.48	3.71	1.36	4.30	0.60	0.35
Indian Trib 3	0.34	3.75	2.18	4.43	0.90	0.16
Limestone 1	0.80	4.71	1.76	5.25	0.52	0.45
Limestone 2	0.68	4.99	2.77	5.69	0.87	0.24
Limestone 3	0.95	5.06	2.16	5.41	0.58	0.44
Limestone 4	0.56	4.81	2.47	5.33	0.85	0.23
Limestone 5	0.94	5.04	2.16	5.67	0.54	0.43
Limestone 6	0.65	3.58	1.59	4.06	0.58	0.41
Limestone Trib 1	0.07	3.13	0.70	3.43	.039	0.10
Lowville 1	0.17	4.47	1.26	4.61	0.38	0.17
Lowville 2	0.12	2.97	.063	3.13	0.37	0.19
Mountsberg 1A	1.22	8.13	5.69	8.91	0.90	0.21
Mountsberg 1B	1.01	7.87	8.45	5.41	0.92	0.19
Mountsberg 3	Undeterminable					
Mountsberg 4	0.11	6.48	1.81	6.61	0.50	0.06
Kilbride 1	0.81	7.27	2.58	7.71	0.47	0.31
Kilbride 2	0.33	4.76	1.57	4.98	0.43	0.21
Kilbride 3	0.15	5.10	1.73	5.30	0.48	0.09
Kilbride 4	0.18	3.50	1.08	3.88	0.43	0.17
Kilbride 5	0.31	5.08	1.35	5.22	0.39	0.23
Mt. Nemo 1	0.10	3.70	0.75	3.93	0.40	0.14

Table 4.3.2 Bankfull Flow Characteristics Determined Using Manning's "n" for Each Site						
Creek, Site	**Bankfull Discharge ($m^3 sec^{-1}$)**	**Bankfull Width**	**Bankfull Flow Area (m^2)**	**Bankfull Wetted Perimeter (m)**	**Bankfull Depth (m)**	**Bankfull Velocity ($m sec^{-1}$)**
Willoughby 1	0.27	3.95	0.61	4.01	0.23	0.45
Flamboro 1	0.28	3.30	0.85	3.50	0.35	0.33
Strabane 1	0.18	6.18	2.36	6.46	0.64	0.08
Strabane 2	Unavailable					

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 a 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 may respond 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.

This brings up an important point about these systems. The presence of wetland complexes in the upstream portions may contribute to a greater energy slope through the downstream reaches than can be determined from standard surveying procedures. Ponded areas like marshes and swamps (and in some cases large pools formed where channel width and depth increase greatly) have the capacity to store a large volume of water to a certain threshold, releasing water slowly (in accordance with a developed energy gradient) up to that threshold. Once the capacity is exceeded, flow is released quickly along a steeper energy gradient than may be predicted, allowing for greater discharges within a given channel capacity. Once the ponded area drains below the threshold, flow decreases and operates according to the energy gradients which existed prior to ponding. This is likely what happens in certain locations on this creek.

As a result of this, care should be taken to retain the overall configuration of the system, including existing channel and wetland complexes, as the creek is clearly in equilibrium with current flow operations.

4.3.3 Sediment Methodology

In order to assess the conditions of stability, and to identify the likelihood of sediment transport associated with the existing flow conditions, bed sediment samples need to be collected and analysed for their grain size characteristics. Additional value in this approach is found when the samples are compared to future samples collected at the same locations, which helps in the determination of impacts (such as sedimentation).

Bed material samples were collected for each sampling reach. If the bed appeared uniform, one sample was taken, if the bed showed varied characteristics, more than one sample was taken. When extremely large particles were present on the bed, 5 were chosen from below the transect line and their long, intermediate and short axes were recorded. Bed material was collected using a scoop sampler, which was dragged along the bed in an upstream direction across the transect line. In the laboratory the bed material/water mixture was allowed to dry. Once dry the sample was mechanically sieved with a Ro-tap sieve shaker. Sieve sizes started at -6 phi, decreasing by 1 phi intervals until the sand range, then decreasing by one-half phi intervals. The last pan represented material finer than +4 phi. Each sieve was weighed and the total weight recorded, and this weight was compared to the total weight of the sample prior to sieving.

Sediment samples were collected at each site to characterize the condition of the bed material, and to gather information relevant to the shear stress analysis which follows. Samples were collected in the field and transported to the lab for mechanical analysis of the grain size distribution. The median diameter (D_{50}) of the material is presented in **Table 4.3.3**, in some instances the D_{16} and D_{84} are also presented. Additionally, water samples were collected for total suspended solids (TSS) analysis. Bulk water samples were obtained from the flow and removed to the lab where the amount of sediment in the sample was filtered out. This information indicates transport competence of the finest fractions of the sediment in the channel, this fraction is generally too small to be extracted from grain size curves.

The concentration of suspended sediment has been shown to be an indication of the contributions of bank and bed erosion as well as being very important in the health of fish habitats. Highly stable concentrations that are below critical levels for fish health are the optimal conditions that can be achieved. Unfortunately, stable conditions are not attainable for any considerable period of time. Spring runoff conditions are responsible for up to 80% of the total suspended load carried by streams in Ontario (Walling, 1977). The greatest amount of the remainder is carried by increased flows from storm events the rest of the year.

Suspended sediment samples were collected at all cross-sections using a DH-48 sampler with large bore nozzle. In instances where depth was too shallow or fluid speed too slow to allow for equal transit of the DH-48, a surface to bed grab sample was taken using DH-48 bottles and equal transit. The location of these samples was determined as either 1) mid-channel, where the channel was of approximate equal depth through the cross-section, or 2) at the thalweg when the channel cross-section depth was varied. Once obtained, the bottle was capped with parafilm (to reduce spilling or evaporative loss), transported back to the lab and analysed.

In the lab the sediment/water mixtures were weighed, then vacuum filtered through pre-weighed and oven-dried Whatman filter paper. The filter containing the water/sediment mixture was oven dried for 24 hours at 100^{o} Celsius (to burn off any organic matter), and then filter and sediment were re-weighed. Subtraction of the initial filter weight left the weight of sediment in grams. This value was converted to give the weight of sediment in milligrams per litre of water.

The results indicate that there is a wide variety of material which makes up the bedload in the study streams, and that concentrations of suspended solids, while variable within and between creeks, are relatively low. With the exception of Indian Creek Sites 2 and 4, most samples are below the OMNR concentration of concern (30 mg L^{-1}).

The fact that there is suspended sediment transported through the systems is an indication of stream health. The finer fractions which constitute these samples are being removed from the system as wash load, and are not being accumulated on the bed of the creeks, where they become detrimental to aquatic habitat (fish and benthos).

4.3.4 Erosion Monitoring

Bank erosion is important to the natural functioning of streams. Eroding banks deliver sediment to the channel which is then transported downstream, a process which assists the stream in lessening the impact of flowing water. If there is no bank delivery of sediment, the energy of the flowing water then is directed at the bed, and downward scour is the result. This is not a favorable situation from a fluvial geomorphological or aquatic habitat perspective. Therefore, it is beneficial to have some bank erosion along a stream corridor.

At each site (refer to **Figure 4.3.1**), erosion pins were located in each bank to determine rates of bank retreat due to natural bank collapse. Each pin was introduced and measured as to its protruding length, at each subsequent visit the pins were again measured and the amount of retreat recorded. Attempts were also made to use sedimentation chains at various locations, with little success. The results that follow indicate how much retreat has occurred; however it should be noted that there were few rain events over the study period, and the creeks have been noted as dropping in volume over the study period. It is recommended that further erosion monitoring be conducted as part of a follow-up study.

Table 4.3.4 shows the erosion pin monitoring results (numbers are in cm) for the study period (April 12 to September 10, 2001): A negative number indicates bank retreat, a positive number indicates a gain of sediment near the erosion pin. Torvane results indicate average strength of the bank material from field samples.

Table 4.3.3 Results of Bed Material Analysis and Total Suspended Sediment Concentrations

Site	D_{16} mm	D_{50} mm	D_{84} mm	TSS mg/L
BC1		20.25		23.7
BC2	>16	12.25	9.00	8.5
BC3		Bedrock		13.2
BC4	>16	12.25	2.83	4.7
BC5	>-3.5	9.00	1.41	9.2
BC6	16.00	0.71	0.35	1.5
BC7	>16.00	16.00	9.00	3.6
BC8		No Sample		6.5
BC9	>16.00	16.00	9.00	3.8
BC10		Bedrock		2.6
BC11	9.00	0.25	1.00	1.3
BC12		>20.25		0.8
BC13	0.71	0.25	0.18	2.1
BC14	14.06	6.25	1.00	4.5
BC15	0.71	0.42	0.25	3.3
BC16		>20.25		3.8
BC17		Organics		2.7
IC1	12.25	4.00	1.00	26.9
IC2		>20.25		29.3
IC3	>-4.00	16.00	5.06	21.4
IC4	16.00	9.00	4.00	32.6
IC5	14.06	2.83	0.50	18.4
IC6	10.56	5.06	1.41	11.1
IC7	12.25	4.00	0.71	6.7
IC8	20.25	6.25	1.19	2.3
IC9	12.25	3.36	0.50	0.7
IC10		Bedrock		1.5
ICT1	12.25	5.06	1.68	3.9
ICT2	16.00	9.00	3.36	5.6
ICT3		Organics		13.5
LC1	12.25	4.00	0.50	7.9
LC2	10.56	2.00	0.42	6.8
LC3	10.56	6.25	0.71	15.4
LC4	10.56	4.00	2.00	9.9
LC5	18.06	9.00	1.41	8.3
LC6	10.56	2.00	0.30	1.6
LCT1	>20.25	0.50	0.21	4.5
KC1	12.25	4.00	0.84	6.8
KC2	10.56	2.00	0.30	5.9
KC3	>16.00	16.00	12.25	7.9
KC4	>16.00	14.06	5.06	10.2
KC5	12.25	6.25	2.00	2.8
LO1	9.00	2.83	0.84	4.0
LO2	12.25	3.36	1.00	0.9

Table 4.3.3 Results of Bed Material Analysis and Total Suspended Sediment Concentrations

Site	D_{16} mm	D_{50} mm	D_{84} mm	TSS mg/L
FC1	14.06	7.56	1.41	3.2
MN1	14.06	6.25	1.41	8.9
WC1	>-3.5	9.00	2.83	8.1
SB1		Organic		21.4
SB2		Organic		18.0
MB1A	4.00	0.50	0.18	6.7
MB1B	2.00	0.35	0.15	9.3
MB3	1.41	0.30	0.13	2.7
MB4	16.00	12.25	4.00	3.1

Table 4.3.4 Erosion Pin Monitoring Results

Site	Left Bank (cm)	Right Bank (cm)	Avg. Torvane (kg/cm^2)
BC1	-12	-5	0.09
BC2	-5	-3	0.28
BC3	-4	-4	Rock
BC4	-13	-0	0.60
BC5	-5	-4	0.29
BC6	-21	-7	0.45
BC7	-6	-3	0.28
BC8	-1	0	0.27
BC9	-3	-12	0.38
BC10	-2	-4	0.72
BC11	0	-1	0.43
BC12	0	-3	0.22
BC13	-6	-5	0.10
BC14	0	-2	0.18
BC15	-2	-4	0.08
BC16	0	0	0.24
BC17	0	0	0.28
IC1	-7	0	0.20
IC2	-12	-3	0.26
IC3	-9	-14	0.28
IC4	-14	-2	0.14
IC5	-5	-1	0.24
IC6	-6	0	0.23
IC7	-3	0	0.22
IC8	0	-1	0.35
IC9	0	-2	0.40
IC10	-1	0	0.16

Table 4.3.4 Erosion Pin Monitoring Results			
Site	**Left Bank (cm)**	**Right Bank (cm)**	**Avg. Torvane (kg/cm^2)**
ICT1	-6	-4	0.43
ICT2	-3	-3	0.23
ICT3	-4	-1	0.20
LC1	0	-1	0.25
LC2	0	-2	N/A
LC3	-2	0	0.38
LC4	-3	-1	0.66
LC5	-1	0	0.72
LC6	-2	-3	0.47
LCT1	0	-4	0.11
KC1	-6	+5	0.19
KC2	-2	0	0.17
KC3	-4	+3	0.24
KC4	0	0	N/A
KC5	-1	-2	0.12
LO1	-1	-1	0.07
LO2	0	+2	0.42
FC1	-2	0	0.53
MN1	0	-4	0.28
WC1	0	0	0.40
SB1	0	-1	0.17
SB2	0	0	0.24
MB1A	-6	-2	0.10
MB1B	-1	0	0.28
MB3	0	0	0.50
MB4	0	0	0.80

These results can be interpreted as exhibiting little in the way of bank retreat over the study period. While there were reaches on Indian Creek which displayed higher retreat than the other sites, the short duration of this monitoring dictates that more detailed and long-term monitoring be completed. It is likely that the retreat seen was natural bank loss of material caused by higher spring flows, in essence a washing away of loose, unconsolidated material that had stored near the bank at the pins sites over the winter. There were some minor instances of banks showing a net gain of material, this was noted in the field as accumulation from slumping near the top of bank and was considered minor.

4.3.5 Rapid Reach Assessment for Erosion Sensitivity

A Rapid Reach Assessment for erosion sensitivity was undertaken to identify reaches of the subwatershed 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. **Table 4.3.5** summarizes the data collected during this assessment and highlights sites which are at risk. This assessment applies to the section of the reach 50 metres upstream and 50 metres downstream of the point.

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. 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.

Those sites which score a value of below 60 out of 100 on the erosion sensitivity scale are at risk for further erosion with changes in land use and/or hydrological behavior within the watersheds. Clearly any development in the Indian Creek basin is going to result in accelerated erosion, and may even further degrade those sites with Moderate Medium Risk to becoming High erosion sensitivity risk. Therefore it is recommended that all sites with a score of below 70 be further assessed to determine management strategies to reduce further erosion potential. One such method would be to assess the channel stability at base level and the riparian vegetation zone width, two of the categories which are mitigable, and proceed from there.

Table 4.3.5 Erosion Sensitivity According To Rapid Reach Assessments

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
Bronte 1	19	14	2	4	15	54	Mod H
Bronte 2	13	11	3	2	18	47	**HIGH**
Bronte 3	12	18	19	11	15	75	LOW
Bronte 4	16	18	20	15	14	73	Mod L
Bronte 5	15	15	15	12	12	69	**Mod M**
Bronte 6	20	19	19	17	13	88	**LOW**
Bronte 7	18	15	14	13	10	70	Mod L
Bronte 8	18	19	12	14	10	73	**Mod L**
Bronte 9	18	19	18	15	4	74	**Mod L**
Bronte 10	16	15	10	10	0	51	**Mod H**
Bronte 11	17	18	15	15	10	75	**Mod L**
Bronte 12	19	20	19	17	20	95	**LOW**
Bronte 13	10	13	15	13	2	53	Mod H
Bronte 14	8	9	13	15	13	58	**Mod H**
Bronte 15	10	13	14	14	18	69	**Mod M**
Bronte 17	17	12	14	15	15	73	**Mod L**
Bronte 18	5	5	10	7	20	47	HIGH
Indian 1	17	19	12	2	10	60	Mod M
Indian 2	15	15	10	5	3	48	HIGH
Indian 3	19	15	14	7	6	61	Mod M
Indian 4	15	13	14	5	7	54	**Mod H**

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
Indian 5	12	10	9	5	0	36	**HIGH**
Indian 6	15	10	13	14	7	59	**Mod H**
Indian 7	12	4	12	14	3	45	**HIGH**
Indian 8	12	1	12	12	5	42	**HIGH**
Indian 9	9	4	12	16	2	43	**HIGH**
Indian 10	17	12	12	13	11	65	**Mod M**
Indian Trib	15	15	8	5	8	51	*Mod H*
Indian Trib	15	13	10	5	7	50	**Mod H**
Indian Trib	13	8	10	10	0	41	**HIGH**
Limestone 1	18	14	6	3	2	33	**HIGH**
Limestone 2	16	12	10	12	2	52	Mod H
Limestone 4	18	19	15	14	15	81	**LOW**
Limestone 5	12	14	10	10	5	51	Mod H
Limestone 6	19	18	12	13	3	75	**LOW**
Limestone 7	17	18	18	19	11	83	**LOW**
Limestone	8	13	12	6	14	53	Mod H
Lowville 1	20	19	14	6	10	69	**Mod M**
Lowville 2	18	15	14	10	15	72	**Mod L**
Mountsberg	5	5	7	8	20	45	**HIGH**
Mountsberg	6	9	11	15	5	46	**HIGH**
Mountsberg	4	8	14	13	20	59	Mod H
Mountsberg	17	14	17	17	15	80	**LOW**
Kilbride 1	18	17	15	10	13	73	Mod L
Kilbride 2	15	15	13	12	10	65	**Mod M**
Kilbride 3	18	12	12	14	3	45	**HIGH**
Kilbride 4	15	12	14	13	10	64	**Mod M**
Kilbride 5	16	12	15	11	6	60	**Mod M**
Mt. Nemo 1	15	15	12	5	15	62	**Mod M**
Willoughby	15	14	11	10	15	65	**Mod M**
Flamboro 1	19	12	8	9	19	67	**Mod M**
Strabane 1	10	13	13	14	17	67	**Mod M**
Strabane 2	5	5	6	6	20	42	**HIGH**

Table 4.3.5 Erosion Sensitivity According To Rapid Reach Assessments

Note:						
	Low Sensitivity		75-100	Moderate Sensitivity		50-74
	Moderate High Risk	Mod H	50-59	Moderate Medium Risk	Mod M	60-69
	Moderate Low Risk	Mod L	70-74	High Sensitivity		0-49

4.3.6 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). **Figure 4.3.2** shows the shear stress analysis sites.

Table 4.3.6 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's (1976) relationship

[4.3.1] $U_c = 57D^{0.46}$

where U_c is the critical velocity (cm sec^{-1}), and D is particle size in cm. This information is presented as an alternative to using shear stress in determining sediment transport potential.

Table 4.3.6 shows the sediment size categories for the D_{16}, D_{50}, and D_{84} fractions, with the critical shear stress (τ_{cr}) for the D_{50} fraction and the boundary shear stress (τ_o) under bankfull flow conditions. Results indicate that none of the bed fraction at the D_{16} size are competent under bankfull conditions. Rows in bold face are those which allow the D_{50} fraction to be mobilized under bankfull conditions. Rows in italicized face are those which allow the D_{84} fraction to be mobilized under bankfull conditions. **Table 4.3.7** shows the critical shear stress required to set a particle in motion, and is to be used as a general guide for information purposes only.

The shear stress analysis indicates that under channel full conditions a majority of the bed is potentially mobile. Field investigation of sediment transport rates shows that under these conditions there is less mobility in the bed than the relationships above may indicate. This is a flaw in the shear stress approach, which does not account for packing or imbrication of bed materials, or the sheltering effects of a high relative roughness value. However, **Table 4.3.6** and **Figure 4.3.2** should be used as a guide for future assessment purposes. Any sites with a red circle are potential sediment accumulation sites; any sites with a purple circle will move fines and not coarse sediment; and any sites with a blue circle will move the medium fraction. None of the D_{16} fraction is competent under this analysis. However, this does not mean this size will not be in motion at times, in fact instantaneous shear velocities will move this material under certain circumstances.

Table 4.3.6 Sediment Size Categories

Site	D_{16}	D_{50}	D_{84}	τ_{cr}	τ_o	τ_o/τ_{cr}	τ_o/τ_{cr}	τ_o/τ_{cr}	U_c
BC1		**20.25**		**14.75**	**49.26**		**3.340**		**78.86**
BC2	>16	12.25	9.00	8.92	3.25	0.279	0.365	0.496	62.58
BC3		Bedrock			15.32				
BC4	*>16*	*12.25*	*2.83*	*8.92*	*6.43*	*0.552*	*0.720*	*3.118*	*62.58*
BC5	*11.31*	*9.00*	*1.41*	*6.56*	*4.10*	*0.498*	*0.625*	*3.991*	*54.30*
BC6	**16.00**	**0.71**	**0.35**	**0.52**	**1.46**	**0.125**	**2.821**	**5.723**	**16.88**
BC7	>16.00	16.00	9.00	11.65	3.82	0.327	0.327	0.582	70.76
BC8					4.19				
BC9	>16.00	16.00	9.00	11.65	4.66	0.320	0.400	0.711	70.76
BC10		Bedrock			6.96				31.89

Table 4.3.6 Sediment Size Categories									
Site	D_{16}	D_{50}	D_{84}	τ_{cr}	τ_o	τ_o/τ_{cr}	τ_o/τ_{cr}	τ_o/τ_{cr}	U_c
BC11	***9.00***	***0.25***	***1.00***	***0.18***	***5.50***	***0.839***	***30.212***	***7.553***	***10.45***
BC12		24.39		17.7	2.88		0.162		85.90
BC13	0.71	0.25	0.18	0.18	0.13	0.250	0.710	0.986	10.45
BC14	14.06	6.25	1.00	4.55	0.31	0.030	0.068	0.427	45.92
BC15	*0.71*	*0.42*	*0.25*	*0.31*	*0.47*	*0.906*	*1.532*	*2.574*	*13.26*
BC16		31.29		22.79	0.98		0.043		96.33
BC17		**0.0075**		**0.01**	**0.18**		**32.97**		**2.08**
IC1	***12.25***	***4.00***	***1.00***	***2.91***	***3.94***	***0.442***	***1.353***	***5.413***	***37.40***
IC2		25.10			2.13				87.04
IC3	>16.00	16.00	5.06	11.65	0.97	0.066	0.083	0.262	70.76
IC4	16.00	9.00	4.00	6.56	0.42	0.034	0.064	0.143	54.30
IC5	14.06	2.83	0.50	2.06	0.06	0.006	0.029	0.163	31.89
IC6	10.56	5.06	1.41	3.69	0.13	0.017	0.035	0.127	41.67
IC7	12.25	4.00	0.71	2.91	0.18	0.021	0.063	0.357	37.40
IC8	20.25	6.25	1.19	4.55	0.01	0.005	0.002	0.082	45.92
IC9	12.25	3.36	0.50	2.45	0.02	0.004	0.010	0.105	34.51
IC10		Bedrock							
ICT1	*12.25*	*5.06*	*1.68*	*3.69*	*1.72*	*0.192*	*0.465*	*1.402*	*41.67*
ICT2	16.00	9.00	3.36	6.56	2.11	0.181	0.322	0.862	54.30
ICT3		0.0082			0.35				2.17
LC1	*12.25*	*4.00*	*0.50*	*2.91*	*2.81*	*0.315*	*0.966*	*7.729*	*37.40*
LC2	*10.56*	*2.00*	*0.42*	*1.46*	*0.83*	*0.107*	*0.567*	*2.700*	*27.19*
LC3	*10.56*	*6.25*	*0.71*	*4.55*	*3.40*	*0.442*	*0.748*	*6.580*	*45.92*
LC4	10.56	4.00	2.00	2.91	0.75	0.097	0.257	0.729	37.40
LC5	18.06	9.00	1.41	6.56	2.27	0.172	0.346	10.378	54.30
LC6	***10.56***	***2.00***	***0.30***	***1.46***	***2.07***	***0.269***	***1.423***	***9.484***	***27.19***
LCT	*>20.25*	*0.50*	*0.21*	*0.36*	*0.21*	*0.014*	*0.577*	*1.373*	*14.37*
KC1	*12.25*	*4.00*	*0.84*	*2.91*	*1.25*	*0.140*	*0.428*	*2.038*	*37.40*
KC2	*10.56*	*2.00*	*0.30*	*1.46*	*0.54*	*0.070*	*0.370*	*2.466*	*27.19*
KC3	>16.00	16.00	12.25	11.65	0.10	0.007	0.008	0.011	70.76
KC4	>16.00	14.06	5.06	10.24	0.40	0.027	0.039	0.108	66.67
KC5	12.25	6.25	2.00	4.55	0.45	0.050	0.099	0.309	45.92
LO1	9.00	2.83	0.84	2.06	0.25	0.038	0.121	0.407	31.89
LO2	12.25	3.36	1.00	2.45	0.66	0.073	0.268	0.900	34.51
FC1	*14.06*	*7.56*	*1.41*	*5.51*	*1.52*	*0.148*	*0.276*	*1.478*	*50.12*
MN1	14.06	6.25	1.41	4.55	0.42	0.041	0.093	0.412	45.92
WC1	*12.25*	*9.00*	*2.83*	*6.56*	*3.53*	*0.396*	*0.539*	*1.713*	*54.30*
SB1		Organic			0.08				
SB2		Organic			0.04				
MB1A	***4.00***	***0.50***	***0.18***	***0.36***	***0.46***	***0.157***	***1.258***	***3.494***	***14.37***
MB1B	***2.00***	***0.35***	***0.15***	***0.25***	***0.36***	***0.247***	***1.413***	***3.297***	***12.19***
MB3	1.41	0.30	0.13	0.22	0.05	0.045	0.213	0.492	11.36
MB4	16.00	12.25	4.00	8.92	0.06	0.005	0.007	0.022	62.58

Table 4.3.7 Critical Shear Stress Required to Set a Particle in Motion

Critical Shear Stress Ranging From -8 phi to 8 phi

Grain Size (phi)	Grain Size (mm)	Critical Shear Stress
8	0.0039	0.00284
7	0.0078	0.00568
6	0.0156	0.01136
5	0.031	0.02258
4.75	0.037	0.02695
4.5	0.044	0.03208
4.25	0.053	0.03860
4	0.0625	0.04552
3.75	0.074	0.05390
3.5	0.088	0.06409
3.25	0.105	0.07648
3	0.125	0.09104
2.75	0.149	0.10853
2.5	0.177	0.12892
2.25	0.21	0.15296
2	0.25	0.18208
1.75	0.3	0.21851
1.5	0.35	0.25493
1.25	0.42	0.30592
1	0.5	0.36419
0.75	0.59	0.42975
0.5	0.71	0.51715
0.25	0.84	0.61162
0	1	0.72839
-0.25	1.19	0.86678
-0.5	1.41	1.02703
-0.75	1.68	1.22369
-1	2	1.45678
-1.25	2.38	1.73357
-1.5	2.83	2.06135
-1.75	3.36	2.44739
-2	4	2.91357
-4	16	11.6542
-6	64	46.6171
-8	256	186.468

5.0 IMPACT ANALYSIS

5.1 Hydrologic Analysis

The existing conditions hydrologic model (Scenario 1) outlined in Section 3 was modified to account for three future scenarios (refer to **Figure 5.1.1**). Scenario 2 (Interim) represents changes in areas already committed for development as per Halton Urban Structure Plan (HUSP) (e.g., Milton Phase 2 residential areas, railway terminals), such as subcatchments 1281, 1282, 1285, 1291, and 1292, but with no stormwater management (SWM) controls. Scenario 3 represents Scenario 2, but with SWM controls in place in subcatchments 1281, 1285, 1291, and 1292. Scenario 4 (Full HUSP Land Use) depicts a full build-out as per the HUSP, and is essentially Scenario 2 with one additional subcatchment developed in lower Bronte Creek, namely 1340. No SWM controls are considered in Scenario 4.

Post-development conditions (Scenarios 2, 3 and 4) are represented in the hydrological model primarily through changes to the following input variables.

- Increased imperviousness, with a corresponding decrease in pervious area (no changes were made to existing wetlands and forest areas). The methodology for estimating impervious areas is outlined in **Appendix A**.
- Changes to the drainage network (represented by different flow cross-sections, and subcatchment length and width) to reflect post-development conditions. In past applications, this has included modifications to channel routing reaches representing future 'channelization' efforts, but with recent trends in 'natural' approaches in watershed management, the existing channel routing reaches remain unaltered.
- In areas with significant hummocky topography, the development of residential or industrial areas results in a removal (decrease) in the runoff contribution to these natural depressions.

Specifically, modifications to the subcatchments were primarily made as increases to impervious areas (e.g., Response Unit 1), with corresponding reductions in the 'open' area or 'low vegetative' cover response units (e.g., RUs 2, 3, 4 and 5). In cases where the revised impervious values were greater than 10%, adjustments were made to the overland flow routing parameters (e.g., decrease in main and off-channel travel times, decrease in overland lag).

The new urban areas within subcatchments 1281, 1282, 1285, 1291 and 1340 are to be residential developments with an assumed imperviousness of 55%, a typical value for medium density residential areas adopted in other studies (e.g. TSH, 1998; Schroeter and Associates, 1998; CH2M-Hill, 1996). The proposed development within Subcatchment 1292 will be industrial in nature, with a planned imperviousness of 60%. These values were taken from the Town of Milton Official Plan.

Appendix A outlines the differences between urban and rural subcatchment elements, in terms of timing or routing parameters. Because Subcatchment 1292 will include an industrial area that is greater than 25% of the subcatchment drainage area, it's influence is believed to be significant, and so the overland routing parameters were adjusted accordingly.

Subcatchments 1281 and 1282 have some hummocky areas, but these totals (less than 5%) are small compared to the amount of developed area proposed, and hence were left unaltered.

The development considered in Scenarios 2 and 3 was all within Indian Creek. In Scenario 4, an area in catchment 1340 was also considered. **Table 5.1.1** lists the impervious percentages by scenario for each subcatchment in the study area.

Table 5.1.1 Subcatchment Percent Imperviousness in Each Scenario

Subcatchment Number	Drainage Area (ha)	Impervious Area in % Scenario 1	Developed Area (ha)	Impervious Area in % Scenario 2	Impervious Area in % Scenario 4
1281	691	2.0	216	19.2	19.2
1282	373	2.0	14	4.1	4.1
1285	623	2.0	156	15.8	15.8
1291	243	2.0	144	34.6	34.6
1292	142	2.0	41	19.3	19.3
1340	895	2.0	94	2.0	7.8
Totals:	2967	2.0	665	12.7	14.4

Note: Scenario 3 is essentially Scenario 2, but with SWM controls.

Flood flow estimates were made using revised GAWSER watershed files for each of the three future scenarios. **Appendix A** provides additional details on these calculations. Scenario 3 results have been reproduced here (**Table 5.1.2**).

Table 5.1.2 Summary of Flood Flow Estimates
Return Period Events for Scenario 3 (Interim Conditions - with Controls)

No.	Point of Interest	Area km^2	Peak Flows ($m^3/_s$) 1:2 yr	1:5	1:10	1:20	1:25	1:50	1:100
6013	Bronte Ck u/s Strabane Ck	36.5	2.9	3.76	4.32	4.82	4.97	5.45	5.9
2013	Strabane Creek Outlet	29.85	2.05	2.67	3.06	3.41	3.51	3.83	4.12
6031	Bronte Ck d/s Strabane Ck	46.31	4.22	5.46	6.23	6.93	7.13	7.81	8.43
6032	Bronte Ck u/s Mountsberg Ck	58.51	5.17	6.74	7.71	8.68	8.94	9.82	10.6
1050	Mountsberg Reservoir Inflow	37.1	1.72	2.18	2.46	2.72	2.79	3.02	3.22
5300	Mountsberg Reservoir	37.1	1.51	1.91	2.16	2.39	2.45	2.65	2.83
6080	Mountsberg Creek Outlet	57.7	8.98	11.7	13.6	15.5	16	18	19.8
2090	Bronte Ck at Carlisle	116.21	10.9	14.4	16.7	19.1	19.8	22.1	24.3
6100	Bronte Ck at Progreston	121.58	11.1	14.8	17.1	19.7	20.4	22.7	25.1
1120	Flamboro Ck Outlet	9.43	0.702	0.97	1.19	1.45	1.52	1.78	2.01
6120	Bronte Ck d/s Flamboro Ck	131.01	11.7	15.6	18.1	20.9	21.7	24.3	26.8
6165	Kilbride Creek Outlet	44.33	5.18	6.77	8	9.27	9.69	11	12.3
6160	Bronte Ck d/s Kilbride Ck	183.53	15.3	20.4	23.7	27.4	28.4	31.8	35.1
1180	Willoughby Creek	12.9	1.69	2.19	2.51	2.81	2.89	3.16	3.42

Table 5.1.2 Summary of Flood Flow Estimates Return Period Events for Scenario 3 (Interim Conditions - with Controls)									
No.	**Point of Interest**	**Area km²**	**Peak Flows (m³/s) 1:2 yr**	**1:5**	**1:10**	**1:20**	**1:25**	**1:50**	**1:100**
6180	Bronte Ck d/s Willoughby Ck	196.43	16.8	22.3	25.9	29.8	31	34.6	38.1
6222	Limestone Creek Outlet	40	10.2	13	14.8	16.3	16.7	18.1	19.5
6225	Bronte Ck d/s Limestone Ck	239.98	22.4	29.5	34.2	39.4	40.9	45.5	50.3
6240	Bronte Ck near Zimmerman	243.84	24.9	32.5	37.4	42.4	43.9	48.9	53.8
1260	Lowville Creek Outlet	9.1	2.83	3.66	4.22	4.73	4.87	5.34	5.77
6260	Bronte Ck d/s Lowville Ck	252.94	27.7	36	41.5	47	48.6	54	59.3
6302	Indian Ck outlet at Bronte	37.32	27.3	34.8	39.1	42.9	44	47.9	51.6
6310	Bronte Ck d/s Indian Creek	290.26	54.7	70.7	80.6	89.8	92.6	102	111
1320	Mount Nemo Creek Outlet	4.79	2.23	2.89	3.34	3.77	3.89	4.29	4.64
6320	Bronte Ck d/s Mount Nemo Ck	296.39	57.2	74	84.4	94.1	97	107	116
1340	Bronte Subcatchment 1340	8.95	11.8	14.7	17	19.1	19.7	21.7	23.5
6340	Bronte Ck d/s Sub 1340	305.34	58.7	75.9	86.8	96.8	99.8	110	119
2360	Bronte Ck at QEW	305.34	58.5	75.3	86.3	96.3	99.3	109	119
2380	Bronte Ck at Lake Ontario	312.5	59.5	76.7	88	98.2	101	111	121

5.2 Additional Analyses

5.2.1 Surfacewater Taking

At present, the number of surfacewater takers within the Bronte Creek watershed is about 10, all of which are located downstream of the Mountsberg Reservoir (see **Table 2.3.1**). According to the maximum rates stated in the water taking permits for these takers, the total amount of water being taken from Bronte Creek and its tributaries could be as high as 820 L/s if all the takers took their maximum rate at the same time. This is not likely, as most of the takers have seasonal operations such as crop and golf course irrigation, or ski hill snow making. One taker in subcatchment 1240 has an approved rate of 710 L/s alone, but it is not clear what they are using the water for (their permit says only 'miscellaneous purposes'), and they may require water for only short bursts. So, if we discard this taker, the total amount of the more 'sustained' takers would be about 110 L/s (or 0.110 m³/s). This amount is of the same order of magnitude of the low flow discharge from Mountsberg Reservoir during the summer. Hence, from a hydrologic perspective, it is difficult to assess the impact of the water takers on downstream flows in Bronte Creek when it appears the Mountsberg Reservoir can supply the entire volume. Please note that about 30 to 50% of the baseflows downstream of Carlisle are essentially outflows from Mountsberg Reservoir.

Any taking of surfacewater from streams such as these ones presents potential problems of decreased supply in the downstream reaches. Therefore, the timing of 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. 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, 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 disadvantages 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.

5.2.2 Rural Settlement Development

As was demonstrated by Scenario 3 (**Table 5.1.2**), the post-development with controls scenario, minimal impacts on the flows in the main stem of Bronte Creek resulted from development in Indian Creek as long as the SWM controls modelled here were in place. If these same controls are imposed on any future development within Carlisle, then the impacts on the flows in Bronte Creek should be minimal.

5.2.3 Water Balance

A 39 year time-series of meteorological inputs (e.g., daily maximum and minimum air temperature, daily rainfall and snowfall depths, and hourly rainfall depths) prepared from records at the Millgrove and Hamilton RBG climate stations was applied to the formulated hydrologic model for each of four scenarios (e.g., existing, interim, interim with controls, and ultimate). This application was carried out to provide information on the water balance quantities for the study area, and to produce extreme flow (both high and low) estimates.

Results of the long-term (39 year) water balance simulations are given in **Tables 5.2.1** to **5.2.3**. Eq. [3.3.1] gives the water balance formula used to compute the infiltration 'losses' or 'net storage' term noted in the tables.

The water balance table is not shown for Scenario 4 (Future 3, Ultimate) because it is essentially the same as Scenario 2.

Table 5.2.1 Mean Annual Water Balance Quantities for Existing Conditions (Scenario 1)

No.	Location	Drainage Area (km²)	PREC*	ET	Runoff	Baseflow	Net Storage	Total Flow
6013	Bronte Creek u/s Strabane Creek	36.5	852	507	117	199	28	317
2031	Strabane Creek Outlet	29.9	852	481	173	153	45	326
6032	Bronte Creek u/s Mountsberg Ck	58.5	852	502	122	200	29	321
1050	Mountsberg Reservoir Inflow	37.1	852	479	149	200	24	349
5300	Mountsberg Reservoir Outflow	37.1	852	527	135	166	24	301
6080	Mountsberg Creek Outlet	57.7	852	521	127	180	24	307
2090	Bronte Creek at Carlisle	116.2	852	511	124	190	26	314
6100	Bronte Creek at Progreston	121.6	852	511	121	194	26	315
1120	Flamboro Creek Outlet	9.43	852	512	69	252	18	321
6165	Kilbride Creek Outlet	44.3	852	509	117	192	33	309
6160	Bronte Creek d/s Kilbride Creek	183.5	852	510	114	201	27	315
6222	Limestone Creek Outlet	40.0	852	525	115	178	33	294
6240	Bronte Creek near Zimmerman	243.8	852	513	116	194	29	309
6285	West Branch Indian Creek Outlet	24.0	852	514	198	83	57	281
6293	East Branch Indian Creek Outlet	4.79	852	511	220	61	61	280
6302	Indian Creek Outlet at Bronte Ck	37.3	852	513	202	78	58	281
6310	Bronte Creek d/s Indian Creek	290.3	852	513	128	177	34	305
2380	Bronte Creek at Lake Ontario	312.5	852	513	132	173	35	304

Note: * Water Balance Quantities given in mm.
Sum of ET + Runoff + Baseflow + Net Storage may not equal precipitation due to round off. Quantities given to nearest 1mm

Table 5.2.2 Mean Annual Water Balance Quantities for Post-Development Future 1 (Scenario 2)

No.	Location	Drainage Area (km²)	PREC*	ET	Runoff	Baseflow	Net Storage	Total Flow
6013	Bronte Creek u/s Strabane Creek	36.5	852	507	117	199	28	317
2031	Strabane Creek Outlet	29.9	852	481	173	153	45	326
6032	Bronte Creek u/s Mountsberg Ck	58.5	852	502	122	200	29	321
1050	Mountsberg Reservoir Inflow	37.1	852	479	149	200	24	349
5300	Mountsberg Reservoir Outflow	37.1	852	527	135	166	24	301
6080	Mountsberg Creek Outlet	57.7	852	521	127	180	24	307
2090	Bronte Creek at Carlisle	116.2	852	511	124	190	26	314
6100	Bronte Creek at Progreston	121.6	852	511	121	194	26	315
1120	Flamboro Creek Outlet	9.43	852	512	69	252	18	321
6165	Kilbride Creek Outlet	44.3	852	509	117	192	33	309
6160	Bronte Creek d/s Kilbride Creek	183.5	852	510	114	201	27	315
6222	Limestone Creek Outlet	40.0	852	525	115	178	33	294
6240	Bronte Creek near Zimmerman	243.8	852	513	116	194	29	309
6285	West Branch Indian Creek Outlet	24.0	852	483	239	79	51	317
6293	East Branch Indian Creek Outlet	4.79	852	436	322	48	46	370
6302	Indian Creek Outlet at Bronte Ck	37.3	852	484	242	74	52	316
6310	Bronte Creek d/s Indian Creek	290.3	852	509	133	176	33	309
2380	Bronte Creek at Lake Ontario	312.5	852	509	137	172	34	304

Note: * Water Balance Quantities given in mm.
Sum of ET + Runoff + Baseflow + Net Storage may not equal precipitation due to round off. Quantities given to nearest 1mm

No.	Location	Drainage Area (km^2)	PREC*	ET	Runoff	Baseflow	Net Storage	Total Flow
6013	Bronte Creek u/s Strabane Creek	36.5	852	507	117	199	28	317
2031	Strabane Creek Outlet	29.9	852	481	173	153	45	326
6032	Bronte Creek u/s Mountsberg Ck	58.5	852	502	122	200	29	321
1050	Mountsberg Reservoir Inflow	37.1	852	479	149	200	24	349
5300	Mountsberg Reservoir Outflow	37.1	852	527	135	166	24	301
6080	Mountsberg Creek Outlet	57.7	852	521	127	180	24	307
2090	Bronte Creek at Carlisle	116.2	852	511	124	190	26	314
6100	Bronte Creek at Progreston	121.6	852	511	121	194	26	315
1120	Flamboro Creek Outlet	9.43	852	512	69	252	18	321
6165	Kilbride Creek Outlet	44.3	852	509	117	192	33	309
6160	Bronte Creek d/s Kilbride Creek	183.5	852	510	114	201	27	315
6222	Limestone Creek Outlet	40.0	852	525	115	178	33	294
6240	Bronte Creek near Zimmerman	243.8	852	513	116	194	29	309
6285	West Branch Indian Creek Outlet	24.0	852	484	238	76	51	317
6293	East Branch Indian Creek Outlet	4.79	852	436	191	181	46	370
6302	Indian Creek Outlet at Bronte Ck	37.3	852	484	206	88	52	316
6310	Bronte Creek d/s Indian Creek	290.3	852	509	132	178	33	309
2380	Bronte Creek at Lake Ontario	312.5	852	509	135	174	34	309

Table 5.2.3 Mean Annual Water Balance Quantities for Post-Development Future 3 (Scenario 3) with Controls

Note: * Water Balance Quantities given in mm.
Sum of ET + Runoff + Baseflow + Net Storage may not equal precipitation due to round off. Quantities given to nearest 1mm

5.2.4 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 surfacewater 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.

To obtain the return period extreme flow estimates, frequency analyses of the annual series of maximum flows and minimum 7-day flows generated by the model were conducted for each point of interest and scenario. Where possible, the generated extreme flows were compared with results of SSFA (conducted using the available discharge data). Please note that the high flows (flood flows) and the mean annual water balance quantities were discussed in previous sections. The 7-day low flow estimates are summarized in this section.

Cumming-Cockburn Ltd. (1989) conducted province-wide low flow analyses using data up to 1986, and included the Progreston and Zimmerman gauges in their work. To make use of the new flow observations for 1987 to 1997 at the Carlisle gauge in particular (e.g., Progreston was closed in 1985, and Zimmerman in 1987), a revised single station frequency analysis was conducted using the observed series of minimum 7-day low flows at all three gauges.

The 7-day low flow records for the Progreston and Carlisle gauges were combined in a similar fashion to the maximum flow frequency work. Here, the Progreston gauge records for 1977 to 1985 were reduced by 4.6% to account for the difference in the drainage areas between the two gauges. This exercise increased the number of data points for the Carlisle gauge from eight to 16. The Zimmerman records (1968 to 1987) were extended by combining them with the Carlisle records for 1990 to 1997, by applying a factor of 1.87 to the Carlisle low flows. This 1.87 adjustment factor represents the mean observed ratio of the 7-day low flows between the Zimmerman and Progreston gauges for the period 1978 to 1985 (this ratio was computed to be 1.792), and adjusting it for the difference in drainage areas between the Progreston and Carlisle gauges. The 7-day low flow statistics at each gauge combination are given in **Table 5.2.4**.

Although the sample statistics given in **Table 5.2.4** were less than ideal for the lognormal distribution (e.g., skewness near zero and kurtosis close to three), it did provide reasonably good fits to both data sets. **Figures 5.2.1** and **5.2.2** show how well the log normal (LN) distribution matches the observed data points at each gauge. The estimated return period 7-day low flows at each gauge are listed in **Table 5.2.5**.

Table 5.2.4 7 Day Low Flow Statistics Used in the SSFA for Each Gauge

Gauge	Transform	N	Mean	Standard Deviation	Skewness	Kurtosis	Maximum	Minimum
Carlisle	Normal (X)	16	0.297	0.062	1.340	7.337	0.473	0.213
	LN X Series		-1.235	0.198	0.509	5.178		
Zimmerman	Normal (X)	28	0.541	0.184	2.112	8.949	1.206	0.317
	LN X Series		-0.657	0.286	1.126	5.156		

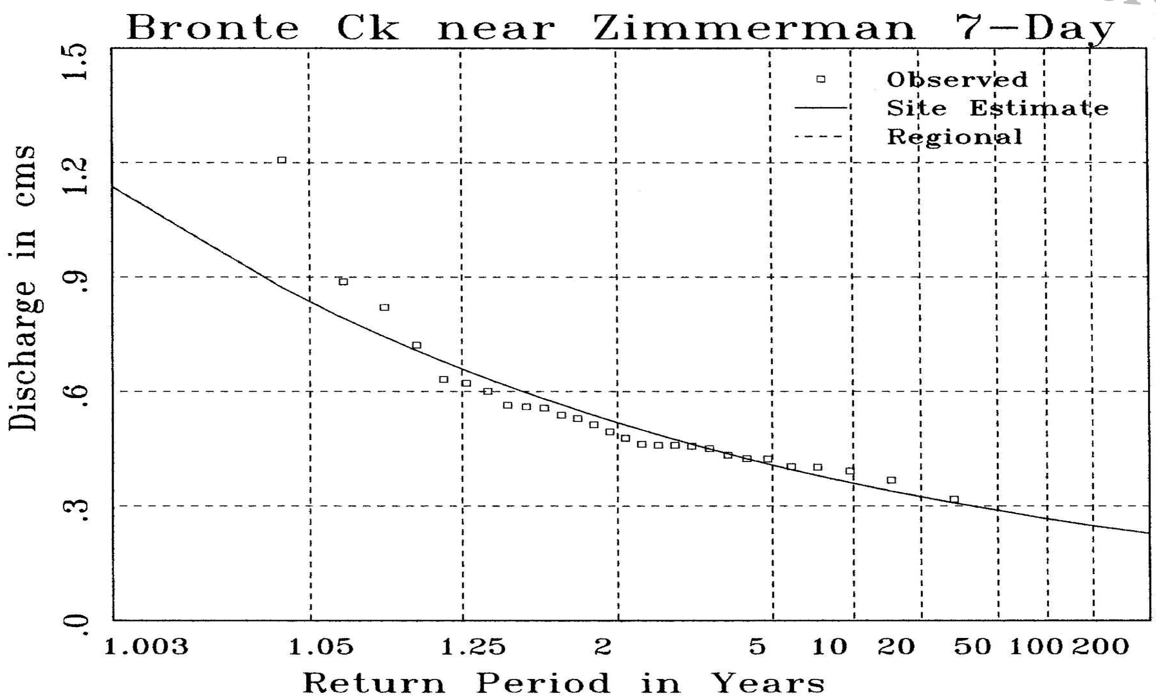


Figure 5.2.1 Day Low Flow Frequency Distribution Plot for Zimmerman Gauge

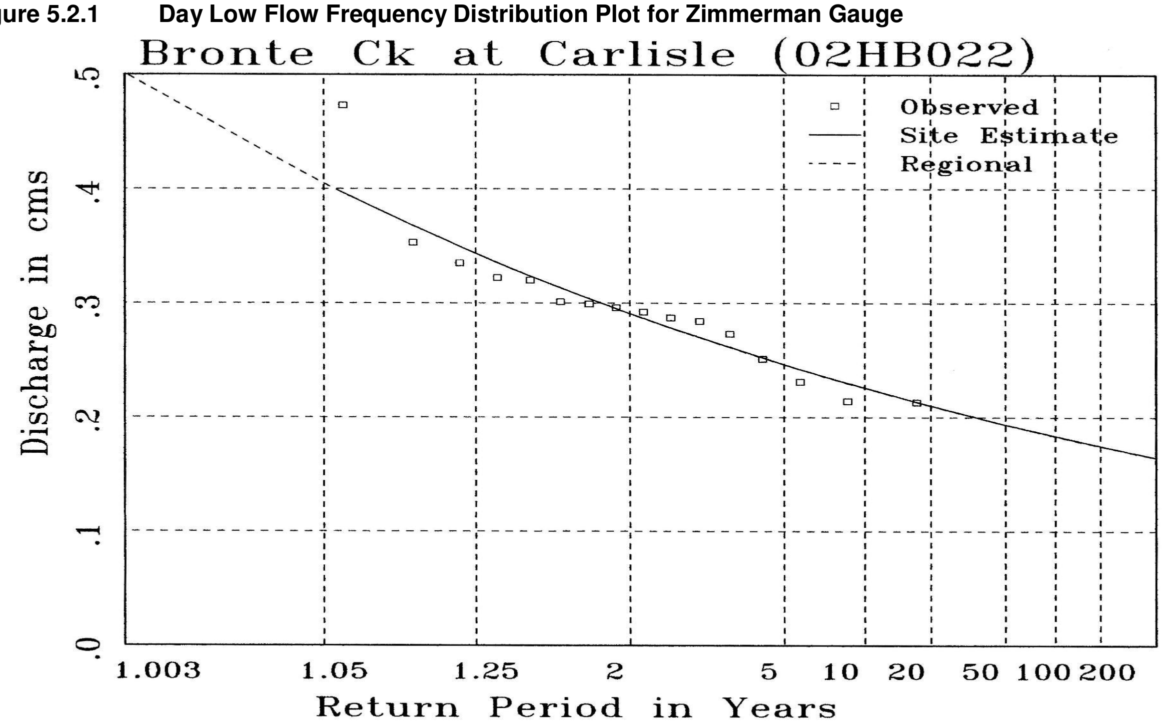


Figure 5.2.2 Day Low Flow Frequency Distribution Plot for the Carlisle Gauge

Table 5.2.5 Estimated Return Period 7-Day Low Flows at Each Gauge Location		
Return Period (Years)	**Carlisle m^3/s**	**Zimmerman m^3/s**
1.25	0.340	0.660
2	0.290	0.520
5	0.250	0.410
10	0.230	0.360
20	0.210	0.320
25	0.210	0.310
50	0.190	0.290
100	0.180	0.270

In order to assess the 'reasonableness' of the computed 7-day low flows, as was done in Section 3 for flood flows, the computer generated values for the 7Q2 and 7Q20 flows under existing conditions (Scenario 1) were compared with estimates derived from single station frequency analyses (SSFA) and by a regional analysis (Cumming Cockburn Ltd., 1995). To this end, **Table 5.2.6** gives various 7-day low flow estimates for the study area. The steps taken to produce these flow estimates are summarized below.

1. Return period 7-day low flows, 2 to 100 year, for the Zimmerman gauge were established by frequency analysis. These flows were transferred to other points of interest by area proration or 'indexed' using

   [5.2.2] $Q_Y = Q_X (A_Y/A_X)$

   where the subscript 'Y' represents the point of interest for which the low flow estimate is required, subscript 'X' denotes the location where the frequency analysis was conducted, Q and A signify flow (in L/s) and drainage area (in km^2), respectively.

2. Return period 7-day low flows were generated through computer application of a specified 39 year meteorological data set using the validated hydrologic model Scenarios 1, 2 and 3 respectively and listed in Table 5.2.7, 5.2.8 and 5.2.9 for existing conditions.

3. For comparison with Steps 1 and 2, additional estimates were obtained by regional analysis as follows:

   a. <u>Regression Method</u>: Cumming Cockburn (1995) developed regression formulas to predict the 7Q2 and 7Q20 low flows for south central Ontario. The two regression formulas are as follows:

   [5.2.3] $7Q2 = -0.7216 + (1.806 \times 10^{-3}) * (\text{Drainage Area}) + 1.7386 * BFI$

   [5.2.4] $7Q20 = -0.2134 + (6.6184 \times 10^{-4}) * (\text{Drainage Area}) + 0.7022 * BFI$

   where the drainage area is in km^2, the 7Q2 and 7Q20 flows are in m^3/s, BFI is a baseflow index. For Bronte Creek, BFI = 0.37. Immediate examination of the first equation for 7Q2 suggests that it should not be used when the drainage area is less than 43.4 km^2, because that is the point at which the formula gives negative low flow values. As long as the BFI=0.370, there is no lower drainage area limit for the 7Q20 equation.

b. Index Flood Method: Cumming Cockburn (1995) also developed regional 7-day low flow index from their regression analyses of observed index low flows (e.g., 2 year) for the whole province. For south central Ontario, which contains the Bronte Creek watershed, the two index equations are given as:

[5.2.5] 7Q2 = 0.383 + (1.61 x 10-3) * (drainage area)

[5.2.6] 720 = 0.209 + (5.89 x 10-4) * (drainage area)

One problem with these two equations immediately is that when the drainage area approaches zero, the 7Q2 and 7Q20 low flows approach constant values of 383 and 209 L/s, respectively. Hence, these two formulas should be used with caution for small watercourses (say under 5 km^2).

Table 5.2.6 Comparison of 7-day Low Flow Estimates for Bronte Creek

No.	Location	Drainage Area (km^2)	This Study $7Q_2$	This Study SSFA Index $7Q_2$	CCL Region Regres $7Q_2$	CCL Region Index $7Q_2$	This Study $7Q_{20}$	This Study SSFA Index $7Q_{20}$	CCL Region Regres $7Q_{20}$	CCL Region Index $7Q_{20}$
6013	Bronte Creek u/s Strabane Creek	36.5	8.9	78		442	1.9	48	71	230
2031	Strabane Creek Outlet	29.9	2.0	20			0.2	13		
6032	Bronte Creek u/s Mountsberg Ck	58.5	15	125	27	477	3.0	77	85	243
1050	Mountsberg Reservoir Inflow	37.1	34	79		443	10	49	71	231
5300	Mountsberg Reservoir Outflow	37.1	150				39			
6080	Mountsberg Creek Outlet	57.7	170	123	26	476	57	76	85	243
2090	Bronte Creek at Carlisle	116.2	210	248	132	570	83	153	123	277
6100	Bronte Creek at Progreston	121.6	210	259	141	579	89	160	127	281
1120	Flamboro Creek Outlet	9.43	3.9	20			0.5	12		
6165	Kilbride Creek Outlet	44.3	10	95		454	1.6	58	76	235
6160	Bronte Creek d/s Kilbride Creek	183.5	250	391	253	678	100	241	168	317
6222	Limestone Creek Outlet	40.0	4.7	85		447	0.3	53	73	233
6240	Bronte Creek near Zimmerman	243.8	260	520	362	776	110	320	208	353
6285	West Branch Indian Creek Outlet	24.0	0.1	51		422	< 0.1	32	62	223
6293	East Branch Indian Creek Outlet	4.79	< 0.1	10		391	< 0.1	6	50	212
6302	Indian Creek Outlet at Bronte Ck	37.3	0.1	80		443	< 0.1	49	71	231
6310	Bronte Creek d/s	290.3	260	619	446	850	110	381	239	380

Table 5.2.6 Comparison of 7-day Low Flow Estimates for Bronte Creek

No.	Location	Drainage Area (km^2)	This Study $7Q_2$	This Study SSFA Index $7Q_2$	CCL Region Regres $7Q_2$	CCL Region Index $7Q_2$	This Study $7Q_{20}$	This Study SSFA Index $7Q_{20}$	CCL Region Regres $7Q_{20}$	CCL Region Index $7Q_{20}$
2380	Indian Creek Bronte Creek at Lake Ontario	312.5	270	666	486	886	110	410	253	393

Table 5.2.7 Return Period 7-Day Low Flows for Existing Conditions (Scenario 1)

No.	Location	Drainage Area (km^2)	1.25*	2	5	10	20	50	100
6013	Bronte Creek u/s Strabane Creek	36.5	20	8.9	4.0	2.7	1.9	1.3	10.
2013	Strabane Creek Outlet	29.9	6.7	2.0	0.6	0.3	0.2	0.1	<0.1
6032	Bronte Creek u/s Mountsberg Ck	58.5	35	15	6.7	4.3	3.0	2.0	1.6
1050	Mountsberg Reservoir Inflow	37.1	63	34	19	14	10	7.8	6.4
5300	Mountsberg Reservoir Outflow	37.1	300	150	75	52	39	27	22
6080	Mountsberg Creek Outlet	57.7	310	170	99	73	57	43	36
2090	Bronte Creek at Carlisle	116.2	330	210	130	100	83	66	56
6100	Bronte Creek at Progreston	121.6	340	210	140	110	89	71	61
1120	Flamboro Creek Outlet	9.43	11	3.9	1.4	0.8	0.5	0.3	0.2
6165	Kilbride Creek Outlet	44.3	27	10	4.0	2.4	1.6	1.0	0.8
6160	Bronte Creek d/s Kilbride Creek	183.5	380	250	160	130	100	85	74
6222	Limestone Creek Outlet	40.0	19	4.7	1.2	0.6	0.3	0.2	0.1
6240	Bronte Creek near Zimmerman	243.8	410	260	170	130	110	86	74
6285	West Branch Indian Creek Outlet	24.0	2.3	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
6293	East Branch Indian Creek Outlet	4.79	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
6302	Indian Creek Outlet at Bronte Ck	37.3	3.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
6310	Bronte Creek d/s Indian Creek	290.3	420	260	170	130	110	86	74
2360	Bronte Creek at Lake Ontario	312.5	430	270	170	130	110	88	76

Note: Return period in year, flows in L/s

Table 5.2.8 Return Period 7-day Low Flows for Future 1 (Scenario 2)

No.	Location	Drainage Area (km^2)	1.25*	2	5	10	20	50	100
6013	Bronte Creek u/s Strabane Creek	36.5	20	8.9	4.0	2.7	1.9	1.3	10.
2013	Strabane Creek Outlet	29.9	6.7	2.0	0.6	0.3	0.2	0.1	<0.1
6032	Bronte Creek u/s Mountsberg Ck	58.5	35	15	6.7	4.3	3.0	2.0	1.6
1050	Mountsberg Reservoir Inflow	37.1	63	34	19	14	10	7.8	6.4
5300	Mountsberg Reservoir Outflow	37.1	300	150	75	52	39	27	22
6080	Mountsberg Creek Outlet	57.7	310	170	99	73	57	43	36
2090	Bronte Creek at Carlisle	116.2	330	210	130	100	83	66	56
6100	Bronte Creek at Progreston	121.6	340	210	140	110	89	71	61
1120	Flamboro Creek Outlet	9.43	11	3.9	1.4	0.8	0.5	0.3	0.2
6165	Kilbride Creek Outlet	44.3	27	10	4.0	2.4	1.6	1.0	0.8
6160	Bronte Creek d/s Kilbride Creek	183.5	380	250	160	130	100	85	74
6222	Limestone Creek Outlet	40.0	19	4.7	1.2	0.6	0.3	0.2	0.1
6240	Bronte Creek near Zimmerman	243.8	410	260	170	130	110	86	74
6285	West Branch Indian Creek Outlet	24.0	4.5	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

Table 5.2.8 Return Period 7-day Low Flows for Future 1 (Scenario 2)									
No.	**Location**	**Drainage Area (km^2)**	**1.25***	**2**	**5**	**10**	**20**	**50**	**100**
6293	East Branch Indian Creek Outlet	4.79	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
6302	Indian Creek Outlet at Bronte Ck	37.3	6.3	0.3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
6310	Bronte Creek d/s Indian Creek	290.3	430	270	170	130	110	87	75
2360	Bronte Creek at Lake Ontario	312.5	430	280	170	130	110	88	75

Note: Return period in year, flows in L/s

Table 5.2.9 Return Period 7-day Low Flows for Future 2 (Scenario 3) (with controls)									
No.	**Location**	**Drainage Area (km^2)**	**1.25***	**2**	**5**	**10**	**20**	**50**	**100**
6013	Bronte Creek u/s Strabane Creek	36.5	20	8.9	4.0	2.7	1.9	1.3	10.
2013	Strabane Creek Outlet	29.9	6.7	2.0	0.6	0.3	0.2	0.1	<0.1
6032	Bronte Creek u/s Mountsberg Ck	58.5	35	15	6.7	4.3	3.0	2.0	1.6
1050	Mountsberg Reservoir Inflow	37.1	63	34	19	14	10	7.8	6.4
5300	Mountsberg Reservoir Outflow	37.1	300	150	75	52	39	27	22
6080	Mountsberg Creek Outlet	57.7	310	170	99	73	57	43	36
2090	Bronte Creek at Carlisle	116.2	330	210	130	100	83	66	56
6100	Bronte Creek at Progreston	121.6	340	210	140	110	89	71	61
1120	Flamboro Creek Outlet	9.43	11	3.9	1.4	0.8	0.5	0.3	0.2
6165	Kilbride Creek Outlet	44.3	27	10	4.0	2.4	1.6	1.0	0.8
6160	Bronte Creek d/s Kilbride Creek	183.5	380	250	160	130	100	85	74
6222	Limestone Creek Outlet	40.0	19	4.7	1.2	0.6	0.3	0.2	0.1
6240	Bronte Creek near Zimmerman	243.8	410	260	170	130	110	86	74
6285	West Branch Indian Creek Outlet	24.0	4.4	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
6293	East Branch Indian Creek Outlet	4.79	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
6302	Indian Creek Outlet at Bronte Ck	37.3	6.1	0.3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
6310	Bronte Creek d/s Indian Creek	290.3	430	270	170	130	110	87	74
2360	Bronte Creek at Lake Ontario	312.5	440	280	170	130	110	88	75

Note: Return period in year, flows in L/s

Upon examination of **Table 5.2.6**, one can see that there are wide discrepancies in the 7-day low flow estimates between the four methods. In general, the Regional Index Method by Cumming Cockburn Ltd. (1995) produced the largest 7-day low flows for both the 2 and 20 year return interval and for all points of interest. Recall, that a problem with this method is that it a 20 year low of 209 L/s will result even if the drainage area were set to zero. There was fairly good agreement between the SSFA prorated values from this study and the Regional Index Method for the 20 year flows, particularly when the drainage area was greater than 200 km^2. In fact, the two 20 year index flows for the Zimmerman gauge and at the Bronte Creek outlet at Lake Ontario were within +10% agreement. This is not surprising, as the same observed 7-day low flows were used to develop the Cumming Cockburn's Ltd. Regional Index equation. Generally, for all locations and return intervals, the low flows estimated using the regional regression method were much lower than for the two indexing procedures.

Overall, the computer generated 7-day low flows were much lower by more than 50% than those estimated from each of the simpler techniques. The main reason for these lower flows is attributed to the meteorological data set, which represents observed climate variables for the period November 1, 1960 to October 31, 1999. This continuous simulation period includes three major droughts not observed by the available streamflow data at both the Carlisle or Zimmerman gauges. These major droughts occurred during 1960 to 1966, 1988 and 1989, and 1998 to 1999. Recall, that the measured streamflows, upon which the SSFA was conducted, were gathered during the 1968 to 1987, and 1990 to 1997 periods. From experience in other watersheds, the severity of the 1960 to 1966, 1988 and 1989, and 1998 and 1999 drought periods is enough to reduce the computed low flows from any 40 year SSFA by at least 50%.

In conclusion, the comparisons made herein (and the previous section for flood flows) strongly suggest that the hydrologic model formulated for this study reasonably represents the hydrology of the study watershed. In light of the known uncertainties in the input meteorological data set, measuring drainage and soil type areas from maps, estimating response unit drainage characteristics, determining how much area drains to aggregate extraction pits and hummocky depressions, seasonal parameter adjustment factors, and securing good quality flow comparison data for model calibration/validation, the results of the simulations presented here are quite remarkable. Although there are some discrepancies between observed and simulated values for a few locations, on the whole we have a good model of the hydrology for Bronte Creek.

5.2.5 Flow Duration Exceedence

Tables 5.2.10 to **5.2.13** present the flow duration estimates for the 10% to 90% time intervals for each scenario. Please note that the flow duration information should be interpreted as follows. The 20% flow means that 20% of the time (during the entire 39 year simulation period, about 2848 days), the mean daily flow is greater than or equal to the value indicated. Conversely, it also means that 80% of the time the mean daily flow is less than this amount. **Figure 5.2.3** displays the flow duration curves for eight locations under existing conditions, whereas **Figure 5.2.4** gives the flow duration curves for the two main branches on Indian Creek under the first three scenarios, Existing, Future 1 and Future 2. **Figure 5.2.5** shows the flow duration curves for the outlet of Indian Creek.

Table 5.2.10 Flow Duration Tables for Existing Conditions (Scenario 1)

No.	Location	Drainage Area (km^2)	10%*	20%	30%	40%	50%	60%	70%	80%	90%
6013	Bronte Creek u/s Strabane Creek	36.5	819	560	444	361	286	212	115	48	18
2013	Strabane Creek Outlet	29.9	233	140	103	82	65	50	32	15	6
6032	Bronte Creek u/s Mountsberg Ck	58.5	1300	891	712	579	460	351	201	88	34
1050	Mountsberg Reservoir Inflow	37.1	874	643	513	415	326	252	167	105	65
5300	Mountsberg Reservoir Outflow	37.1	659	394	292	283	273	263	247	222	191
6080	Mountsberg Creek Outlet	57.7	1090	740	547	471	425	379	324	277	230
2090	Bronte Creek at Carlisle	116.2	2320	1650	1300	1070	889	744	532	372	272
6100	Bronte Creek at Progreston	121.6	2420	1730	1380	1140	947	792	567	391	280
1120	Flamboro Creek Outlet	9.43	187	152	127	106	87	68	46	25	11

Table 5.2.10 Flow Duration Tables for Existing Conditions (Scenario 1)											
No.	**Location**	**Drainage Area (km^2)**	**10%***	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
6165	Kilbride Creek Outlet	44.3	938	673	534	429	337	261	162	76	25
6160	Bronte Creek d/s Kilbride Creek	183.5	3700	2700	2160	1780	1460	1200	821	514	324
6222	Limestone Creek Outlet	40.0	729	526	413	330	263	196	118	55	17
6240	Bronte Creek near Zimmerman	243.8	4920	3510	2790	2270	1850	1490	1010	598	349
6285	West Branch Indian Creek Outlet	24.0	383	134	108	90	76	60	38	12	2
6293	East Branch Indian Creek Outlet	4.79	66	22	16	15	13	10	6	1.0	0.2
6302	Indian Creek Outlet at Bronte Ck	37.3	550	198	159	135	113	91	56	17	3
6310	Bronte Creek d/s Indian Creek	290.3	5660	3870	3060	2480	2020	1620	1090	633	360
2360	Bronte Creek at Lake Ontario	312.5	6060	4100	3230	2620	2130	171	1160	672	379

Note: * Percentages of time, and the flows are in L/s

Table 5.2.11 Flow Duration Tables for Future 1 Conditions (Scenario 2)											
No.	**Location**	**Drainage Area (km^2)**	**10%***	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
6013	Bronte Creek u/s Strabane Creek	36.5	819	560	444	361	286	212	115	48	18
2013	Strabane Creek Outlet	29.9	233	140	103	82	65	50	32	15	6
6032	Bronte Creek u/s Mountsberg Ck	58.5	1300	891	712	579	460	351	201	88	34
1050	Mountsberg Reservoir Inflow	37.1	874	643	513	415	326	252	167	105	65
5300	Mountsberg Reservoir Outflow	37.1	659	394	292	283	273	263	247	222	191
6080	Mountsberg Creek Outlet	57.7	1090	740	547	471	425	379	324	277	230
2090	Bronte Creek at Carlisle	116.2	2320	1650	1300	1070	889	744	532	372	272
6100	Bronte Creek at Progreston	121.6	2420	1730	1380	1140	947	792	567	391	280
1120	Flamboro Creek Outlet	9.43	187	152	127	106	87	68	46	25	11
6165	Kilbride Creek Outlet	44.3	938	673	534	429	337	261	162	76	25
6160	Bronte Creek d/s Kilbride Creek	183.5	3700	2700	2160	1780	1460	1200	821	514	324
6222	Limestone Creek Outlet	40.0	729	526	413	330	263	196	118	55	17
6240	Bronte Creek near Zimmerman	243.8	4920	3510	2790	2270	1850	1490	1010	598	349
6285	West Branch Indian Creek Outlet	24.0	461	193	127	102	84	69	53	28	5
6293	East Branch Indian Creek Outlet	4.79	123	42	17	13	11	9	7	0.9	0.06
6302	Indian Creek Outlet at Bronte Ck	37.3	685	288	189	150	125	102	79	37	7
6310	Bronte Creek d/s Indian Creek	290.3	5700	3910	3090	2520	2050	1670	1150	689	388
2360	Bronte Creek at Lake Ontario	312.5	6130	4140	3260	2650	2160	1740	1210	722	398

Note: * Percentages of time, and the flows are in L/s

Table 5.2.12 Flow Duration Tables for Future 2 Conditions (Scenario 3) (with Controls)											
No.	**Location**	**Drainage Area (km^2)**	**10%***	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
6013	Bronte Creek u/s Strabane Creek	36.5	819	560	444	361	286	212	115	48	18
2013	Strabane Creek Outlet	29.9	233	140	103	82	65	50	32	15	6
6032	Bronte Creek u/s Mountsberg Ck	58.5	1300	891	712	579	460	351	201	88	34
1050	Mountsberg Reservoir Inflow	37.1	874	643	513	415	326	252	167	105	65
5300	Mountsberg Reservoir Outflow	37.1	659	394	292	283	273	263	247	222	191
6080	Mountsberg Creek Outlet	57.7	1090	740	547	471	425	379	324	277	230
2090	Bronte Creek at Carlisle	116.2	2320	1650	1300	1070	889	744	532	372	272
6100	Bronte Creek at Progreston	121.6	2420	1730	1380	1140	947	792	567	391	280
1120	Flamboro Creek Outlet	9.43	187	152	127	106	87	68	46	25	11
6165	Kilbride Creek Outlet	44.3	938	673	534	429	337	261	162	76	25
6160	Bronte Creek d/s Kilbride Creek	183.5	3700	2700	2160	1780	1460	1200	821	514	324
6222	Limestone Creek Outlet	40.0	729	526	413	330	263	196	118	55	17
6240	Bronte Creek near Zimmerman	243.8	4920	3510	2790	2270	1850	1490	1010	598	349
6285	West Branch Indian Creek Outlet	24.0	585	247	132	103	84	69	52	27	5
6293	East Branch Indian Creek Outlet	4.79	179	64	21	13	11	9	7	0.9	0.06
6302	Indian Creek Outlet at Bronte Ck	37.3	844	361	199	152	125	102	79	36	6
6310	Bronte Creek d/s Indian Creek	290.3	5790	3940	3100	2520	2060	1660	1140	686	386
2360	Bronte Creek at Lake Ontario	312.5	6230	4170	3280	2660	2170	1740	1210	720	397

Note: * Percentages of time, and the flows are in L/s

Table 5.2.13 Flow Duration Tables for Future 3 Conditions (Scenario 4)											
No.	**Location**	**Drainage Area (km^2)**	**10%***	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
6013	Bronte Creek u/s Strabane Creek	36.5	819	560	444	361	286	212	115	48	18
2013	Strabane Creek Outlet	29.9	233	140	103	82	65	50	32	15	6
6032	Bronte Creek u/s Mountsberg Ck	58.5	1300	891	712	579	460	351	201	88	34
1050	Mountsberg Reservoir Inflow	37.1	874	643	513	415	326	252	167	105	65
5300	Mountsberg Reservoir Outflow	37.1	659	394	292	283	273	263	247	222	191
6080	Mountsberg Creek Outlet	57.7	1090	740	547	471	425	379	324	277	230
2090	Bronte Creek at Carlisle	116.2	2320	1650	1300	1070	889	744	532	372	272
6100	Bronte Creek at Progreston	121.6	2420	1730	1380	1140	947	792	567	391	280
1120	Flamboro Creek Outlet	9.43	187	152	127	106	87	68	46	25	11
6165	Kilbride Creek Outlet	44.3	938	673	534	429	337	261	162	76	25
6160	Bronte Creek d/s Kilbride Creek	183.5	3700	2700	2160	1780	1460	1200	821	514	324
6222	Limestone Creek Outlet	40.0	729	526	413	330	263	196	118	55	17
6240	Bronte Creek near Zimmerman	243.8	4920	3510	2790	2270	1850	1490	1010	598	349
6285	West Branch Indian Creek Outlet	24.0	461	193	127	102	84	69	53	28	5
6293	East Branch Indian Creek Outlet	4.79	123	42	17	13	11	9	7	0.9	0.06
6302	Indian Creek Outlet at Bronte Ck	37.3	685	288	189	150	125	102	79	37	7
6310	Bronte Creek d/s Indian Creek	290.3	5700	3910	3090	2520	2050	1670	1150	689	388
2360	Bronte Creek at Lake Ontario	312.5	6150	4140	3260	2660	2170	1750	1220	728	401

Note: * Percentages of time, and the flows are in L/s

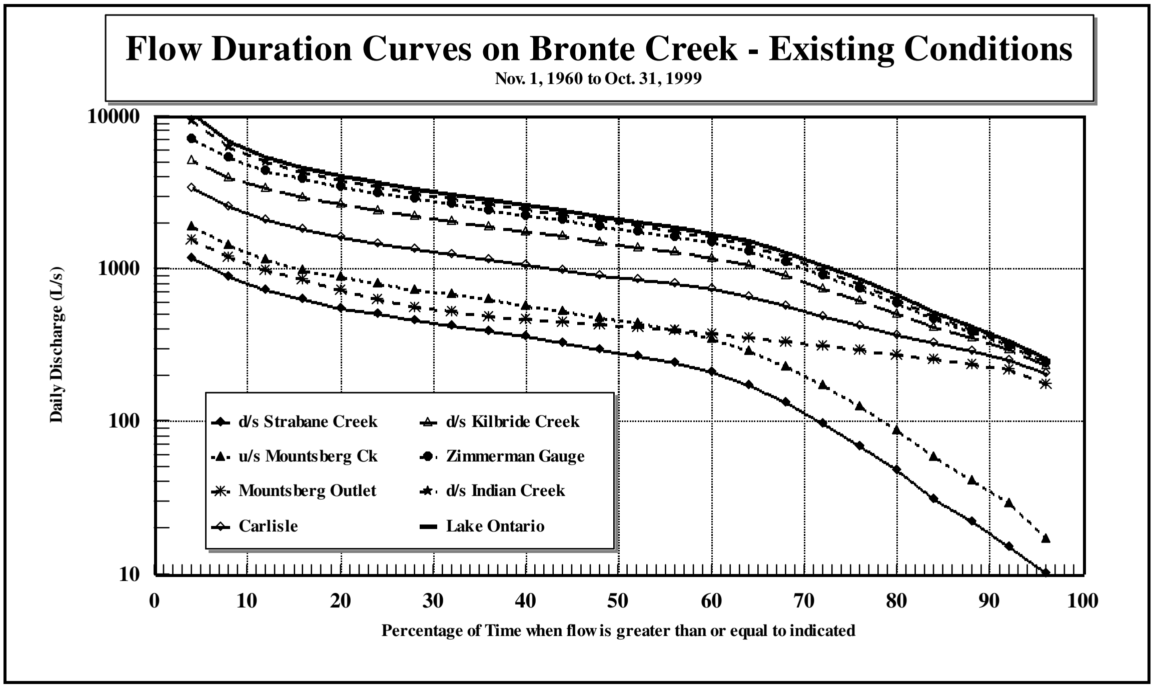


Figure 5.2.3 Flow Duration Curves on Bronte Creek for Existing Conditions (Scenario 1)

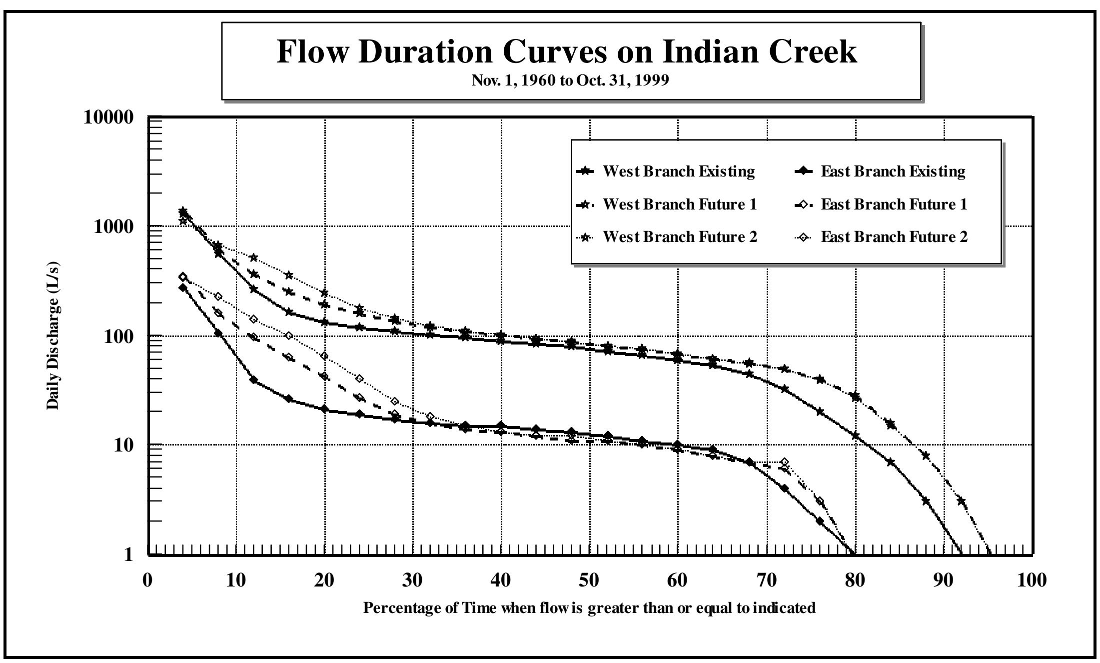


Figure 5.2.4 Flow Duration Curves for East and West Branches of Indian Creek Resulting from Three Scenarios

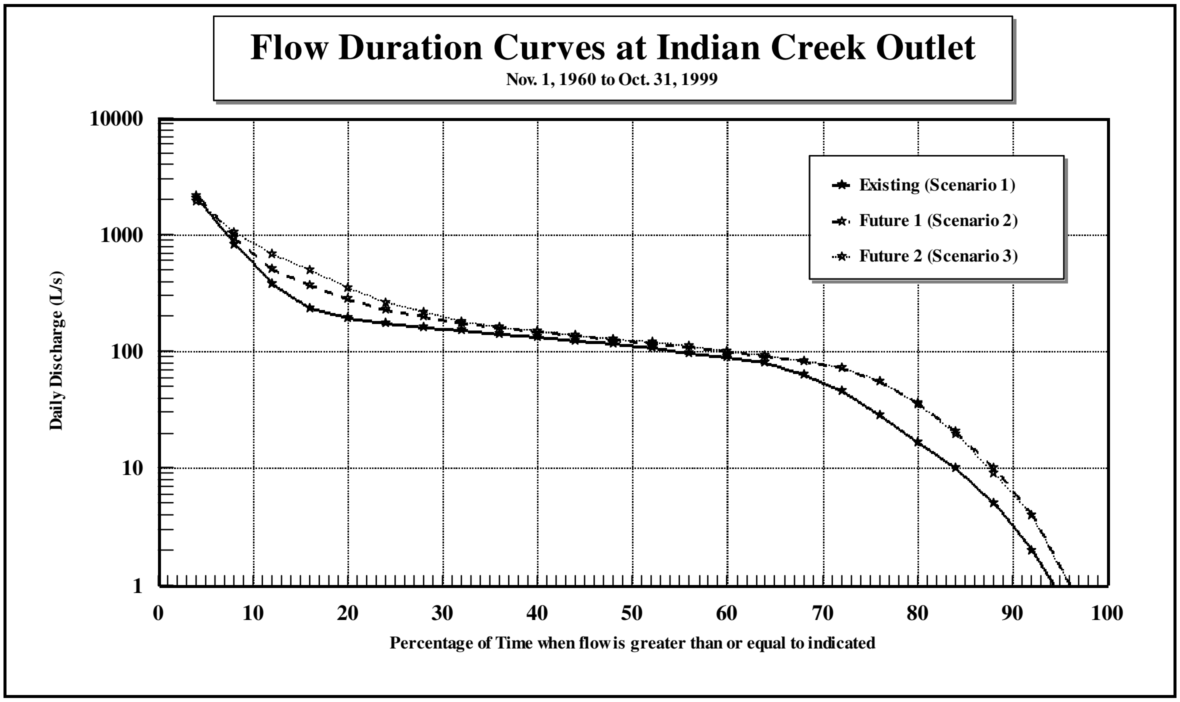


Figure 5.2.5 Flow Duration Curves for the Outlet of Indian Creek Resulting from Three Scenarios

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-channel full 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-channel full depths do not have the expected effect on boundary shear. At the moment, the definitive answer eludes us. Therefore we shall rely on the channel full stage for our analysis.

In most of the creeks at the study sites, given the sizes of materials comprising the bed, flow duration exceedence is not a concern simply because the boundary to critical shear stress relationship is less than 1.0. However, our data indicates that there are 10 of the 53 reaches where flow duration exceedence would cause excessive mobilization of the median fraction of the bed material (refer to **Figure 4.3.2**). Additionally, results indicate that a greater majority of the D_{84} (fine) fraction would be mobile, while results indicate that none of the D_{16} fraction would move. The fact that bed material is in motion at the D_{50} and D_{84} fraction in and of itself could 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 lowering 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 system needs to be assessed independently.

Shear stress results were compared to the hydrological modelling results as presented in **Table 3.3.5** and **5.1.2**, which present peak discharges at the 1:2 year storm to 1:100 year level. As would be expected, the values for discharge even at the 1:2 year event are greater than the channel full discharges presented in the channel morphology summary tables. Excess critical shear and cumulative shear were analyzed by interpreting the shear stress values for increasing flow depth as a function of increased discharge during storm events as modelled. Over the duration of a modelled hydrograph the total shear acting on the bed was determined and compared to the total shear acting on the bed during an existing hydrograph. If the modelled hydrograph (for example a post-development hydrograph) and existing hydrograph exhibit the same total shear then there would be no additional impact related to the condition (in this case the development). As long as the fluvial condition of sediment supply as indicated earlier was allowed to continue, then there would not be any specific issue. If however the excess shear for the post-development hydrograph were greater than pre-development, further erosion would occur and instability would result. This would cause further instability in the channel at the location of excess shear and in the surrounding reaches as the channel attempts to reach a new equilibrium. On the other hand, a decrease in total excess shear would result in sedimentation at the site, which is an instability in itself and would therefore result in channel adjustments as well.

While concern exists whether the critical shear stress for a particular particle size of the bed fraction is exceeded or not, geomorphologically this is not a concern as long as a supply of sediment is allowed to enter reaches where excess critical shear is operating at the bed. In simpler terms, this is a non-issue in this system unless there is armouring of the beds (which would cause excessive bank erosion) or armouring of the banks (which would cause excessive bed lowering). While some consulting geomorphologists would express concern at the excessive shear stress, researchers in this field are clear in their assessment that excessive shear is a normal function of flow in rivers and should not be altered. Only when the existing shear relationships are exceeded or diminished is there going to be significant alteration to channel process.

It is clear from **Table 4.3.6** that some locations are showing a critical shear to boundary shear stress ratio of greater than one, which indicates that fraction would be in motion under certain circumstances, while other locations do not reach that threshold. In some instances channel locations where the threshold is not reached are experiencing erosion and instability issues; while in other areas where the threshold is exceeded there appear to be no instability concerns. This indicates that the cause of instability (or stability for that matter) is not found within the flow regime, rather it is found in the riparian area and in some instances in response to site-specific remediation measures.

This highlights a very important limitation in the shear stress approach to analyzing channel stability. These shear stress values are representative of the bed condition only, and the general instability found in these and other creeks in Southern Ontario is found in lateral movement of the creek (bank erosion). The shear stress approach does not factor into the bank situation at all. Therefore a value of critical to boundary shear of greater than one is not going to be a key indicator of bank instability, nor is a value of less than one an indicator of bank stability. It is impossible to categorize channel stability according to the shear stress approach, and in fact attempts to do so, and designs of 'natural' channel segments which have utilized this approach (for example within the City of Vaughan) have met with spectacular failure. This is why we utilized the Erosion Sensitivity Index (see **Table 4.3.5**) to highlight areas of concern. Please refer to the Appendices for further discussion as to the relevance and limitations of using a shear stress approach.

Keep in mind that streams are dynamic and need to alter their form over time. Only in situations where existing constraints on a stream system require no lateral or vertical migration does one have to match exactly the critical shear relationships—keeping in mind this is a near-impossible task over a wide range of flows—for decreasing shear stresses causes sedimentation of the bed and initiates a wide range of channel alterations.

Herein lies the connection between geomorphological functioning and hydrological modeling. While the models show the potential for excess shear, the streams are in a state of quasi-equilibrium. Therefore it is essential that any post-development hydrograph match existing hydrograph conditions. If that is achieved then there would be few problem areas resulting from flow energy in itself. Matching overall hydrograph shape is a challenging task which cannot be achieved in soils other than sandy soils, where infiltration can be expected to occur freely. In clay soils, much like the soils of the Bronte System, infiltration capacity is easily reached and it therefore is virtually impossible to match the tailing ends of hydrographs. However it is possible to match the rising limb and peak of the hydrograph in a pre- and post-development scenario. This is the most important component of the hydrograph to be matched. On the falling limb there exists the potential for sediment accumulation as the tail winnows out, however as the sediment associated with the tail is fine-grained, it will settle out for a temporary period and be resuspended at the next rising limb.

Where the erosional issues arise is in the alteration to the buffer. Reduction of riparian buffering decreases the resilience of the stream to absorb alterations in a natural rate. If we add to this any site-specific alterations to the channel in one or more locations, and invoke a cumulative impact hypothesis, we end up with sections of channel which are re-establishing to absorb these site-specific alterations. This is what we see in Indian Creek. Alterations to the flow properties and channel are attempting to achieve a new equilibrium, which is causing erosion, and given time the creek will be able to rehabilitate itself if no further damage is imposed on the system.

This does not mean that there should not be site-specific rehabilitation on Indian Creek, in fact the rate of damage over time appears to exceed the ability of the stream to fix itself within its current boundaries. This means that over time as the system fixes itself it will likely blow out some banks and form a new path. Existing constraints (roads and property lines) prevent this natural adjustment from occurring, so site-specific treatments of Indian Creek are required.

5.2.6 Stormwater Management Volumes

As noted previously, Scenario 3 is essentially Scenario 2, but with SWM controls in place. The SWM controls were placed in Subcatchments 1281, 1285, 1291 and 1292 only. The SWM controls or ponds were sized according to the following criteria:

a. Extended detention volumes are calculated as the runoff volume generated from the developed areas for a 25 mm 4 hour Storm.
b. The extended detention volumes are drawn down over 48 hours.
c. The SWM ponds are sized to control the post-development flood flows generated by the 2, 5, 10, 25, 50, and 100 year return period storms to pre-development levels.
d. No infiltration of 'excess runoff' is considered in the SWM ponds because the hydraulic conductivity for the surficial soils in the area is less than 20 mm/h.

To determine the magnitude of the stormwater management volumes required in each subwatershed, the Scenario 2 hydrology model was modified by inserting detention pond elements at the outlet of subcatchments 1281, 1285, 1291 and 1292 in Indian Creek. This created Scenario 3 (also called Future 2) or the Interim post-development with controls. As noted in Section 3, detention ponds are sized to capture runoff from a 25 mm 4 hour storm, and release this volume for extended detention purposes within 48 hours. Furthermore, these ponds were further sized to control the post-development flood flows resulting from return period events (2, 5, 10, 25, 50, and 100 year) to pre-development levels. No infiltration to groundwater storage was permitted.

The computed volumes per unit upstream drainage area, and per impervious area, are summarized in **Table 5.2.14** and **5.2.15**. We provide the following explanatory comments on the results shown in **Table 5.2.14** and **5.2.15**.

1. Subcatchments 1281 and 1285 have drainage areas of 691 and 623 ha, respectively; much larger than Subcatchments 1291 and 1292 (whose drainage areas are 243 and 142 ha, respectively).
2. The 24 hour 100 year storm used to establish the pre and post-development flows for Indian Creek generates 102 mm runoff from impervious areas, and 76 mm from the Halton Tills (Response Unit 4). More than 75% of the pervious areas within Indian Creek contain Response Unit 4 soils. So, if we assume for the moment a subcatchment in the pre-development case consisting of 3% impervious area, and 97% in the Halton Tills, then we would expect a 100 year runoff volume of about 77 mm. Now, if this same subcatchment is developed to that it now has 20% impervious area, and 80% in the Halton Tills, then the increased runoff volume due to development would be 81 mm. Resultingly, the impervious area has increased by 567%, but the runoff volume has only increased by 5%.
3. The level of development modelled in Subcatchments 1281 and 1285 is low, because their impervious percentages are only 19.2 and 15.8%. Because these subcatchments have significant areas within the

Niagara Escarpment, it was assumed their overall overland routing response would not change. Hence, there were no adjustments made to their overland routing parameters for pre to post-development. For this reason, and in light of the comments in Point 2 above, the control volumes are low for subcatchments 1281 and 1282.

4. For the post-development scenario, the revised impervious area percentages in subcatchments 1291 and 1292 are 34.6 and 19.3%, respectively. Because these subcatchments will be completely urbanized, their overland flow response (the drainage network) will definitely be changed, and they were modelled as such. Peak flow increases (pre to post-development) were significantly larger than those modelled in Subcatchments 1281 and 1285. Consequently, the control volumes are much larger in these subcatchments in order to control the post-development flows at pre-developments.
5. Following from Point 2, and using the impervious percentages noted for subcatchments 1291 and 1292 in Point 4, the increased runoff amounts for these two subcatchments are 11% (85.5 mm) and 5% (72 mm), respectively. In terms of the 100 year control volume quoted on a unit area basis, the ratio in runoff amounts between Subcatchments 1291 and 1292 is preserved (85.5 to 72 versus 568 to 476).
6. The reason the stormwater management control volume quoted on a unit impervious area basis is so much higher for Subcatchment 1292 relative to 1291 is not unusual, as Subcatchment 1292 has half the amount of impervious area relative to Subcatchment 1291.
7. Halton Hill tills have a high runoff generation potential.
8. As no drainage network changes were modelled in Subcatchments 1281 and 1285, the increased runoff volumes going from pre to post-development were low (relatively speaking). Since the runoff generated by the impervious areas for the 100 year storm is 102 mm, and for the greatest soil group in Indian Creek, the computed runoff volume is 77 mm. These volumes differ by only 25%.
9. The stormwater management control volumes, on a per unit area for the fully developed subcatchments (e.g., 1291 and 1292), are consistent with other studies. In Huttonville and Springbrook Creeks (Credit Valley Conservation Subwatersheds 7 and 8a), two areas that contain significant amounts of Halton Tills, 100 year SWM volumes were determined in the range of 299 to 567 m^3/ha, depending on the amount of imperviousness in each subcatchment. For Torrance Creek in Guelph, one in which a slightly different design storm (a 48 Hour Storm versus 24 hour SCS) was used and the watershed contains mostly sands and gravels, the 100 year control volumes were found to be in the range of 480 to 600 m^3/ha. The per unit area 100 year control volumes for Subcatchments 1291 and 1292, which are fully developed, are comparable to those generated in other studies where fully developed subcatchments are involved (see Schroeter & Associates, 1999b).

Table 5.2.14 Summary of Extended Detention Volumes				
Subcatchment	**Extended Detention Volume (m^3)**	**48 hour Drawdown Rate (L/s)**	**Volume/area (m^3/ha)**	**Volume/Impervious Area (m^3/ha)**
1281	42,000	243	60.8	317
1285	35,000	203	56.2	356
1291	37,000	214	152	440
1292	16,800	97.2	118	613

Table 5.2.15 Summary of 100 Year Storm Control Volumes				
Subcatchment	**100 Year Detention Volume (m^3)**	**Peak Outflow (m^3/s)**	**Volume/area (m^3/ha)**	**Volume/Impervious Area (m^3/ha)**
1281	60,000	5.24	86.8	452
1285	45,000	11.4	72.2	457
1291	138,000	2.94	568	1640
1292	67,600	2.97	476	2470

5.2.7 Pre-Development and Post-Development Hydrograph Shape

It is becoming more recognized in fluvial geomorphological research that the shape of a hydrograph for any particular event is a major area of concern for restoration and rehabilitation projects. Clearly the purpose of any hydrological analysis is to ensure that there are no alterations to flow volumes (from pre- to post-development), and this has been used to indicate that stream processes would not be altered given a particular development scenario. However we now realize that the distribution of energy in streams as stage rises is vital to maintaining proper sediment transport relationships. Therefore it is essential that, in designing water volume control structures in development areas that the shape of the hydrograph curve on the rising limb in particular be matched exactly to the pre-development curve.

The reasons for this matching are fundamental. It has been well documented that hydrograph shape changes significantly when development occurs in a basin, with the time to peak in the hydrograph being arrived at much more quickly. This means that the delivery of water to the system is more rapid than would occur naturally. The implications are that energy relationships between the flow volume and the sediment on the bed (and in some cases in the banks) are altered. There is a higher concentration of energy over a shorter period of time. This impact on sediment causes larger than predicted sized particles to be set in motion, and is the actual, documented cause of some rather spectacular stream design failures in Canada and the United States. Conversely, if stormwater management structures are 'over-efficient' and retain water for longer periods of time than would naturally be delivered to the stream system (in other words if the post-development hydrograph has a gentler rising limb (time to peak) and a lower overall peak than the pre-development hydrograph), a potential for sedimentation or accumulation of sediment on the bed is created.

It is recognized that matching the entire hydrograph shape may be impossible, and research indicates that the technology to do this is not at hand. This should not preclude attempts to match the rising limb. It is not as vital that the falling limb of the post-development hydrograph match the pre-development one, the falling limb can be stretched out over a longer period of time to match volume issues. The one caveat which must be stated is that the peak flow cannot be increased in magnitude, and that the falling limb can not decrease at a faster rate than the pre-development hydrograph.

Matching the shape of the rising limb of a pre-development hydrograph is therefore fundamental if the receiving stream is to continue to maintain pre-development function. Therefore it is vital that the hydrological modelling for a post-development condition be matched in respect to the rising limb of the hydrograph of the pre-development condition.

5.2.8 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 which 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 which 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.

5.3 Hydrology Summary

The simulation results for each scenario are summarized in **Table 3.3.5** and **Table 5.1.2** for the flood flows generated by the event modelling and **Tables 3.3.4** and **5.2.1** to **5.2.3** for the water balance quantities determined from the 39 year long-term (continuous) simulations. The latter also produced the 7-day low flow estimates in **Tables 5.2.4** to **5.2.9**, and flow duration information in **Tables 5.2.10** to **5.2.13**. A graphical representation of these flow duration tables are given in **Figures 5.2.3** to **5.2.5**.

Upon examination of these tables and figures, the following general trends can be seen.

1. Increases in peak flows along the main stem of the Bronte Creek and along Indian Creek resulting from increased impervious areas in the subcatchments (see **Table 5.1.1**) are noted for Scenario 2, 3 and 4. On the main stem of Bronte Creek upstream of Indian Creek, there are no changes in the peak flows, because these areas have not been modified in the three future scenarios. However, on Bronte Creek downstream of its confluence with Indian Creek the increases in peak flows are as high as 6 to 11% for the 2 to 100 year flow in Scenario 2 and 4. Along Indian Creek, the increases in peak flow are significant for Scenario 2 and 4, being as high as 32 to 42% for the 2 to 100 year flow in Scenario 2 and 4 at the outlet. For the East Branch of Indian Creek, the increases in the 100 year peak flows are more than 700% for Scenario 2 and 4, whereas the increases in the 100 year flow for the West Branch of Indian Creek are much lower at about 280%. These increases in peak flows, in terms of percentage change, are fairly typical of specific subcatchment elements undergoing full development, as in the case of subcatchments 1291 and 1292.

2. In Scenario 3, stormwater management controls (SWM ponds) were modelled in four Indian Creek subcatchments, namely 1281, 1285, 1291 and 1292. These SWM ponds were successful in controlling the post-development return period flood flows (2 to 100 year) to their pre-development (existing conditions) levels. The SWM controls modelled in Indian Creek resulted in very little changes to flood flows on the main stem of Bronte Creek (comparing **Tables 3.3.5** and **5.1.2**).
3. Mean annual streamflow at the outlets of Bronte and Indian Creeks increases by 1.6% and 12%, respectively, for Scenario 2 and 4.
4. The mean annual total runoff volume computed at the outlet of Bronte and Indian Creeks increases by 4% and 20%, respectively, for Scenario 2 and 4. The corresponding changes in mean annual baseflow are minimal (less than +1%) at the outlet of Bronte Creek, but are less than 5% at the outlet of Indian Creek both Scenario 2 and 4.
5. For individual branches in Indian Creek (e.g., East or West), the changes in total runoff volume and baseflow are more dramatic. For instance, in the East Branch (that is subcatchments 1291, 1292 and 1293) the runoff volume increased by 46% in Scenario 2, with corresponding decreases in baseflow of 21%. For the West Branch (subcatchments 1281 to 1285), the mean annual runoff volume increases by 21% for Scenario 2, and baseflow decreases by 5%.
6. The total actual evapotranspiration (ET) in Bronte Creek is reduced by 4 mm (0.8%) in Scenario 2 and 4. For Indian Creek only, the total actual evapotranspiration is reduced by 29 mm (6%) in Scenario 2 and 4. The total ET in the East Branch of Indian Creek is reduced by 75 mm (15%) for Scenario 2, whereas ET in the West Branch is reduced by only 31 mm (or 6%).
7. In terms of 7-day low flows, the increased flows resulting from development in Indian Creek have minimal (less than 2%) impact on those along the main stem of Bronte Creek. Along Indian Creek per se, the 7Q20 flows are unaffected by development modelled in Scenario 2. However, there is an increase in the 7Q2 flow at the outlet of Indian Creek of 0.2 L/s over the existing conditions.
8. The flow duration curves for existing conditions (**Figure 5.2.3**) at different locations along Bronte Creek clearly show that a good portion (about 30 to 50%) of the baseflow (say, the 90% duration) for downstream locations is essentially outflow from the Mountsberg Reservoir.
9. The flow duration curves for Indian Creek (**Figures 5.2.4** and **5.2.5**) show a definite shift from left to the right resulting from the post-development uncontrolled flows, particularly the increased volume. These shifts are 20% flow for existing conditions at the outlet of Indian where flow is 198 L/s and increases to 288 L/s for Scenario 2 (Future1), a total increase of 46%. Similarly, the 20% flow for the East Branch increases from 22 L/s for existing conditions to 42 L/s for Scenario 2, a 110% increase. For the West Branch, the 20% flow increases from 134 L/s to 193 L/s. These shifts in the flow duration curves are noticeable up to the 80% duration. The modelled SWM ponds are successful in altering the flow duration curves to maintain the central portion (40 to 60%) near existing conditions. As far as flows on the main Bronte Creek are concerned, the increased flows resulting from post-development in Indian Creek have minimal (less than 2%) impact.

In general, the impact of future development in Indian Creek on the hydrology of the main stem of Bronte Creek will be minimal as long as the stormwater management controls modelled here are in place.

5.4 Geomorphology Summary

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

1. The streams move most of the sediment found on the streambed.

   Streamflow is 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.

2. 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 coarser painted rocks is consistent with the concepts of Phase I and Phase II transport.

3. 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, with the exception of some reaches on Bronte and Indian Creeks.

A common feature of most gravel bed streams is armour or pavement – surface grains are coarser than grains found in the subsurface (Parker and Klingeman, 1982). The presence of armour has been interpreted (Dietrich et al., 1989) to be the consequence of a channel able to transport more sediment than is supplied to it. This hypothesis has been supported in the flume (Dietrich et al., 1989; Iseya and Ikeda, 1987; Ikeda and Iseya, 1987) and in the field (Kinerson, 1990). In essence, streamflow winnows the bed surface of the most easily moved finer particles leaving a coarse armour. A well-known example of supply limitation is a streambed below a dam. The impoundment cuts off most, if not all, the upstream supply of material typically found on the stream bed. The streamflow generally retains sufficient energy to erode and transport material, but without upstream supply, the bed below the dam is mined of the most easily moved material and the bed surface coarsens (Williams and Wolman, 1984).

4. There are significant erosion risks within the Bronte Creek watershed, and in particular along the Indian Creek system.

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 Bronte Creek watershed.

6.0 MANAGEMENT STRATEGIES

6.1 General

The initial phases of this watershed study established background information, and provided detailed hydrology and morphology studies. Based on the information documented in these sections, the management plan recommends requirements and criteria to be implemented across the watershed to preserve or enhance existing environmental features while allowing some development to proceed.

6.2 Erosion

Streambank erosion will increase with changes in land use if the proper stormwater controls are not used. The control of peak flows to existing levels is not sufficient for erosion control. Increased stream bank erosion results from increased volume of runoff and increased frequency of peak flows as well as the increases in peaks themselves. Therefore, as outlined previously, the control of runoff volume is critical in controlling steam bank erosion problems.

Morphological analysis is required, on a subwatershed basis, to ensure that the stormwater management approach used will control flows effectively for erosion protection. The target is to ensure that the forces creating streambank erosion are not increased.

6.3 Riparian Buffers

In earlier sections of this report it has been recommended that riparian buffers be established in areas where there are no buffers around the creek systems. While the concept of establishing a protected zone around streams is a simple one to grasp, the difficult question becomes determining the width that the buffer has to have in order to perform its intended function.

Considering there are a number of reasons for establishment of riparian buffers, there is also the issue of which criteria to use to base dimension requirements on: water quality, temperature control, erosion and flood protection, and so on. It is clear that the widths for each of these separate requirements would be different (for instance establishing a 10 metre buffer would contribute enough canopy shade to control temperatures in cold-water streams, but would be insufficient to provide flood protection and erosion control).

It is recommended here that the criteria for determining the width of riparian buffers be the fluvial functioning of the system in question, as this buffer would require greater width than the other requirements, and would therefore satisfy their concerns. Based on previous studies it has been suggested that the meander beltwidth is an appropriate minimum buffer width, however further study needs to be done to determine the impacts of establishing this minimum buffer on Indian Creek in particular, and on a number of streams in general, as this minimum is not the direct result of empirical studies.

Based on the morphological analysis of the Indian Creek subwatershed documented earlier in this report, the average meander beltwidth on Indian Creek is 17.38 m, with a range of averages in the upper portion of the creek of 20.2 m and the lower portion of the creek of 14.6 m.

It is our contention that establishing this as the riparian buffer would not be sufficient to protect Indian Creek from development pressure, and would not contribute to proper rehabilitation of the existing degraded sections of the Creek. Therefore we recommend that the riparian buffer which needs to re-establish within this subwatershed be a minimum of double the average meander beltwidth, or a minimum of 35 m.

It is also our contention that this riparian buffer width not be applied to other sections of the Bronte Creek Watershed without detailed study.

6.4 Indian Creek

Due to increased development pressures within the Indian Creek subwatershed it was considered in greater detail than the rest of the Bronte Creek watershed. Stormwater management targets were determined for the Indian Creek watershed.

As shown in earlier sections of the report stormwater controls for any new development in other parts of the Bronte Creek watershed will also be required. Detailed stormwater management studies will need to be conducted at the design stage to determine volume and size requirements for any stormwater controls in any new development within the watershed.

6.4.1 Hydrologic Targets

To get some idea of the magnitude of the stormwater management volumes required in each subwatershed, the Scenario 3 hydrology model was modified by inserting detention ponds within Indian Creek at the outlet of Subcatchments 1281, 1285, 1291 and 1292. These detention ponds were sized to control the 100 year flood flow to pre-development levels, with a 48 hour draw down for quality control. The computed extended detention volumes per unit upstream drainage area are summarized in **Table 5.2.14** and the 100 year control volumes are summarized in **Table 5.2.15**.

In addition, target hydrographs for all nodes in Indian Creek are presented in **Appendix C**. Future development must ensure that these hydrographs are met as a result of any proposed development.

6.4.2 Geomorphology Issues

Based on the results of the field and desktop analyses, there are a number of areas within Indian Creek which require attention for future study. The reaches contained in this study are those such reaches: they were selected early in the site selection process as we were aware of the concerns facing this watershed. Therefore it is recommended that those reaches studied within be considered candidate reaches for further, detailed study, as well as any other reaches that are under potential stress from development. These reaches are sensitive to any change within the Indian Creek system, whether that change be induced by changing land use practices or by alteration of the hydrological regime. It is important to note that sensitivity to change does not indicate a lower threshold of magnitude of change, it means this system will respond to even minor changes in land use / hydrology.

Given the nature of the Indian Creek system at the study sites, it is anticipated that adjustments to changes in land use / hydrology would be felt first in this system, due to its high sensitivity to erosion. Depending on whether appropriate stormwater management strategies are in place, as imperviousness increases it is anticipated that accelerated erosion in the main branch and the lower tributaries would result in a situation of sediment accumulation, as the bankfull stage does not have the competence to move larger materials out of the system. The result of this occurring is flow divergence around bars, directed toward the banks, and further bank erosion and sediment accumulation. This positive feedback loop would continue if not properly managed until the system becomes choked with sediment and then attempts to attain a new equilibrium channel (which, if left alone, it will do over time).

Conversely, if there is too much flow control, the streams will not have the competence to move the materials it naturally does through the system, and accumulations will result in flow divergence and bank erosion. With development comes the threat of water-taking as discussed briefly in Section 5.2.1. In summary, any development in the Indian Creek system, and in specific locations on some of the other systems, has the potential for causing significant change and thereby needs further study and potential rehabilitation.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Bronte Creek

Overall, the Bronte Creek Watershed and its component subwatersheds are in relatively good health from a fluvial geomorphological and hydrologic perspective. With increased development there will be greater flows which will impact on the Bronte Creek watershed. Section 5.2 summarizes the impacts of this increased development. The hydrologic and geomorphological management strategies are summarized in Section 6.4.1 also summarizes the stormwater management targets for the Indian Creek subwatershed required to maintain the current flows in Bronte Creek.

1. Stormwater and land development control measures are required to ensure that any new development proposed does not increase erosion or the existing levels of flood risk;
2. Prior to any urban development, it is recommended that a subwatershed study be undertaken and then detailed stormwater management plans be developed during the site development phase;
3. Surfacewater withdrawals continue to be assessed for their impacts on the system as part of the Regional Aquifer Management Plan; and
4. Any proposed future development requires a full fluvial geomorphological and hydrological assessment.

7.2 Indian Creek

The state of the Indian Creek Subwatershed is of particular interest, since it is about to undergo additional pressures from development in the headwater areas. This system requires detailed assessment and rehabilitation if it is to improve health.

Specifically, this assessment raises the following recommendations for the Indian Creek Subwatershed:

1. Indian Creek requires detailed rehabilitation works in order to absorb the existing pressures and changes within the system, and in order to retain a semblance of resilience to future development in the headwater areas. These rehabilitation works would primarily be bank stabilization, establishment of a riparian buffer and getting cattle out of the stream;
2. A full riparian buffer zone be established along all creeks where none exists, consisting of a spatial distance of at least 35 metres on each side of the creek;
3. Existing cattle operations in the watersheds be prohibited from accessing the creeks directly;
4. Existing channelization works be assessed as to their stability over the long term, with a recommendation that all artificially straightened reaches be rehabilitated to provide a naturally sinuous or meandering channel; and
5. Further and continuing assessment of all reaches detailed in this report be undertaken at regular intervals (twice yearly at the minimum) to ensure existing conditions are not altered. If a problem is identified, the scope of the problem must be detailed and the cause of the problem must be identified. The cause of the problem should be fixed. The boundaries of the impact upstream and downstream must also be identified and the rate of change and any structures at risk determined. Possible rehabilitation opportunities should be assessed and a decision made on implementation.

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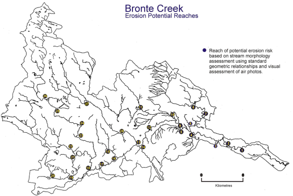

Bronte Creek Hydrology and Stream Morphology Study

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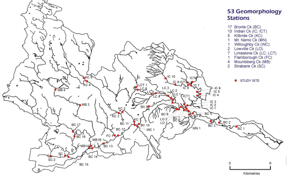
SCHROETER & ASSOCIATES

Scale:	Date: January, 2002
Project No.: K1177	Figure: 4.2.1

Field Assessment: Geomorphology Analysis Sites



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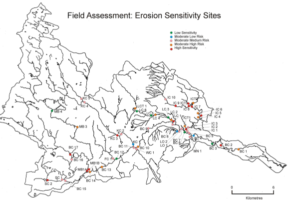
Scale:	Date: January, 2002
Project No.: K1177	Figure: 4.2.2

Field Assessment: Erosion Sensitivity Sites



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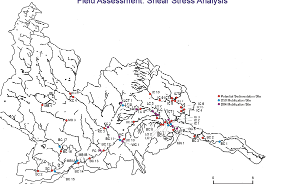
Scale:	Date: January, 2001
Project No.: K1177	Figure: 4.3.1

Field Assessment: Shear Stress Analysis



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Appendix A

Hydrology

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1.0 INTRODUCTION

This technical appendix provides more in-depth discussion about the specific approaches and procedures used in the hydrologic modelling activities conducted in support of Bronte Creek Hydrology and Stream Morphology Study.

We are confident that the results reported here and in the main study report are informative and useful to the process of developing appropriate watershed management strategies for the Bronte Creek Watershed. It should be recognized, however, that much of the work was not carried out at the level of detail of research studies; the results should therefore be interpreted with this in mind, and considered more valuable as indicators of direction and priorities than absolute predictions.

2.0 MODEL SET-UP

2.1 Delineation of Subcatchment Boundaries

The total drainage area of the Bronte Creek watershed to its outlet at Lake Ontario was found to be 312.5 km^2. One reservoir element was identified with significant storage and considered in the model. The level of modelling detail, in terms of mean subcatchment size and channel lengths, is comparable to other recent GAWSER applications (e.g. Alder Creek, GRCA, 1997; Maskinonge River, Schroeter & Associates, 1998).

2.2 Response Unit Drainage Characteristics

Each pervious zone or response unit in GAWSER is considered as two soil layers (see **Figure A 1**). The top or first layer has specified thicknesses up to 300 mm (in the soils examined to date), which typically corresponds to the 'A' horizon (e.g. Chapman and Putman, 1984). The thickness of the second layer is usually set in the range of 250 to 1250 mm, depending on whether the response unit contributes to subsurface flow or groundwater storage. The second layer generally corresponds to the 'B' horizon.

Rainfall (or snowmelt) falling on a response unit is separated into overland runoff and infiltrated components (See **Figure A2**). The term infiltration is used here to describe the rate of water movement downward through the soil surface. Seepage indicates the water movement downward from the bottom of the first soil layer into the second layer, whereas percolation refers to the downward movement out of the bottom of the second layer of a response unit. Percolated water appears as subsurface flow (e.g. tile drainage) in response units assumed to contribute to this storm flow component, or to groundwater storage in all other response units. The rate of water movement into each soil layer (either from rainfall, snowmelt, or soil-water) depends on the drainage characteristics of each soil layer. The selection of drainage characteristics (parameters) is fully explained below.

Previously published values were employed wherever possible as first estimates for most parameters. Generally, parameter values were selected from a review of values given in the *GAWSER Training Guide and Reference Manual* (see Lessons 4, 7 and 8) and Watt et al. (1989, chapter 8) for like soil groups and land cover types. Where published values do not exist, starting values were assumed based on field observations and experience. **Table A 1** shows the soil parameters used for the Bronte Creek Watershed.

Table A 1 Bronte Creek Watershed Soil Parameters									
		Open	**Peat**	**Silty**	**Silty**			**Forest**	**Cover**
	IMP	**Water**	**Muck**	**Clays**	**Sand**	**Sand**	**Gravel**	**Low**	**High**
DS	2	0	5	5	5	5	5	15	15
KEFF	0	0	2	3	8	16	30	16	50
CS	0	0.2	1.5	2	6	12	23	12	38
D	0	0.2	0.5	0.3	0.8	2	3	2	5
SAV	0	200	200	200	200	250	250	200	250
HI	0	0.01	100	100	100	150	150	200	200
SMCI	0	0.56	0.56	0.54	0.5	0.4	0.4	0.5	0.4
FCAPI	0	0.46	0.46	0.4	0.32	0.1	0.1	0.32	0.1
IMCI	0	0.46	0.46	0.4	0.32	0.1	0.1	0.32	0.1
WILTI	0	0.27	0.27	0.19	0.13	0.04	0.04	0.13	0.04
HII	0	0.01	150	250	300	600	600	500	600
SMCII	0	0.56	0.56	0.54	0.5	0.4	0.4	0.5	0.4
FCAPII	0	0.46	0.46	0.4	0.32	0.1	0.1	0.32	0.1
IMCII	0	0.46	0.46	0.4	0.32	0.1	0.1	0.32	0.1
WILTII	0	0.27	0.27	0.19	0.13	0.04	0.04	0.13	0.04
X	0	1	1	1	1	0	0	0	0
FATR	1	1	1	1	1	1	1	1	1
INCS	0	0	1	1	1	1	1	5	5

Initially, some parameters (e.g., saturated soil-water content, field capacity soil-water content) were believed to have different values for each soil layer within a response unit type. GAWSER has been structured to allow independent specification of such parameters for each response unit and soil layer, but as first estimates (except when obvious differences are identified, e.g. hydraulic conductivity for clay over sandy soils), the same parameter values are used for all layers in a given response unit.

Soil Layer Thickness, HI and HII (mm): Generally, the first soil layer is set at 200 mm for well-drained soils, and 100 mm for poorly drained soils. The second soil layer is generally set at 600 mm for response units that contribute to subsurface flow and 1000 mm for those that contribute to groundwater storage. The soil layer thicknesses listed in **Table A 1** were selected based on information given on the quaternary geology maps, soil type maps, soils reports and previous experience.

Maximum depth of interception storage, INC (mm): This represents the depth of water intercepted and held on the surface of vegetative growth (e.g. leaves) after rainfall, and gradually depleted by evaporation only. Its depends on the type of vegetative surfaces, with forest cover having the largest values. Typical values were determined by Schroeter and Boyd (1998).

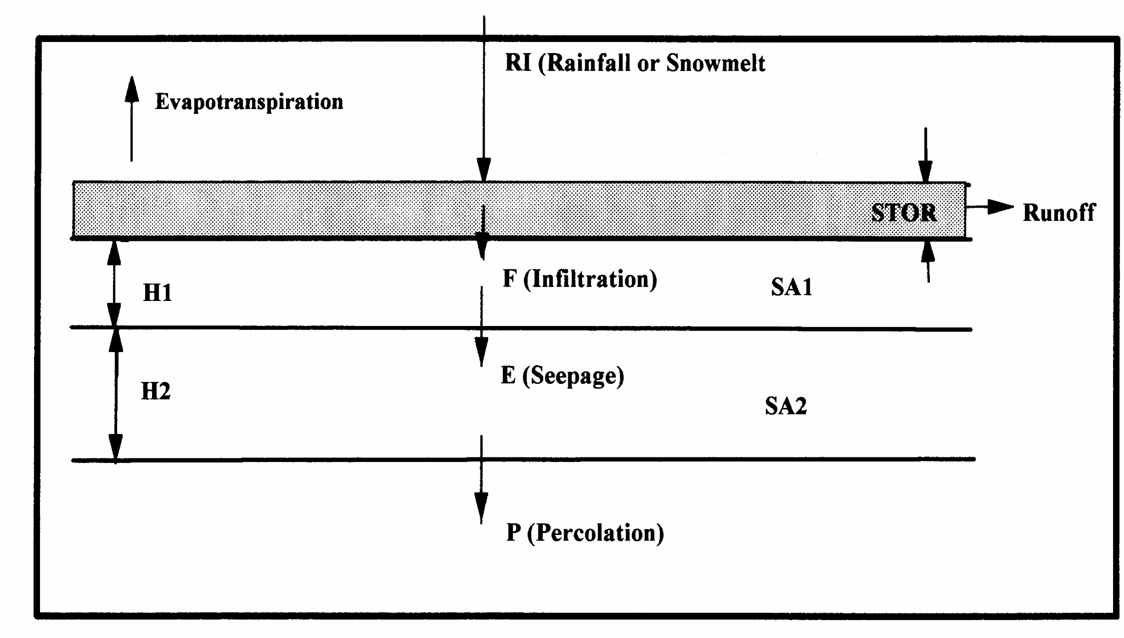

Figure A 1 Two-layer Soil Concept for Runoff Generation Model

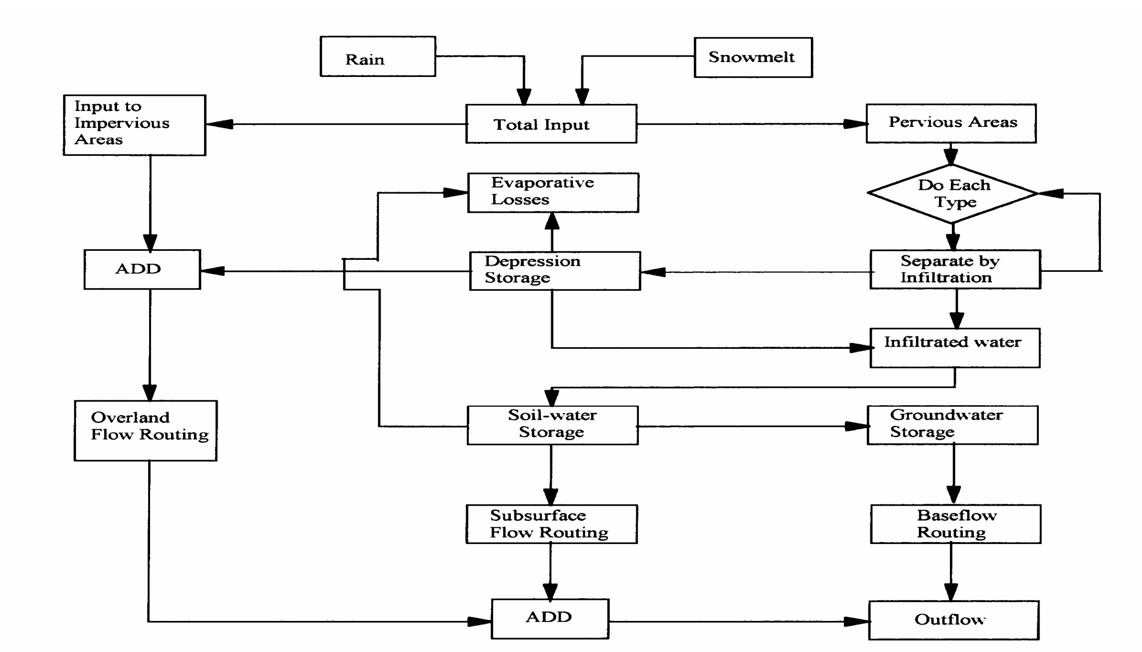

Figure A 2 Flow Chart of Runoff Generation Procedures in GAWSER

Maximum depth of depression storage, DS (mm): This parameter represents the maximum depth that water can pond temporarily on the surface of a response unit, and is gradually depleted by evaporation or infiltration. It depends on surface topography (e.g. potholes, slope) and vegetative cover. (Note, these depressions do not include the large ones that occur in hummocky topography.) For example, a relatively smooth surface (no potholes) on grade so that water does not remain ponded after a heavy rainfall would have a depressional storage value of 1 to 5 mm. The values selected were taken from a review of Table 8.1 in *The Hydrology of Floods in Canada* (Watt et al., 1989).

Effective hydraulic conductivity, KEFF (mm/h) at the soil surface: In some publications, this parameter is referred to as the 'net infiltration capacity' of a soil or the 'final infiltration rate', and is a function of soil type and vegetative cover. In Table 8.4 of Watt et al. (1989), KEFF=1.3 mm/h for a fine textured clay with bare ground cover. This table suggests KEFF for the same soil with "good pasture" cover is 5.0 mm/h, and 6.4 mm/h with forest cover.

Maximum seepage rate, CS (mm/h) and maximum percolation rate, D (mm/h): These control soil-water movement out of the first and second soil layers. They are a function of the soil hydraulic conductivity in each layer, which generally, decreases with depth in the unsaturated zone (area above water table). This happens because the macro pores (caused by roots, worm holes, cracks, and bugs) are larger near the surface, yielding higher hydraulic conductivity. With depth, the macro pores decrease, and so the conductivity is reduced.

Because there is no detailed information about the hydraulic conductivity of the soils in each response unit just a few metres from the surface, these parameters are estimated from the KEFF values. In past applications of GAWSER (see Ecologistics, 1988; Schroeter & Associates, 1992b), the percolation rate (D) was estimated as half of KEFF, with CS being set at some value between D and KEFF, or CS=0.5*(KEFF+D). Recent applications of GAWSER on the Oakridge Moraine (CPM, 1996), suggested percolation rates (D) should be set much less than KEFF/2, more like KEFF/10 or KEFF/20. In this study, CS=0.75*KEFF.

Average suction at the wetting front, SAV (mm): This is a parameter in the Green and Ampt infiltration formula (see Eq. [A.18], *GAWSER Training Guide*). It can be estimated from soil-water characteristic curves, a plot of volumetric water content versus pressure head, which can be measured in a laboratory using soil samples taken in the field. In the absence of detailed information, previously published estimates of SAV will suffice. Mein and Larsen (1973) and Skaggs (1982) give representative values of SAV for several different soil types. The values selected in **Table A 1** were taken from a review of these documents.

Soil-water contents; saturated, SMC; field capacity, FCAP; and Wilting point, WILT: They are important for defining the amount of water stored in each soil layer of a response unit. Each variable is defined separately below.

The *saturated soil-water content, SMC* (vol/vol) is the condition of the soil when all the void space is filled with water and no storage is available. Any infiltration into a saturated top soil layer must equal the seepage, the rate at which soil-water leaves the bottom of the first soil layer. Any seepage to a saturated second layer must equal the percolation rate to subsurface or groundwater storage. Generally, the saturated soil-water content is estimated by the porosity of the soil.

The *field capacity soil-water content, FCAP* (vol/vol) is the condition whereby the soil void space contains the maximum residual water that can be held by capillary forces after gravity drainage. When a soil-water characteristics curve is available, FCAP is estimated at a pressure head of 0.33 bar.

The *wilting point soil-water content, WILT* (vol/vol) is the amount of water contained in the void spaces that cannot be removed by evaporation, and is held by capillary forces. WILT is estimated from soil-water characteristic curves, and defined at 15 bar pressure.

Typical values of SMC, FCAP and WILT for various soil types are listed in Table 8.2 of Watt et al. (1989). The values selected here were taken directly from this source.

Although it is possible in GAWSER to specify separate values of SMC, FCAP and WILT for each soil layer, they were set equal as first estimates. This means, for instance, that the SMC used for layer 1 (e.g. SMCI) was also used for layer 2 (SMCII).

Initial soil-water content, IMC (vol/vol): This variable specifies how much soil-water is present in a soil layer at the start of the simulation. In most GAWSER applications to date, IMC is set equal to FCAP for that layer. Actual values of IMC used in the calculations are set by applying an adjustment factor (in this case FIMCI or FIMCII), as an aid to calibration that is discussed in later in this report.

2.3 Subcatchment Characteristics

Most natural watersheds contain numerous side or off-channels which collect runoff water that feeds a main stream channel. Consequently, for subcatchment runoff hydrograph calculations, representative cross-sections must be specified for the main and off channels. GAWSER uses these sections, the subcatchment drainage area, main and off-channel slopes, and a representative length (L) and width (W), to determine the overland routing parameters required in the area/time versus time method (e.g. main channel travel time, TMC, off-channel travel time, TOC and the linear reservoir lag, KO). To compute TMC and TOC, reference flows are specified (QRMC, QROC), which typically correspond to bankfull conditions in the representative main and off-channel cross-sections.

Subcatchment areas (A), lengths (L), and main channel slopes were measured from the available topographical maps (1:50,000).

For headwater subcatchments (e.g. 1011,1081, 1021) the length was found by extending the main channel back to the drainage boundary (see Lesson 7 in *GAWSER Training Guide*). The subcatchment width (W) was then computed as

[2.2.1] $W = A/L$

For lateral inflow subcatchments (e.g. 1013, 1200, 1302) (see Lesson 7 of *GAWSER Training Guide* for explanation), the length was found using

[2.2.2] $L = A/L_C$

where L_C is the length of the channel routing reach that traverses the lateral inflow subcatchment. Next, the subcatchment width was taken as half of L_C.

In GAWSER, the overland flow linear reservoir lag (KO) is specified as a function of the base time (TB) of the area/time versus time curve, or

[2.2.3] $KO = FTB * TB$

where TB=TMC+TOC, and FTB is the overland flow basetime factor. In previous applications of GAWSER, FTB has been set at 2. However, for swampy or hummocky topography dominated subcatchments, FTB is set between 3 and 5. For urban subcatchments, with an imperviousness greater than 10%, we set FTB=1.2.

Outflows from subsurface and groundwater storage are modelled in GAWSER using a linear reservoir procedure, which requires two recession constants to be specified; KGW for discharge from groundwater storage and KSS for subsurface flow. These constants are estimated from observed hydrograph data or hydrogeologic studies, when available. Nevertheless, previous values were deemed to be acceptable here, and so KSS=5 h, and KGW=384 h (see *GAWSER Training Guide*, Lesson 5 and 7).

In GAWSER, the total outflow (runoff plus baseflow) from a subcatchment is assumed to contribute to streamflow at its outlet. However, sometimes it is necessary to have part of the baseflow leave the subcatchment entirely, and contribute to the regional groundwater flow system. To do this, a groundwater flow factor (or GWFACT) has been introduced in GAWSER. When GWFACT=1.0, all the baseflow leaves the subcatchment. Setting GWFACT=0 (default value) causes all baseflow to appear in the subcatchment outflow.

In this study, a new feature in GAWSER was utilized to direct baseflow into the regional groundwater flow system, and allow it to reappear in downstream locations. This procedure is outlined in Section A 2.5.

The subcatchment characteristics for existing conditions, particularly the response unit percentages, length, width and FTB, are listed in **Table 2.2.3**.

2.4 Stream Channel Data

Stream channel data are necessary inputs to both the overland flow (runoff) and channel routing calculations in GAWSER. Consequently, representative cross-sections are required inputs to the routing procedures, where the parameters are computed directly by the program using the channel length, bed slope and a characteristic rating curve developed for the section.

A typical off-channel section was used for all rural locations, and taken from the GAWSER files used in the Proctor and Redfern FDRP Study (1986). For urban subcatchments, representative 'sheet flow' cross-sections were developed for both the main and off channels.

All the channel cross-sections utilized in the Proctor and Redfern FDRP Study (1986) were applied directly in the current work. Sections were confirmed from Geomorphology work completed in this study.

Channel roughness coefficients (Manning's n) were initially selected from typically values given in hydraulics texts (e.g. Chow, 1959). Slopes and channel lengths were measured directly from 1:50,000 mapping.

It was not possible to obtain cross-section data for main channels in each subcatchment or channel routing element. Therefore, some sections were used ('borrowed') for several elements, with minor adjustments in slope and roughness to account for local conditions.

2.5 Treatment of Detention Ponds and Marshes

Distinct hydraulic features within the subwatershed were isolated, and considered as diversion of flow, or reservoir (pond) elements. Special seepages to groundwater storage are described in the next section.

Storage-outflow characteristics were established for Mountsberg Reservoir. For Mountsberg Reservoir, elevation-area data were extracted from data supplied by HRCA. From this information an expression for lake storage S (in ha-m) was developed

[2.2.4] $S = 8.64\,(Z - 411.57)^{1.21}$

where Z is the water surface elevation in m. Water stored in Mountsberg Reservoir is available for evaporation and recharge to groundwater storage through the lake bottom.

The influence of hummocky topography in the Bronte Creek Watershed was modelled using the recharge pond option that accompanies the subcatchment outflow calculations. Here, a portion of the runoff water is directed to a detention pond from which water can percolate and contribute to groundwater storage. The fraction of hummocky area within a subcatchment determines how much runoff is captured by the recharge pond. The amount of hummocky area within each subcatchment was measured from the quaternary geology maps.

In the Eramosa River Watershed Hydrology Study (Schroeter and Boyd, 1998), the storage relationship for the hummocky area recharge ponds was expressed as

[2.2.5] $S = A_N\,(Z - Z_o)^{1.5}$

where S is in ha-m, Z_o is the elevation at which live storage is zero, and A_N is a storage constant. The constant, A_N was estimated by assuming that

[2.2.6] $S = (A_H/3)$ x (1 m depth of water)

where A_H is the total area of hummocky topography in a given subcatchment. Substituting Eq. [2.2.6] into Eq. [2.2.5] when $(Z\text{-}Z_o)=1$, gives $A_N=A_H/3$.

2.6 Treatment of Special Groundwater Seepage and Discharge

Each subcatchment element in GAWSER is considered to be a total self-contained hydrologic unit. This means that all the precipitation falling on a given subcatchment is accounted for in the computations. Infiltrated water returns as baseflow, so the total outflow becomes the sum of computed runoff, subsurface and baseflow components. Although this is an idealized situation that facilitates hydrograph calculations, it is not always true in nature; infiltrated water may reappear as baseflow at some other point downstream in the watershed, or flow to another watercourse entirely. The GWFACT factor, noted earlier, accounts for deeper groundwater contributions, but these amounts are completely lost from further computations. In the Torrance Creek Subwatershed Study (TSH, 1998), GAWSER was modified so that infiltrated water in the normal runoff computations (which includes recharge from detention ponds) or seeping from channel reaches during low flow periods could be re-directed to a 'groundwater storage array' in program memory. At some other point downstream in the drainage network, water can be released from this storage array.

To help explain how this new feature works in GAWSER, two model schematic diagrams are presented in **Figures A 3** and **A 4**. The first diagram (**Figure A 3**) gives a schematic representation of typical watershed model. Here, the total outflow from each subcatchment (including surface runoff and baseflow) is routed through the drainage network. In the second diagram (**Figure A 4**), the original model (**Figure A 3**) is modified to direct some outflows from the two headwater subcatchments (101 and 102) to the 'groundwater storage array' (denoted by the large rectangular box). The diamond symbols signify a diversion to groundwater storage. Later on downstream, where the outflows from subcatchment 104 are added to the main channel flows at node 204, some water from 'groundwater storage' is released and added to the total outflow of the entire watershed. A diamond coupled with a valve (the circle with an X) are symbols used to indicate where some of the groundwater storage is released to the main stream. To facilitate these procedures, two new commands have been introduced in the GAWSER program: DIVERT FLOWS TO GW, and REMOVE FLOW FROM GW.

Each command has options to enter a specified discharge or a percentage of the total inflow at a node to signal how much water is diverted in either direction to the groundwater storage array. For instance, in a DIVERT FLOWS TO GW immediately downstream of a subcatchment outflow command (e.g. COMPUTE FLOWRATE), a flowrate of 0.050 m^3/s might be specified. This means that all flows equal to or less than the stated amount are directed to the groundwater storage array. Typically in a REMOVE FLOW FROM GW command, a percentage is given rather than a designated flowrate. For example, suppose a value of 30% is specified, then it means that 30% of the water in the groundwater storage array would be released at this point in the model.

A major advantage of this approach for directing flows to a groundwater storage array is that if you have an existing GAWSER watershed model, you can introduce the new commands without changing your existing modelling logic (as represented by the schematic diagram). In **Figures A 3** and **A 4**, notice how the original schematic has not changed, and only new commands (signified by diamond and value symbols) are introduced.

From the Characterization Report, a portion of upper Bronte Creek Watershed is known to be hummocky, with very high infiltration soils attributed to outwash gravel. This area generates runoff only during exceptionally rare and large volume precipitation events. These seepages to and discharges from groundwater storage are modelled using flow diversions (DIVERT FLOWS TO GW and REMOVE FLOW FROM GW commands in GAWSER). Some of these are inserted at the outlets of subcatchment elements, while others are placed at the outlets of channel routing reaches. Only flows above a designated value are allowed to contribute downstream, while all other flows contribute to groundwater storage. Flows released from groundwater storage are entered as percentages of amounts already in storage.

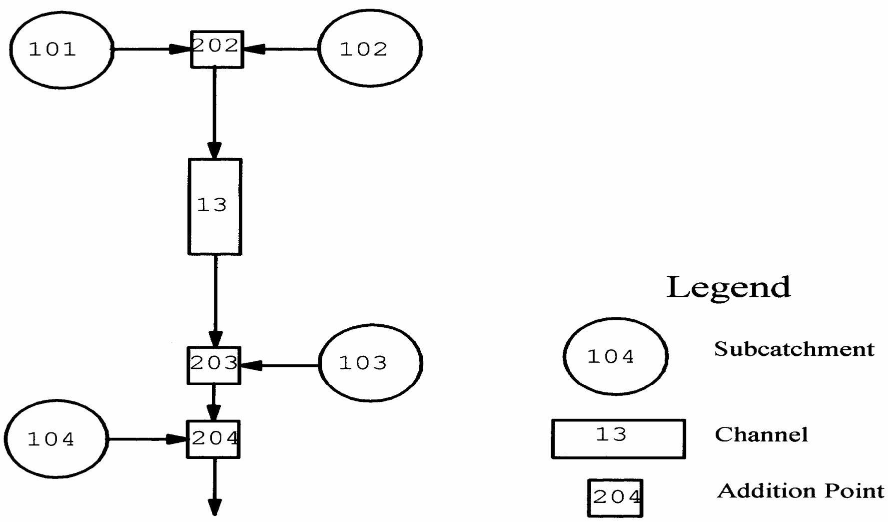

Figure A 3 Schematic Representation for a Typical Watershed Model

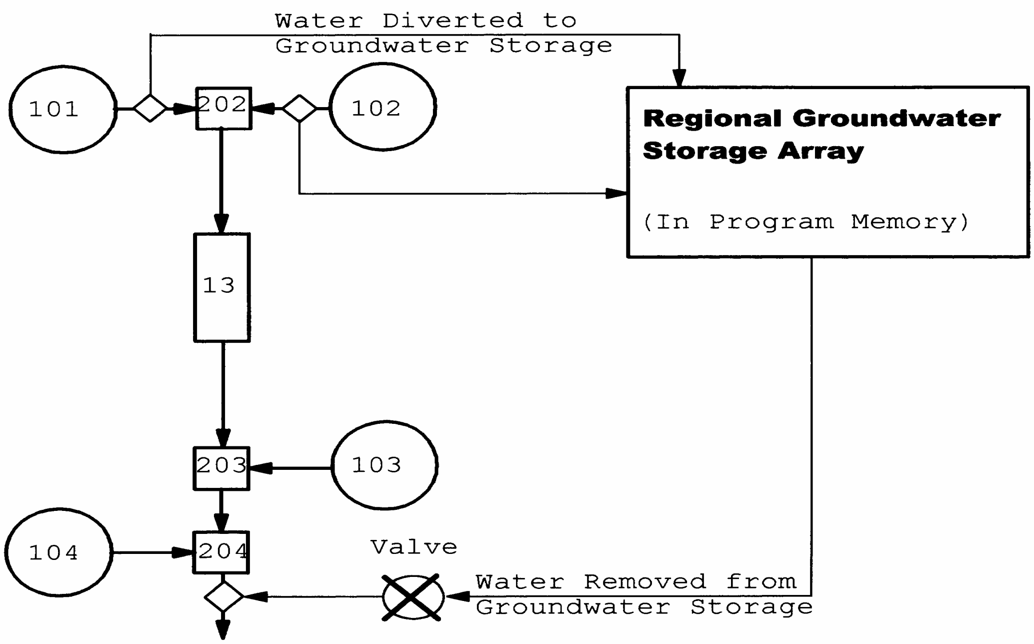

Figure A 4 Schematic Representation with Diversions to and Withdrawals from Groundwater Storage

2.7 Sensitivity Analysis

Once the model was operational, a sensitivity analysis was conducted to ascertain whether the model output was particularly sensitive to the selected values for the response unit drainage parameters. To accommodate this procedure, GAWSER uses 'parameter adjustment factors' to modify the values of several soil drainage parameters at one time. For example, the depression storage adjustment factor (FDS) would be used to modify the specified values of maximum depth of depression storage for each response unit in the model (see **Table A 1**). A value of FDS=1 tells the program that the 'as specified' values of depression storage are to be used in the calculations. A value of FDS=0.80 would be mean that 80% of the specified depression storage was used in the computations.

Two events March-April 1985, a typical snowmelt (with rain) and August 1982, representing a rainfall-only event were used for the sensitivity analysis. The results are summarized in **Table A 2** and **Table A 3**, respectively. The part A of each table shows the differences in peak flows as percentages of the 'standard run' values. The part B of each table shows the percentage differences in hydrograph volume when the indicated parameter is adjusted. For instance, at the top of **Table A 2a** we that a +25% change (an increase) in FKO (the overland runoff lag factor) results in –10.3% change (a reduction) in the peak flow at Strabane Creek (Hydrograph 1031). Similarily, in **Table A 2b**, a –25% change (a reduction) in FCS (the seepage rate adjustment factor – controls movement of water from layer 1 to 2) results in a 1.1% increase in the hydrograph volume at Strabane Creek.

For the snowmelt event (**Table A 2**), notice that adjustments of ±25% in FKEFF (effective hydraulic conductivity), the most sensitive soil drainage parameter according to previous applications of GAWSER, influenced peak flows and hydrograph volumes by less than ±7%. In most cases, changes in anyone of the parameters (e.g. FDS, FKEFF, FCS, FD, FKO and FKMF) produced changes in the model output quantities (e.g. peak flow or hydrograph volume) that were still less (±6%) than adjustments to the model parameters.

For the rainfall-only event (**Table A 3**), we get a much different picture of model output sensitivity to changes in the input parameters. There is a significant difference in the changes above and below the Limestone Creek Outlet. This is mainly caused by the differences in soils above and below the Niagara Escarpment.

Due to the high infiltration soils and the presence of hummocky topography in the upper portion of the Bronte Creek Watershed, very little runoff is produced, and most of the baseflow is lost to groundwater storage. Consequently, the total volume of flow arriving at the locations above Limestone Creek is very low relative to the rainfall volume for this event. Most of the runoff is generated by the impervious surfaces in each subcatchment (which for rural areas is about 2 to 3%), whereas most of the pervious area runoff is coming from subcatchments with very little hummocky topography.

For locations below the Limstone Creek outlet, notice how ±25% adjustments in FDS, FKO, FCS and FIMCI result in peak flow changes of more than ±50%, whereas these same adjustments cause much less variation for the hydrograph volumes (less than ±20%). These are unusally high variations in model output quantities in response to changes in the parameter adjustment factors, when compared to previous applications of GAWSER. FDS (depression storage factor) controls how much precipitation is forced to infiltrate, whereas FCS (seepage factor) ultimately controls how much water is released to baseflow. In this instance, slight changes in FDS and FCS can produce large changes in the peak flows, because the magnitudes of these flows are already low.

Table A 2a Sensitivity Analysis Results for Bronte Creek Watershed – March – April 1985 Event (in terms of % differences in peak flows)

		Parameters Adjusted												
		FDS	**FDS**	**FKEFF**	**FKEFF**	**FCS**	**FCS**	**FKO**	**FKO**	**FKMF**	**FKMF**	**FIMCI**	**FIMCI**	
No.	**Location**		**-25.0%**	**25.0% -**	**25.0%**	**25.0%**	**-25.0%**	**25.0%**	**-25.0%**	**25.0%**	**-25.0%**	**25.0%**	**-25.0%**	**25.0%**
2015	Bronte Ck u/s Strabane Ck	2.5	-2.4	1.7	-1.1	4.1 -	3.8	13.1	-10.7		6.5 -	2.6	-4.3	4.0
1031	Strabane Creek 1.7		7	-.7	.7	.0	2.6	-2.8	13.1	-10.3		7.7	-2.0	-2.3
6032	Bronte Ck u/s Mountsberg Creek	2.1	-1.9	1.9	-1.0	3.7	-3.6	8.9	-8.5	3.5	-6.4	-3.6	2.9	
5300	Mountsberg Reservoir	1.1	-1.8		.3	-.2	3.5	-2.5	11.3	-8.1	2.4 -	1.9	-3.9	4.1
6080	Mountsberg Creek at Bronte	6.4	-3.6	4.9	-3.2	2.2	-2.3	13.0	-10.7	-.2	-8.0	-2.8		3.0
6100	Bronte Ck at Progreston	4.1	-3.5	4.2	-3.2	3.1	-4.0	9.3	-9.5	1.2	-7.9	-4.4		3.2
6140	Bronte Ck u/s Kilbride Creek	4.3	-3.7	4.8	-3.7	3.0	-3.8	9.2	-9.0	1.3	-8.1	-4.1	3.1	
6165	Kilbride Ck at Bronte Creek	8.9	-5.3	6.7	-4.0	5.3	-2.8	11.2	-10.2		6.2	-7.5	-4.5	4.6
6160	Bronte Ck at Kilbride Creek	4.2	-4.0	4.5	-3.6	3.1	-3.8	8.0	-8.6		.9	-8.0	-4.3	3.1
6222	Limestone Creek outlet	2.7	-1.3	1.7	-.9	1.3	-1.5	11.7	-10.0		3.5	-10.0	-2.3	1.7
6240	Bronte Ck near Zimmerman	3.7	-3.4	3.6	-3.0	2.4	-3.0	7.0	-7.1	1.9	-7.6	-3.7	2.7	
6284	West Indian Ck at Britannia 1.2	1.4	-1.0		.5	-.6	1.1	-1.3	12.1	-10.1		3.4	-11.0	-2.2
1291	East Indian Ck at Landfill .8	.1	.0	-.5	.4	1.0	-1.3	14.6	-13.3		2.1	-10.5	-2.4	
6292	East Indian Ck at CNR Culvert .6	.5	-.4	.0	-.1	.9	-1.1	13.5	-12.5		1.2	-12.1	-1.8	
6302	Indian Creek at Bronte Ck	.8	-.6	.2	-.3	1.0	-1.2	8.8	-9.0	4.5	-10.6	-1.6		.7
6310	Bronte Creek d/s Indian Creek	2.6	-2.4	2.4	-2.1	1.9	-2.3	7.8	-7.6	3.2	-8.1	-3.0	2.0	
2380	Bronte Creek at L. Ontario	2.6	-2.3	2.3	-2.0	2.1	-2.2	7.1	-6.5	2.7	-9.8	-2.9	2.0	

Table A 2b Sensitivity Analysis Results for Bronte Creek Watershed - March-April 1985 Event (% differences in hydrograph volumes)

		Parameters Adjusted												
		FDS	**FDS**	**FKEFF**	**FKEFF**	**FCS**	**FCS**	**FKO**	**FKO**	**FKMF**	**FKMF**	**FIMCI**	**FIMCI**	
No.	**Location -**	**25.0%**	**25.0%**	**-25.0%**	**25.0% -**	**25.0%**	**25.0%**	**-25.0%**	**25.0%**	**-25.0%**	**25.0%**	**-25.0%**	**25.0%**	
2015	Bronte Ck u/s Strabane Ck 4.3	1.5	-1.9		.4	-.1	1.3 -	2.3	.8	-1.2		.5	-.1	-3.5
1031	Strabane Creek 3.3	1.1	-1.3		.4	-.1	1.1	-2.1		.1	-.2	.1	.0	-2.8
6032	Bronte Ck u/s Mountsberg Creek	1.3	-1.8		.4	-.2	1.2 -	2.3	.4	-.8	.4	-.2	-3.3	3.9
5300	Mountsberg Reservoir 3.9	1.2	-1.7		.4	-.1	1.2	-2.0	2.0	-2.8		.5	-.2	-3.2
6080	Mountsberg Creek at Bronte -3.2 3.8	1.4	-1.8		.5	-.1	1.6	-2.0		1.3	-1.8		.7	-.4
6100	Bronte Ck at Progreston 3.2 3.8	1.4	-1.9		.5	-.2	1.5	-2.2		.8	-1.3		.6	-.4 -
6140	Bronte Ck u/s Kilbride Creek 3.8	1.4 -	1.7	.6	-.2	1.7	-2.1		.9	-1.1		.8	-.5	-3.1
6165	Kilbride Ck at Bronte Creek	1.6 -	1.9	.5	-.2	2.1	-1.9		.3	-.5	1.0	-.7	-3.1	3.7
6160	Bronte Ck at Kilbride Creek 3.7	1.5	-1.8		.6	-.2	1.8	-2.1		.7	-.9	.9	-.5	-3.0
6222	Limestone Creek outlet 4.9	1.8	-1.7		.7	-.2	3.4	-2.2		.0	.0	1.4	-1.0	-3.7
6240	Bronte Ck near Zimmerman 4.0	1.5	-1.7		.6	-.2	2.1	-2.1		.6	-.7	.9	-.6	-3.3
6284	West Indian Ck at Britannia 5.6	1.0	-1.1		.3	-.1	3.0	-3.2		.0	.0	.5	-.4	-4.3
1291	East Indian Ck at Landfill	.8	-.8	.2	-.1	2.9	-3.3		.0	.0	.2	-.2	-4.3	5.7
6292	East Indian Ck at CNR Culvert	.8	-.9	.2	-.1	2.9	-3.3		.0	.0	.3	-.3	-4.3	5.7
6302	Indian Creek at Bronte Ck	.9 -	1.0	.3	-.1	3.0	-3.2		.0	.0	.4	-.3	-4.2	5.6

6310	Bronte Creek d/s Indian Creek 4.3	1.3	-1.7		.4	-.3	2.3	-2.4		.4	-.6	.8	-.6	-3.5
2380	Bronte Creek at L. Ontario 4.4	1.4	-1.6		.4	-.2	2.4	-2.4		.3	-.5	.8	-.6	-3.5

Table A 3a Sensitivity Analysis Results for Bronte Creek Watershed - August 1982 Event (in terms of % differences in peak flows)

Parameters Adjusted

No.	**Location -25.0%**	**FDS 25.0%**	**FDS -25.0%**	**FKEFF 25.0%**	**FKEFF -25.0%**	**FCS 25.0%**	**FCS -25.0%**	**FD 25.0%**	**FD -25.0%**	**FKO 25.0%**	**FKO -25.0%**	**FIMCI 25.0%**	**FIMCI**	
2015	Bronte Ck u/s Strabane Ck	3.0	-3.7	1.0	1.3	.8	.4	-7.6	9.9	7.8	-6.7	-2.6	3.2	
1031	Strabane Creek	6.1	-7.3	2.0	2.6	4.4	-.8	-.7	2.4	21.2	-14.7	-.4	4.7	
6032	Bronte Ck u/s Mountsberg Creek	4.4	-5.0	1.5	1.9	1.6	.8	-2.2	4.8	11.7	-8.6	-1.4	4.5	
5300	Mountsberg Reservoir	.0	-.1	.0	.0	.0	.0	-.3	.3	.1	-.2	-.1	.0	
6080	Mountsberg Creek at Bronte	4.2	-5.3	1.1	2.2	4.1	-1.8	-.1	.1	15.2	-13.7	-.1	3.4	
6100	Bronte Ck at Progreston 3.6	4.7	-4.9	1.4	2.1	3.8	-1.4		.8	.4	12.0	-12.1		.3
6140	Bronte Ck u/s Kilbride Creek 4.0	4.7	-5.1	1.4	1.9	3.7	-1.6		.6	.5	12.3	-11.6		.0
6165	Kilbride Ck at Bronte Creek	6.0	-7.3	1.8	2.7	5.5	-2.6	-.1	.1	13.7	-14.1	-	.2	4.9
6160	Bronte Ck at Kilbride Creek 4.4	5.1	-5.7	1.5	2.2	4.1	-1.7		.2	.6	9.0	-10.5		-.1
6222	Limestone Creek outlet 41.9	13.0	-22.1		4.6	-8.5	6.0	-13.8		-.2	.3	18.9	-14.7	-11.2
6240	Bronte Ck near Zimmerman 13.3	6.6	-10.1		1.5	-1.0	4.1	-4.7		.0	.3	9.3	-9.8	-3.2
6284	West Indian Ck at Britannia -16.8 51.6	15.0	-30.3		5.1	-14.7		4.5	-19.9		-.1	.1	17.3	-15.2
1291	East Indian Ck at Landfill -19.2 63.5	16.1	-32.9		5.4	-17.0		4.7	-22.4		-.1	.1	21.5	-17.9
6292	East Indian Ck at CNR Culvert -19.2 68.2	18.0	-33.4		7.7	-17.3		4.7	-22.8		-.1	.1	21.1	-16.6
6302	Indian Creek at Bronte Ck -13.0 50.0	17.1	-27.2		7.7	-10.7		4.6	-16.3		-.1	.2	14.5	-9.3
6310	Bronte Creek d/s Indian Creek	9.5	-16.6		2.5	-5.7	4.2	-9.7	-.1	.2	11.9	-11.1	-7.8	25.9
2380	Bronte Creek at L. Ontario	9.7	-16.8		3.0	-5.5	4.2	-9.5	-.2	.2	9.2	-8.3	-7.6	26.9

Table A 3b Sensitivity Analysis Results for Bronte Creek Watershed - August 1982 Event (% differences in hydrograph volumes)

Parameters Adjusted															
No.	Location	-25.0%	FDS 25.0%	FDS -25.0%	FKEFF 25.0%	FKEFF -25.0%	FCS 25.0%	FCS -25.0%	FD 25.0%	FD -25.0%	FKO 25.0%	FKO -25.0%	FIMCI 25.0%	FIMCI	
2015	Bronte Ck u/s Strabane Ck		2.4	-1.6		.8	.8	1.6	.0	-8.7	11.0	-.8	1.6	-3.1	3.1
1031	Strabane Creek			3.8	-4.9	1.6	1.6	3.3	-1.1	-4.9	6.0	-2.2	2.7	-1.1	3.3
6032	Bronte Ck u/s Mountsberg Creek		2.3	-3.1		.8	.8	1.5	-.8	-7.7	9.2	-1.5	1.5	-3.1	3.1
5300	Mountsberg Reservoir		.0	.0	.0	.0	.0	.0	-.6	.0	.0	.0	.0	.0	
6080	Mountsberg Creek at Bronte		1.4	-.7	.7	.7	.7	.0 -	1.4	2.1	.0	.7	-.7	1.4	
6100	Bronte Ck at Progreston		1.5	-2.2		.0	.7	.7	-.7	-5.2	5.2	-1.5		.7	-2.2
	1.5														
6140	Bronte Ck u/s Kilbride Creek		1.6	-1.6		.8	.8	1.6	.0	-4.7	6.3	-.8	1.6	-1.6	2.4
6165	Kilbride Ck at Bronte Creek		3.5	-4.3	1.4	1.4	2.8	-.7 -	5.7	6.4	-.7		.7	-2.8	5.0
6160	Bronte Ck at Kilbride Creek		1.5 -	3.1	.8	.8	1.5	-.8	-5.3	5.3	-1.5	.8	-2.3	3.1	
6222	Limestone Creek outlet			6.0	-9.0	3.0	-2.0	2.0	-5.0	-5.0	6.0	-4.0	4.0	-7.0	18.0
6240	Bronte Ck near Zimmerman		3.3	-4.1		.8	.0	1.6	-1.6	-4.9	5.7	-1.6	1.6	-3.3	6.5
6284	West Indian Ck at Britannia		9.7	-17.2		5.4	-8.6	2.2 -	10.8	-4.3	5.4	-1.1	1.1	-9.7	34.4
1291	East Indian Ck at Landfill		11.3	-18.6		6.2	-10.3		2.1	-12.4	-5.2	6.2	-1.0	1.0	-11.3
	39.2														
6292	East Indian Ck at CNR Culvert		11.7	-19.1		6.4	-9.6	2.1	-11.7	-4.3	6.4	-1.1	1.1	-10.6	39.4
6302	Indian Creek at Bronte Ck			10.6	-17.0		6.4	-8.5		2.1	-10.6	-4.3	6.4	-1.1	1.1
-9.6	36.2														
6310	Bronte Creek d/s Indian Creek		4.2	-5.1	1.7	-.8	1.7	-2.5	-5.1	5.9	-.8	1.7	-3.4	10.2	
2380	Bronte Creek at L. Ontario		4.2	-6.7	1.7	-1.7	1.7	-3.4	-5.0	5.0	-1.7		.8	-4.2	10.1

Tables A 2 and **A 3** illustrate that the variability of the model output to changes in the input parameters for event modelling is still about the same as the errors (+10%) typically associated with model input and output comparison data (e.g., precipitation, streamflow data). Any further adjustment in the model parameters to improve the simulated results would simply incorporate the uncertainties associated with the measured input and output comparison data, These findings are consistent with sensitivity analyses reported in other GAWSER applications (e.g., Schroeter & Boyd, 1998; Ecologistics, 1988).

2.8 Schematic Representation

A schematic representation of Bronte Creek hydrology model, showing the linkage of subcatchment, channel and reservoir elements, is displayed in **Figure A 5**.

Notice in **Figures A 5** that a consistent numbering scheme has been adopted to help identify points of interest within each subwatershed. Subcatchments utilize four digit numbers, which were assigned in order of occurrence as they are added to the flow in the major tributary channels. Catchment elements are numbered in the 1000's. Channel elements are numbered in the 3000's sequentially as they occur in the model. Hydrograph addition points are numbered in the 6000's and reservoir elements are numbered in the 5000's.

3.0 MODEL CALIBRATION/VERIFICATION

3.1 Procedures

In any hydrologic modelling exercise, it is generally assumed that if a given model reproduces an observed or measured sequence of quantities (e.g. streamflow volume, reservoir water levels) that 'confidence' can be placed in its predictive capability, from which management options or decisions are often made. Obviously, if additional comparisons between model output and measured quantities are made and their agreement is deemed to be 'acceptable', then more confidence can be placed in predictions from the model, particularly for impact analyses. Consequently, an important step in any hydrologic modelling exercise is to establish the 'level of confidence' in the predictive results, or 'validating the model'.

This important confidence building or 'validation' step in the modelling procedures is often referred to as 'calibration', although the term 'calibration' has been used interchangeably with 'verification', 'validation' and 'confirmation'. This is unfortunate, because 'calibration' is a unique step in the modelling procedures, apart from 'validation', 'verification' or 'confirmation'.

Model *calibration* is a process of adjusting model parameters, variables or other inputs in order to reduce the differences between simulated and observed flows (or other hydrologic quantities) to levels that are deemed acceptable (see Watt et al., 1989; James and Burgess, 1982). The 'adjusted' or 'calibrated' parameters or variables are then 'verified' or 'validated' by applying the model to an independent data set that was not used for calibration.

According to James and Burgess (1982), model *calibration* involves a trial-and-error procedure to achieve optimum parameter levels that produce a reasonably good match between model results and observed data. The parameters, whose values are based on field measurements or well-established from previous studies, remain fixed. Those to be calibrated are adjusted based on a goodness of fit criterion using visual or statistical comparisons between measured and simulated results (see James and Burgess, 1982; Schroeter and Boyd, 1998). A model is said to be 'robust' if its parameter settings can be transferred from one watershed to another (Schroeter and Watt, 1989).

A simple comparison of model output with any observed values does not constitute a 'calibration' exercise, unless the parameters are adjusted to improve the agreement between observed and simulated results. On the whole, any comparison between measured and modelled results is always considered part of the model 'confirmation' or 'validation' procedures.

In summary then, the Bronte Creek watershed model has been adequately 'confirmed' or 'validated'. In this regard, the following validation checks have been made.

1. The GAWSER (Guelph All-Weather Sequential-Events Runoff) model has been extensively calibrated, verified and validated in more than 33 watershed modelling studies within the last 14 years. 32 of these studies were conducted for Ontario watersheds. These applications (as of April 2000) constitute model comparisons with observed flow data from more than 104 gauges for 1500 gauge-events. For continuous simulation work, the model has been compared with long-term streamflow data from 32 gauges for 300 gauge-years. For urban runoff modelling, the model has been tested with data from 10 gauges for more than 46 gauge-events. The experience gained in applying the model over the last 14 years in Ontario was utilized directly in formulating the revised Bronte Creek watershed model.

2. Of particular relevance to the present work, GAWSER was applied in the Halton Region Integrated Flood Forecast System (HRIFFS) model setup study (Schroeter & Associates, 1993), of which Bronte Creek formed a significant component. In that study, the model was calibrated/verified with streamflow data from six events, three of which involved large snowmelt inputs. Since then, GAWSER has been applied in four other hydrology studies involving significant model comparisons with streamflow data in a continuous simulation mode for watersheds situated in geologically similar areas: Grindstone Creek (EWRG Ltd, and Schroeter & Associates, 1997), Eramosa River (Schroeter and Boyd, 1998), Caledon Creek (also called Subwatershed 16 and 18, Schroeter & Associates, 1999a), and Credit Valley Subwatershed 7 (Huttonville Creek) and 8a (Schroeter & Associates, 1999b). Consistent values of the monthly parameter adjustments factors were confirmed in each of these studies by comparing observed and simulated monthly flow volumes for periods greater than seven years, and through detailed event modelling with hourly discharge measurements from more than 80 gauge-events.

3. Mean annual evapotranspiration amounts estimated by the physically-based GAWSER model were well within acceptable ranges reported in numerous southern Ontario climatology documents and maps (e.g. Brown et al., 1974; OMNR, 1984).

In this study, the main objective of the 'validation' procedures was to ensure that the level of performance provided by the Bronte Creek watershed model was at least as good, if not better than the previous model, without collecting, assembling and processing additional meteorological and streamflow data (aside from the new streamflow measurements for Indian Creek). Consequently, only 'readily' available meteorological and streamflow data were used for 'validating' the revised hydrology model (see Section 3.2.3, Streamflow Data).

The validation procedures were divided into two parts. First, the model was applied in a continuous simulation mode for the eight-year period June 1, 1977 to September 22, 1985 to verify the monthly parameter adjustment factors. Second, the model was applied to 15 individual events and the simulated results compared with observed hourly flows available for the Progreston and Zimmerman gauges. Six of these events were included in the 1993 HRIFFS set-up study by Schroeter & Associates (1993). The event modelling exercise provided further confirmation on the parameter settings checked during the eight-year simulations, but also permitted the routing calculations in the different hydrologic elements (e.g. overland flow, channel and reservoir) to be assessed, in terms of hydrograph timing and peak flows estimates.

3.2 Meteorological and Streamflow Information

For the eight-year continuous simulation period applied to the Bronte Creek hydrologic model, the mean annual precipitation was 999 mm, with a mean annual discharge at the Progreston gauge of 1.53 m^3/s (or 386 mm expressed as a depth), and 2.90 m^3/s (or 378 mm) for the Zimmerman gauge. **Table A 4** summarizes the meteorological inputs and streamflow characteristics for the validation events. In terms of peak flows, the events simulated include those with return periods in the range of 1.25 to 50 years.

Table A 4 Characteristics of the Validation Events

Event	Model Dur. (d)	Mean Rain (mm)	Inputs Snowmelt (mm)	Gauge Name	Vol. (mm)	Hydrograph Peak m^3/s		TP (h)
Mar 20 to Apr 13, 1982	24	38.3	181.0	Progres	126.1	15.600	294.0	
				Zimmer	113.6	30.600	295.0	
Jun 27 to Jul 3, 1982	6	20.8	0.0	Progres	4.6	1.320	70.0	
				Zimmer	5.5	3.330	53.0	
Aug 24 to Aug 30, 1982	6	59.1	0.0	Progres	7.1	3.470	37.0	
				Zimmer	7.6	17.100		33.0
Sep 21 to Oct 3, 1982	12	71.5	0.0	Progres	14.1	2.740	162.0	
				Zimmer	15.2	10.900	185.0	
Dec 20 to Jan 1, 1982	12	35.3	60.9	Progres	35.2	7.490	163.0	
				Zimmer	32.3	18.100	131.0	
Jan 30 to Feb 11, 1983	12	31.6	36.0	Progres	21.1	5.480	117.0	
				Zimmer	26.6	18.500	106.0	
Apr 28 to May 10, 1983	12	77.9	0.0	Progres	25.7	5.030	143.0	
				Zimmer	25.5	14.300	113.0	
Mar 20 to Apr 13, 1984	24	52.7	139.4	Progres	79.9	8.040	413.0	
				Zimmer	74.5	19.800	394.0	
Jun 16 to Jun 28, 1984	12	58.9	0.0	Progres	7.7	1.570	67.0	
				Zimmer	7.7	4.050	57.0	
Jul 4 to Jul 16, 1984	12	35.0	0.0	Progres	3.2	1.010	80.0	
				Zimmer	3.5	4.960	61.0	
Mar 23 to Apr 16, 1985	24	71.1	110.7	Progres	105.3	9.690	158.0	
				Zimmer	103.9	24.700	214.0	
Aug 17 to Aug 23, 1985	6	23.4	0.0	Progres	1.7	0.740	47.0	
				Zimmer	1.6	3.780	50.0	
Nov 1 to Nov 25, 1985	24	182.2	184.3	Zimmer	67.8	16.800		91.0
Sep 28 to Oct 10, 1986	12	96.6	0.0	Zimmer	41.3	18.000		52.0
Mar 30 to Apr 23, 1987	24	69.8	149.5	Zimmer	75.5	19.900	190.0	
Mean Characteristics:	14	48.0	44.0	Progres	36.0	5.182	145.9	
	15	63.0	55.6	Zimmer	40.1	14.988	135.0	

3.3 Meteorological input data adjustments

In the Bronte Creek watershed, meteorological inputs can vary significantly with location. To account for these variations, the GAWSER program accepts inputs on the basis of separate *Zones of Uniform Meteorology (ZUM*). A ZUM is defined as “a portion of a watershed throughout which one set of meteorological measurements can be used to calculate snowmelt and runoff” (Schroeter and Whiteley, 1990). Typically, several subcatchments are covered by one ZUM. Usually, ZUM boundaries are made to agree with the drainage areas at streamgauge locations, so that the meteorological inputs can be adjusted or confirmed directly with discharge data. In the 1993 HRIFFS study (Schroeter & Associates, 1993), the Bronte Creek portion of the model was divided into three ZUMs. However, for the present study, at total of nine ZUMs have been defined to account for the complex rainfall patterns caused by the Niagara Escarpment. **Table A 5** summarizes which subcatchments comprise each ZUM and **Figure 2.3.1B** shows their locations.

Table A 5 Zones of Uniform Meteorology in the Bronte Creek Watershed		
ZUM Number	**Total Area (km^2)**	**Subcatchments**
1	29.9	1011, 1012
2	28.7	1013, 1031, 1032
3	37.1	1050
4	20.6	1080
5	5.37	1100
6	17.6	1120, 1140
7	34.3	1161, 1162
8	70.4	1165, 1180, 1200, 1221, 1222, 1240
9	68.7	1260, 1281, 1282, 1283, 1284, 1285, 1291, 1292, 1293, 1301, 1302, 1315, 1320, 1340 and 1360

For meteorological inputs to the model, generally the closet available recording raingauge, climate station or snow course to a given ZUM provides direct input for that ZUM. In this study for example, Conservation Halton's Mountsberg raingauge would supply input for ZUMs, 1, 3, 4 and 7, whereas the Kelso gauge would supply input to ZUM 8 directly. Inputs for the remaining four ZUMs (2, 5, 6 and 9) were created by adjusting the direct measurements from the Mountsberg and Kelso gauges as outlined below. A similar allocation procedure was applied to the initial snowpack information (mean snow depth and equivalent solid water content), as well as the daily climate variables (maximum and minimum air temperature, and daily snowfall depths).

During the historic event modelling, the appropriate recording raingauge information was not always available (e.g. gauge malfunctioning), and had to be estimated from other sources. For instance, rainfall records from some of the other gauges (e.g. Guelph Arboretum, Hamilton RBG, Oakville SE WPCP) were used in place of any missing data for the primary gauges. Daily climate records for the Georgetown WPCP (AES 6152695) and Millgrove (AES 6155183) were used as checks on the daily totals. Recording raingauge data from the Toronto Pearson International Airport were used for winter simulation events, because the AES hourly rainfall data were not available for the November 1st to March 31st period.

The volume of the recording raingauge pattern actually used in the model calculations was adjusted to be more representative of the rain that actually fell on the study area. To do this, GAWSER has global rainfall adjustment factors that can modify the rainfall pattern for each ZUM. This rainfall adjustment factor (GFRF) is computed as:

$$GFRF = V_{used}/V_{measured}$$

where V is the volume of the rainfall pattern, subscript 'used' represents the actual volume used in the calculations, and 'measured' refers to the volume entered into the model directly from measured records. These adjustments were made on the basis of simple isohyetal maps drawn for each event. **Figure A 6** shows a sample rainfall isohyetal map drawn for the June 27-29, 1982 event.

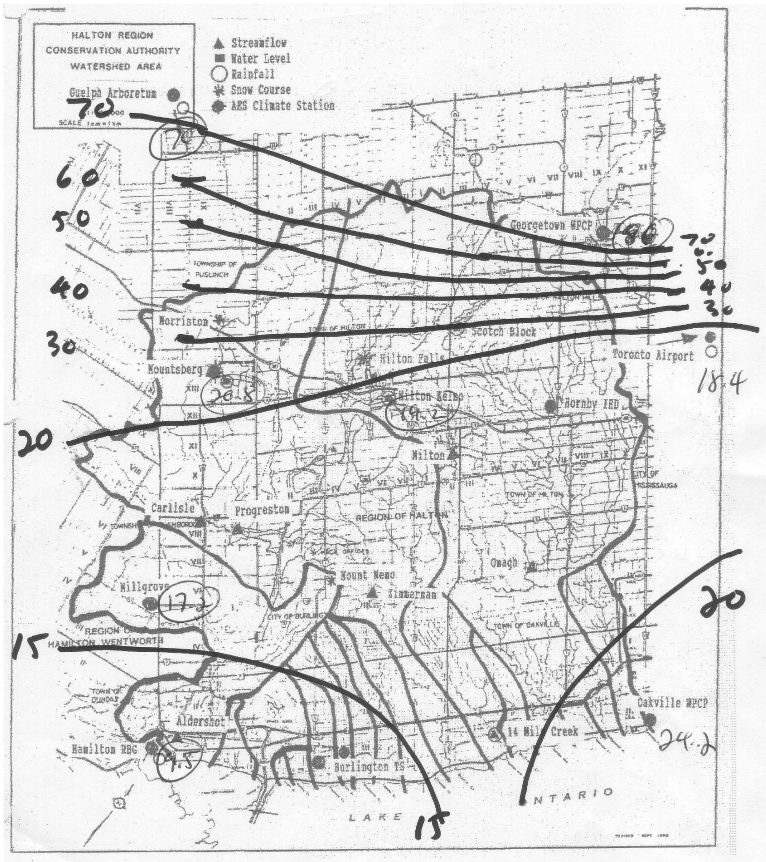

Figure A 6 Sample Rainfall Isohyetal Map for the June 27-29, 1982 Event

For long-term simulations, the Guelph Arboretum/OAC, Hamilton RBG and Toronto Pearson Airport 39-year datasets (1960-1999) prepared in the ongoing Grand River Water Management Strategy and climate change project (Schroeter et al., 2000a,b) were used for all the ZUMs. A 21-year dataset developed using records for the AES Milton Kelso (6155187) station was prepared for R.J. Burnside Associates as part of a Clublinks project (Personal Communication with Jeremy Blair, October 1998), and was also available for use in the present study. Because of the uncertainty in which dataset was the most applicable for the Bronte Creek watershed, each set was applied in the present study. These datasets represent the closet available climate stations with complete records for 20 plus years.

3.4 Streamflow Data Adjustments

The streamflow comparison data were adjusted to account for missing values in the records caused by ice conditions or gauge malfunctions. When only a few values were missing in the records, the missing flows were estimated by interpolation from the observed values. For some events, where the hourly discharges were not available for complete days, the published mean daily flows for the same period were entered to fill-in the 24 missing values, and hence provide hydrograph volumes for model assessment purposes. In these instances, it is difficult to compare hourly simulated flows with the mean daily values, and some imagination is required to make a qualitative assessment, as illustrated in **Figure A 7**.

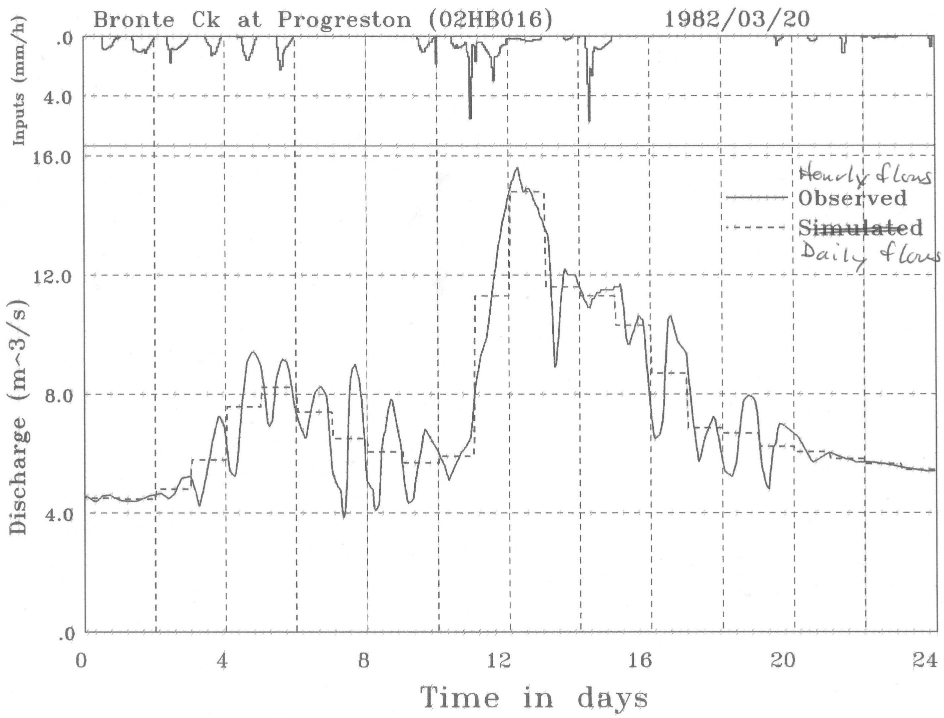

Figure A 7 Observed Daily and Hourly Flows at Progreston, March 20-April 12, 1982

3.5 Snowmelt Input Data

Snow accumulation and melt in different land cover units within a watershed are accounted for in GAWSER by defining 'blocks of equivalent accumulation' (BEAs) within each zone of uniform meteorology (ZUM). For the Bronte Creek watershed, six BEAs were identified and considered: two types of field blocks (ploughed and grass/pasture/grains), forests, and three edge blocks (e.g. road easements, fence lines and forest edges). Edge blocks are areas with significant capacity to store snow during blowing snow conditions. See Schroeter and Whiteley (1986), Schroeter (1988) and Burkart et al. (1991) for further information about snow accumulation characteristics among differing landscape units in southwestern Ontario.

The BEAs were estimated from land cover information given in **Table A 6** using similar relationships between blocks found in the Grand River (Schroeter & Whiteley, 1986; Schroeter & Associates, 1993a). The relationships used to compute the block areas are as follows:

a. Fenceline edge areas represent 15% of the open space or agricultural land.

b. The roadway easement blocks can be determined by measuring the total length of road within each subcatchment, and applying a representative width. For a typical county road (with two lanes, hard gravel surface), an appropriate width would be 25 to 30 m. For this analysis, the roadway easement blocks were estimated as 80% of the fenceline edge blocks.

c. 33% of the forested areas lie in forest-field snow accumulation edge areas,

d. the total forest edge area is twice amount found in item c, and

e. 62% of the remaining open spaces were considered to be grassy or pasture fields.

Table A 6 Blocks of Equivalent Snow Accumulation in Each Bronte Creek ZUM

ZUM	Units	Fields Ploughed	Fields Grass	Forest	Roadway Easements	Fence Lines	Forest Edges
1	(% Area)	16.9	27.6	18.0	8.8	11.0	17.8
2	(% Area)	20.6	33.7	11.8	9.9	12.4	11.7
3	(% Area)	13.2	21.6	24.1	7.7	9.6	23.8
4	(% Area)	13.7	22.3	23.4	7.8	9.8	23.0
5	(% Area	24.2	39.4	6.0	10.9	13.7	5.9
6	(% Area)	11.9	19.4	26.4	7.3	9.1	26.0
7	(% Area	12.9	21.1	24.6	7.6	9.5	24.3
8	(% Area	12.5	20.4	25.4	7.5	9.3	25.0
9	(% Area	21.0	34.3	11.2	10.0	12.5	11.0

The snowmelt model parameters applied in the Credit Valley Subwatershed 16 and 18 Study (Schroeter & Associates, 1999a) were used directly with no adjustments, see **Table A 7**.

3.6 Initial Conditions

Initial watershed conditions are represented by three variables in the GAWSER program: initial soil-water content, initial streamflow at time zero (also called baseflow), and initial snowpack conditions (for snowmelt events only). The methodology outlined in the Subwatershed 16 and 18 Study were used directly and were not altered beyond incorporating the new land use information.

Table A 7 Model Parameters for Each Block of Equivalent Snow Accumulation and Typical Initial Conditions in each ZUM

Parameter	Symbol	Units	Fields Ploughed	Fields Grass	Forest	Roadway Easements	Fence Lines	Forest Edges
Constant melt factor	KMI	(mm/d-C^{o})	0.3	2.0	0.2	4	4	0.2
Variable melt factor	KMII	(mm/d-C^{o})	32	29	22	24	24	23
Refreeze factor	KF	(mm/d-C^{o})	16	16	11	16	12	11
Base Temperature	TBAS	(C^{o})	0	0	0	0	0	0
Sublimation rate	SUBLIM	(mm/d)	0.33	0.33	0.33	0.33	0.33	0.33
Threshold density	MRHO	(vol/vol)	0.40	0.37	0.35	0.40	0.70	0.37
Compaction Constant:	A	(hours)	0.10	0.10	0.10	0.10	0.10	0.10
Compaction Constant:	B	(1/C^{o})	7.0	7.0	7.0	7.0	7.0	7.0
Holding Capacity	HCAP	(cm)	9.5	17	44	35	55	2000
Initial Depth	IDEPTH	(cm)	7.2	18.0	22.8	26.6	55.5	63.8
Initial Snow WE	ISWC	(mm)	26.6	52.8	57.0	106.4	222.0	223.3

General Parameters Applied to All Blocks

Parameter	Symbol	Units	Value
New snow density when BETA=0	NEWDEN	(vol/vol)	0.125
Temperature constant for New snow density	BETA	1/C^{o}	0.119
Eroded snow density	RHOE	(vol/vol)	0.120
Irreducible water saturation	SWI	(vol/vol)	0.07
Initial liquid water content	ILWC	(mm)	0.00

3.7 Parameter Selection and Adjustments

Previously published values were employed as first estimates for all model parameters. In this case, parameter values were taken directly from the Eramosa River (Schroeter and Boyd, 1998) and Credit Valley Subwatershed 16 and 18 studies (Schroeter & Associates, 1999a).

Once the model was completely set-up, the number of parameters requiring additional adjustment during calibration are relatively few. As mentioned earlier, the model comparisons made in this report did not involve any model calibration. Previously published values were used throughout.

The program adjusts the specified parameters for all response units and subcatchments in a similar manner, as shown here for effective hydraulic conductivity (KEFF).

[3.7.1] $KEFF(i)_{used} = FKEFF * KEFF(i)_{specified}$

where FKEFF is the effective hydraulic conductivity adjustment factor, the subscript 'used' denotes the value of KEFF actually used in the runoff calculations for response unit (i), and the subscript 'specified' represents the value of the parameter (e.g. KEFF) for response unit (i) actually entered in the input files during model set-up.

In previous GAWSER applications, these are the most commonly adjusted parameter factors:

Symbol	Description
FDS	Maximum depth of depression storage factor
FKEFF	Effective hydraulic conductivity factor (for surface infiltration)
FCS	Maximum seepage rate (movement of water from layer 1 to 2)
FD	Maximum percolation rate (movement of water out of layer 2)
FKO	Overland runoff lag factor
FKMF	Combined refreeze/snowmelt factor
FIMCI	Initial soil-water content adjustment factor for soil layer 1
FIMCII	Initial soil-water content adjustment factor for soil layer 2
FEDAY	Potential evapotranspiration adjustment factor
FINS	Interception storage adjustment factor

Values of unity for any of the above factors means that the 'as set-up' values specified in the watershed files are used directly in the calculations. The rationale for adjusting these factors is given below.

Depression storage, FDS: This factor diverts water from overland runoff. During snowmelt, depressions may be ice-filled and hence ineffective. Because total streamflow is modelled in GAWSER, including subsurface stormflow and groundwater baseflow, the effect of depression storage is to alter the amounts of overland and subsurface components. If the soil is initially at field capacity or wetter, depression storage does not represent a loss from input to total streamflow.

Effective hydraulic conductivity, FKEFF: This factor allows for changes in the hydraulic conductivity due to viscosity changes as the ground surface temperature varies. This effect accounts for a reduction to 0.25 of the midsummer values (specified in the model) for early spring and fall rainfall events. The presence of frozen water in the upper soil layers causes additional loss in hydraulic conductivity. For snowmelt events, reductions in KEFF of 0.020 to 0.075 of the midsummer values are common to account for frozen ground conditions in different parts of the watershed.

Maximum seepage (FCS) and percolation (FD) rates: These factors allow for changes in the rates of water movement between soil layers. Their influence can be seen on the recession tails of simulated hydrographs. Depending on the amount of frost penetration in a soil, these factors may be reduced from their midsummer values, as with FKEFF. Generally, these parameters should not change much between events, although they can be influenced by soil cracking as well (e.g. higher values). For large events where the top soil layer becomes saturated (e.g. Regional Storm), these factors will control the amount of infiltration (see *GAWSER Training Guide*, Section A.2.2).

<u>Overland linear runoff lag constant, FKO</u>: A major adjustment factor of the shape of the overland runoff hydrograph is the linear reservoir lag constant through which the translated hydrograph developed from the area/time versus time curve is routed. Recall, that KO is set equal to two times the basetime (TB) of the area/time curve. Each subcatchment was set-up with KO=2*TB as an initial value (with KO=3*TB for swampy areas), and hence FKO=1. However, for snowmelt events FKO is set higher (around 4.0) to account for the delayed routing effects caused by the presence of a snow cover in fields. Similarly, higher FKO values (about 4 to 5) are required for late summer and early fall events to account for the presence of unharvested crop cover.

<u>Refreeze/Snowmelt factor, FKMF</u>: There will be variations in the amount of melt per degree-day depending on the amount of incoming solar radiation. This quantity varies with season, cloudiness and surface cover type (e.g. forests or open fields) and is imperfectly related to air temperature. Heavily forested subwatersheds will have smaller melt factors than those dominated by open fields (Schroeter et al., 1991). The variability of air temperature through the day is a further complication. Reduction in reflectivity of the snow surface as it ages means that more energy is available for melt from the same solar radiation as snow ages. The general tendency of these trends is to produce a higher melt factor in late spring events (about 0.7 to 0.9). Because refreeze and snowmelt are influenced by the same energy balance considerations, the comments made earlier about snowmelt can also be applied to the refreeze factors.

<u>Initial soil-water content for first layer, FIMCI</u>: This has a major influence on the initiation of runoff and the overall hydrograph volume. Initially dry soils produce less runoff, whereas initially wet soils produce more runoff. Usually, the soil-water contents are set initially at field capacity, and so FIMCI=1.0. Rarely is this factor adjusted for spring and fall events. For summer events, FIMCI may be less than unity (say about 0.3 to 0.5).

<u>The subsurface and groundwater recession constant, FKSS</u>: This factor controls the linear reservoir lag constant for subsurface and groundwater storage, which determines when the percolated water (output from the second soil layer) appears as baseflow. This value is normally kept at unity, but it will be higher for the midsummer to early fall period.

<u>Relative density of freshly fallen snow factor, FNEW</u>: Observations have shown that values for the relative density of fresh snow range from 0.02 to 0.15, depending on what time during the winter (early, middle or late), and the prevailing weather system. For most applications in southern Ontario to date, the fresh snow relative density has been set at 0.085. The FNEW factor allows for some variation in this parameter throughout the winter. Generally, new snowfalls in the late winter will be wetter (more dense).

<u>Potential Evapotranspiration adjustment factor, FEVAP</u>: In GAWSER, the potential daily evapotranspiration rate (EDAY) is set as a constant. FEVAP provides a means of varying EDAY on a monthly basis, representative values of which are given in climate reports (e.g. Hare and Thomas, 1979). At present, EDAY is set at 1 mm/d, which means that the stated values for FEVAP directly represent the monthly average values for EDAY.

<u>Interception storage adjustment factor, FINS</u>: This is relatively new feature in GAWSER, and such, has seen limited application. However, initial experience in applying this factor in the Eramosa River has yielded stable values.

The monthly parameter adjustment factors used in the present work are given in **Table A 8** below. This table represents parameter factor values at the midpoint of each month (say the 15th). The actual parameter adjustments used in the calculations are then linearly interpolated from the monthly table depending on the Julian date. The variation in FKEFF throughout the year using the interpolation procedure by date, and the straight tabular values are illustrated in **Figure A 8**.

Table A 8 Monthly Parameter Adjustment Factors

Symbol	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
FDS	0.75	1.00	0.00	1.00	1.20	1.15	1.15	1.50	1.50	1.00	0.75	0.75
FKEFF	0.02	0.02	0.02	0.10	0.40	0.65	0.75	0.90	0.65	0.25	0.10	0.02
FCS	0.03	0.02	0.02	0.09	0.40	0.50	0.60	0.75	0.35	0.30	0.13	0.06
FD	0.05	0.03	0.03	0.05	0.05	0.06	0.10	0.11	0.09	0.08	0.07	0.05
FKO	5.0	6.0	3.5	4.0	3.0	4.5	5.5	6.0	5.0	4.0	3.5	3.0
FKSS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FKMF	0.25	0.33	1.10	1.30	1.50	1.00	1.00	1.00	1.00	1.00	0.25	0.15
FNEW	1.00	1.00	1.10	1.10	1.00	1.00	1.00	1.00	1.00	1.00	1.10	1.10
FEVAP	0.00	0.00	0.00	1.21	1.65	3.85	4.20	4.18	2.75	1.20	0.44	0.00
FINS	0.20	0.20	0.20	.50	0.70	1.20	1.50	1.50	1.20	0.70	0.20	0.20

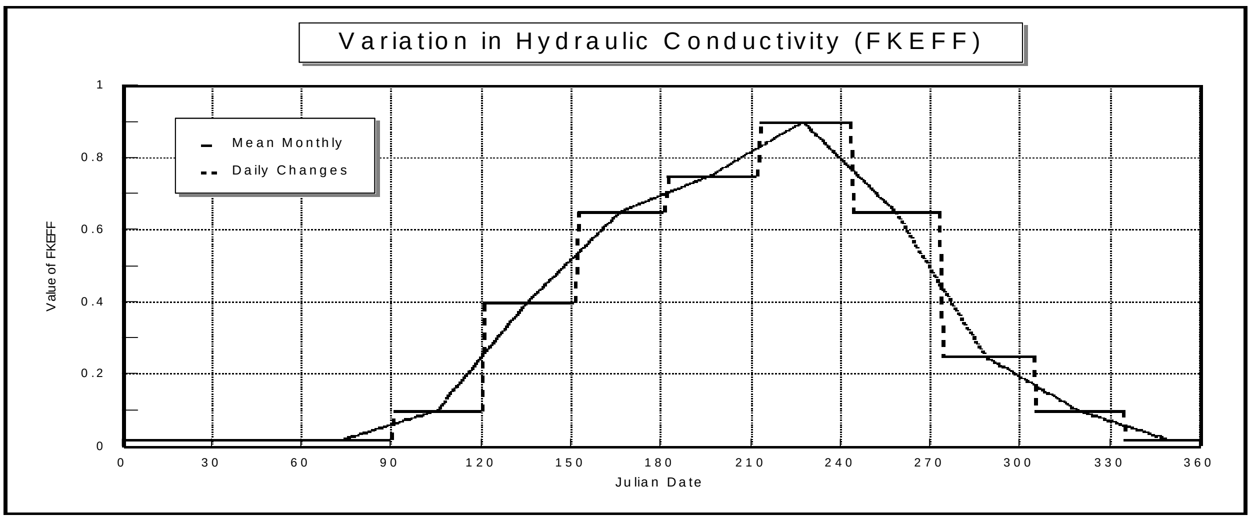

Figure A 8 Variation in Effective Hydraulic Conductivity Factor with Time

3.8 Assessment of Event Modelling Results

To date, the modelling results from GAWSER have been assessed using the following key hydrograph statistics: peak flows, times to peak flows, hydrograph volumes, and the Nash-Sutcliffe (1970) model efficiency (which is something like a correlation coefficient, See Appendix B of *GAWSER Training Guide and Reference Manual* for details). These statistics (or objective measures of model performance) do not always reflect the “goodness of fit”, as the example below illustrates.

Suppose the modelled hydrograph has the same overall shape as the measured curve, with excellent (less than $\pm$10%) agreement between the peak flows and hydrograph volumes, but the simulated curve is shifted by let’s say 5 to 10 hours, and so the computed Nash-Sutcliffe R^2 of 0.50 indicates an extremely poor fit. This simulation actually suggests a very good model fit, where the shift in peak timing is likely due to model inputs, which often occurs when the rainfall data are collected from gauges outside or at either end of the watershed. A delay (late time shift) in the modelled hydrograph relative to the observed plot may indicate that the watershed received the rain before the gauge measured it. On the other hand, an early time shift means that gauge recorded the event before the watershed ‘felt’ it. In the Bronte Creek watershed time shifts in the hydrologic modelling results are very possible, because the recording raingauges are located outside the watershed.

As a result of these considerations, we evaluated model performance subjectively by giving significant weight to the overall shape of the simulated hydrograph viewed together with the observed curve. Moreover, the level of agreement is governed by the closeness of the statistics (e.g., peak flow, volume, time to peak, and R^2) for the simulated and observed hydrographs. The subjective terms, 'excellent', 'very good', 'good', 'fair', and 'poor' are defined as follows:

Table A 9 Qualifying Levels of Agreement

% Difference in Peak Flow or Volume	Computed Nash-Sutcliffe R2	Time to peak Difference as No. of DTs	Goodness Of Fit Index (GFI)	Qualifying Level of Agreement
<5	>0.90	< 2	> 90	Excellent
5 to 10	0.80 to 0.90	2 to 4	80 to 90	Very Good
10 to 15	0.70 to 0.80	4 to 6	70 to 80	Good
15 to 20	0.60 to 0.70	6 to 10	60 to 70	Fair
>20	< 0.60	> 10	< 60	Poor

where DT is the computational time step. In hydrological practice, corresponding simulated and measured values are said to be in agreement when their magnitudes differ by less than the level of error normally associated with measuring hydrologic variables, i.e. $\pm$10% for snow depth, snow water equivalent, precipitation depths, and streamflow.

Hydrograph shape enters the assessment by causing a jump in the stated level of performance if the hydrograph statistics show less agreement. In the above example, the hydrographs statistics, R^2 and time to peak, suggest a poor fit, even though the peak flows and volumes are in excellent agreement. Because the hydrograph shapes are reasonably the same, the overall assessment would be rated as very good.

To facilitate the assessment and review of modelling results, a 'goodness of fit' index (or GFI) was developed by Schroeter and Boyd (1998) to combine the key hydrograph statistics into one objective measure. The GFI has been formulated so that a value of 100 represents a perfect fit. Key hydrograph statistics were computed in terms of percent departure from the observed values, so that negative values represent underestimates and positive values are overestimates. The timing parameters (e.g. time to peak or time to centroid) were calculated as differences in hours, divided by the duration of the event. Hence, if a hydrograph timing departure statistic was of the same order of magnitude as the duration of the event, the timing is obviously poor. The Nash-Sutcliffe model efficiency (R^2) was multiplied by 100 to make it a percent as well. It is the only statistic allowed to take on negative values. The hydrograph departure statistics were computed as:

$$\Delta V = 100*(V_{sim} - V_{obs})/V_{obs}$$

$$\Delta P = 100*(P_{sim} - P_{obs})/P_{obs}$$

[3.8.1] $$\Delta TP = 100*(TP_{sim} - TP_{obs})/TDUR$$

$$\Delta TTC = 100*(TTC_{sim} - TTC_{obs})/TDUR$$

$$\Delta R = 100*R^2$$

where ΔV is the hydrograph volume departure statistic, V is the hydrograph volume, the subscripts 'sim' and 'obs' denote the simulated and observed values, ΔP is the hydrograph peak flow departure statistic, P is the peak flow, ΔTP is the time to peak departure statistic, TP is the time to peak, TDUR is the hydrograph duration, TTC is the time to centroid, ΔTTC is the time to centroid departure statistic, R^2 is the Nash-Sutcliffe model efficiency, and ΔR is the model efficiency departure statistic.

The absolute values of the above statistics are combined into a weighted-average expression to compute the goodness of fit index, or GFI

[3.8.2] $GFI = 0.25*(100-\Delta V) + 0.20*(100-\Delta P) + 0.45*\Delta R + 0.05*(100-\Delta TP) + 0.05*(100-\Delta TTC)$

The goodness of fit index (GFI) has been included as aid in the qualifying levels of agreement in **Table A9**. Therefore, a GFI of 83 would represent a very good model fit, whereas 55 would indicate a poor fit.

3.9 Assessment of Continuous Modelling Results

Procedures for assessing the event modelling were discussed in the previous section. While this information provides some guidance in evaluating the continuous simulation results, they cannot be applied directly because of several key differences in the way meteorological input data are applied in the event and continuous modelling work as summarized below.

1. In event modelling, most of the available meteorological information was utilized to build an input data set for each individual event. Spatial rainfall distributions (e.g., **Figure A 7**) were considered to develop unique inputs for up to nine zones of uniform meteorology. Snow course data were used to distribute the initial snowpack conditions, while observed streamflows provided estimates for the initial outflows from each subcatchment.

2. This level of detail (as noted in Item 1 above) is warranted in event modelling, because the number of events considered (here 15) is relatively low compared to the number of events encountered in a continuous simulation period. A typical water year will have some 40 or so rainfall events, with about half producing noticeable changes in stream discharge. For an eight year period, that's about 310 to 330 events. Consequently, it is simply not possible with the resources available (both economic and manpower) for this study to work-up the rainfall data with the same level of detail found in the event modelling. Even so, a significant level of effort was expended to estimate the missing hourly rainfall depths in the continuous simulation data set (see Schroeter et al., 2000b).

3. The meteorological inputs for the continuous simulation work utilized data for locations (e.g. Guelph Area, Hamilton RBG, Toronto Pearson International Airport) outside and surrounding the study. (Recall, that time shift problems were discussed in Section 3.8.) These stations were selected because they had the longest continuous record of data in the general vicinity of the Bronte Creek watershed. Morever, these stations lie in the prevailing direction (west to east) for weather sequences in this area, and hence were deemed to be more representative than other available data. For instance, a 37 year meteorological data set was available from records at the Toronto Pearson International Airport (from the Subwatershed 7 and 8a study, see Schroeter & Associates, 1999b). Although the annual rainfall totals are similar to those recorded for the Guelph Area, the annual snowfall amounts were too low for the Bronte Creek watershed.

4. The purpose of the event modelling is to show that the formulated hydrologic model can reasonably reproduce the streamflow response of the study area for historical events. Consequently, the 'goodness of fit' requirements for event modelling are more stringent than for continuous simulation.

The main objective of any continuous simulation exercise is to understand how the hydrologic system in a watershed responds, in terms of frequency of occurrence for selected quantities, to the sequences of climate inputs. For example, in pre-and post development comparisons, we are interested in how often a certain level of response (e.g. hydrograph volume, water level in a detention pond) occurs over the course of a long-term period for each scenario. With this purpose it is not as important to have the absolute correct data (in terms of volumes and timing) for input to the hydrologic model. However, the input data must be sufficiently representative so as to generate meaningful 'statistics' for the system response quantities. In this regard, the model must be able to reproduce the general response of the watershed in terms of major movements of water (e.g. runoff, groundwater recharge, evapotranspiration), in both time and space.

In light of the above considerations, the continuous simulation results were compared with observed hydrograph data, but were assessed primarily in terms of qualitatively matching the volumes at gauged points of interest on an annual and monthly basis. Matching measured and modelled hydrographs on an hourly or daily basis is meaningless, because we know that the meteorological inputs are not entirely representative of those occurring on the watershed, especially for specific events.

The most important tools for assessment are water balance tables, visual comparisons of annual and monthly hydrograph plots, and flow duration curves. The assessment of the continuous simulation results is summarized in **Section A 4**.

4.0 MODEL APPLICATION FOR IMPACT ANALYSIS

4.1 Outline of Procedures

The formulated hydrologic model for the Bronte Creek watershed, once validated, is now ready for use in assessing the impacts of proposed land use changes. How the model is modified to account for the different land use scenarios is outlined in the next section. Following this, flood flow estimates are made first by statistical analysis of the available flow data, and then by applying return period Storm events to the model for three scenarios: existing conditions, and two future conditions (interim and ultimate). A 39 year meteorological data sequence was applied to the model for determining long-term water balance quantities, extreme (high and low) flows, and flow durations resulting from each scenario. Where possible, estimated quantities (e.g. high and low flows) are compared with those from previous studies or alternative methods.

4.2 Statistical Analysis of Flood Flows

Moin and Shaw (1985; 1986) conducted a regional frequency analysis for Ontario streams using annual maximum flow data from 415 gauges. Their work included frequency analyses for the Bronte Creek at Progreston and Bronte Creek near Zimmerman gauges. However, because Moin and Shaw's analyses utilized flow data up to 1982, it was necessary to update the frequency results with the most recent flow information. Moin and Shaw did not include analyses for the Bronte Creek at Carlisle gauge, because the gauge was not yet in operation. Data from the Carlisle gauge were included in the present analysis.

Consequently, single station frequency analyses were conducted using additional annual maximum flows for 1983 to 1990 reported in the *Historical Streamflow Summary: Ontario* (Water Survey of Canada, 1992), and 1991 to 1997 data obtained from WSC CD-ROM, HYDAT'97. None of the records for the available gauges had sufficient numbers of data points to produce a reliable frequency analysis according to the suggestions of Watt et al. (1989). Therefore, all the available flow data were combined to produce one reliable frequency analysis for the Bronte Creek near Zimmerman gauge (02HB011) data, although analyses of the Carlisle data occurred as well.

In order to have a consistent record of maximum instantaneous flows at one site with at least 25 data points, a few adjustments and additions were made as outlined below:

a. The records (1977 to 1985) for the Bronte Creek at Progreston gauge (02HB016) were combined with the records (1990 to 1997) for the Bronte Creek at Carlisle gauge (02HB022), because their respective drainage areas differ by less than 10%. To do this, the Progreston gauge flows (1977-1985) were reduced by 4.4% to account for the difference in the drainage areas. This adjustment added eight annual maximum flows to the Carlisle gauge records.

b. Missing instantaneous flows (due mostly to ice conditions, or not given in the older records prior to 1967) were approximated from the maximum daily values using a linear relationship. For the three gauges considered, a total of only four maximum instantaneous flows were missing. The missing maximum flows were estimated by a applying a factor to the available daily maximum flow. This factor represented the average ratio of the maximum instantaneous to maximum daily flows. For the Zimmerman gauge, this ratio was found to be 1.26, 1.09 for the Progreston gauge, and 1.08 for the Carlisle gauge.

c. The Carlisle gauge records were combined with the Zimmerman gauge records to yield a total data set comprising 31 points. For this purpose, the Carlisle maximum flows were multiplied by 2.61 to give estimated flows at the Zimmerman gauge. This 2.61 factor represents the average of the drainage area ratio between the two gauges (243.84/116.21 = 2.10), and the eight year mean of ratio (here, 3.12) between maximum flows about both gauges for the 1977 to 1985 period.

Single station frequency analyses (SSFA) were carried out for each gauge using procedures built into the GAWSER (Guelph All-Weather Sequential-Events Runoff model) program. The procedures for fitting the log normal (LN) and the three parameter log normal (LN3P) distributions are identical to those utilized in the Consolidated Frequency Analysis (CFA) program (Pilon et al., 1985; 1993) provided by Environment Canada, and also described in Kite (1978) and Watt et al (1989). Although CFA and GAWSER can fit more statistical distributions, the three parameter log normal distribution (LN3P) was selected exclusively for two compelling reasons. First, the goodness of fit for the LN3P was quite acceptable according to visual inspection of the distribution plots (**Figures A 9** and **A 10**), and the agreement between the computed and theoretical values for the higher statistical moments (skewness and kurtosis, zero and 3 for the LN3P). Secondly, the LN3P produced good fits on the basis of a regional analysis (e.g., Moin and Shaw 1985; 1986). The requisite tests for independence, trend, homogeneity and randomness (see Watt et al., 1989; Kite, 1978) indicated that the annual maximum flow records for each gauge were acceptable for SSFA.

Table A 10 outlines the sample statistics used in the SSFA for each gauge. Frequency distribution plots are given for each gauge in **Figures A 9** and **A 10**, where the fitted curves shown are for the LN and LN3P distributions. In general, the LN3P (the dashed line) fits the observed data points quite well. The estimated flood flows are given in **Table A 11** for both the LN and LN3P distributions. Estimates from two statistical distributions are given so as to bound the computer generated results presented later in this chapter. Notice that the LN3P estimate for the 100 year flow is 6% higher than the LN value for the Zimmerman gauge. The method of moments was used to fit the LN3P distribution, because it is simpler to apply and more stable for the relatively small sample sizes normally found in hydrology (Watt et al., 1989).

Flood flow estimates are given in **Table A 11** for both the 20 and 25 year return periods, because previous studies are inconsistent in listing the 20 or 25 year flow. The CFA program gives the 20 year flow as output, while AES provides the 25 year rainfall volumes in their IDF (intensity-duration-frequency) curves which are used to generate runoff estimates. Showing both values here facilitates comparisons with between different studies.

Table A 10 Maximum Flow Summary Statistics used in the SSFA for Each Gauge

Gauge	Transform	N	Mean	Standard Deviation	Skewness	Kurtosis	Max	Min
Carlisle	Normal (X)	17	11.119	4.475	0.377	3.310	20.8	4.41
	LN X Series		2.326	0.432	-0.383	3.004		
	LN (X-A) Series With A=-24.717		3.572	0.124	0.138	2.971		
Zimmerman	Normal (X)	31	26.552	8.593	1.404	5.840	54.3	13.9
	LN X Series		3.235	0.296	0.514	3.719		
	LN (X-A) Series With A=7.009		2.889	0.411	0.163	3.644		

Note: Estimates of A in LN (X-A) series produced through the method of moments.

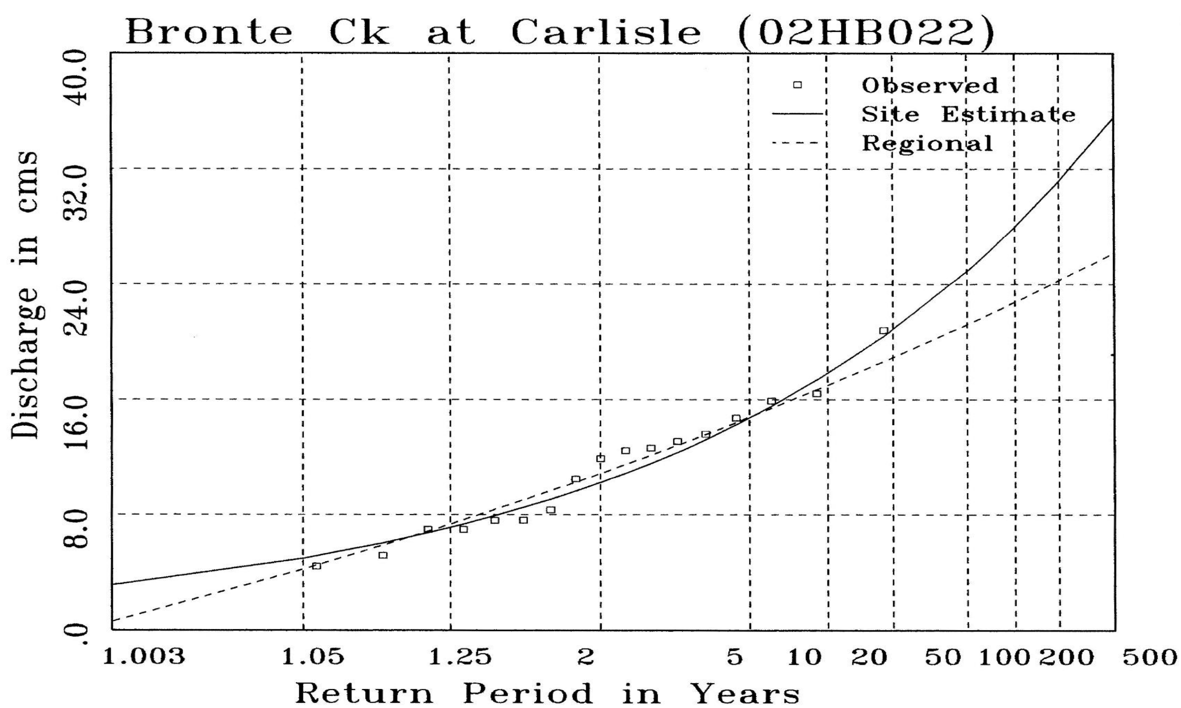

Figure A 9 Flood Flow Frequency Distribution Plot for the Carlisle Gauge (Solid line is LN, and dashed is LN3P)

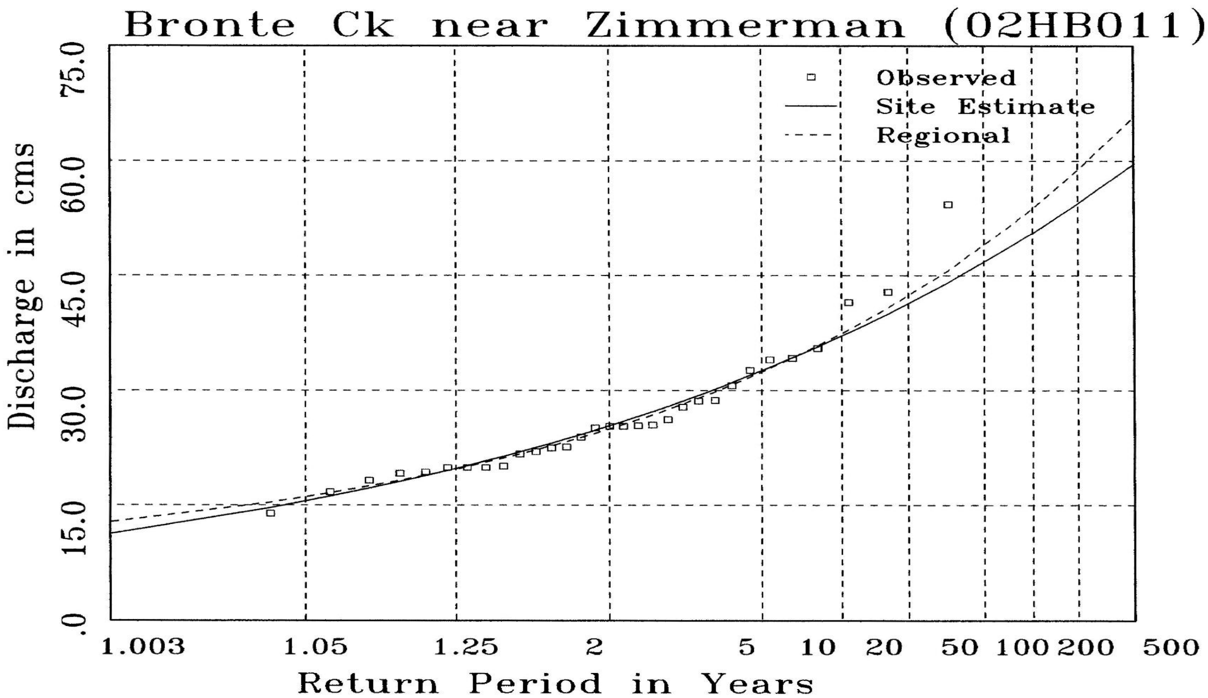

Figure A 10 Flood Flow Frequency Distribution Plot for the Zimmerman Gauge

Table A 11 Estimated Return Period Flood Flows at Each Gauge Location				
Return Period (Years)	**Carlisle LN**	**Carlisle LN3P**	**Zimmerman LN**	**Zimmerman LN3P**
2	10.2	10.9	25.4	25.0
5	14.7	14.8	32.6	32,4
10	17.8	17.0	37.1	37.4
20	20.8	18.9	41.3	42.3
25	21.8	19.5	42.6	43.9
50	24.9	21.2	46.7	48.8
100	28.0	22.7	50.6	53.8

Note: All flows given in m^3/s, and the LN3P distribution fitted by method moments.

Table A 12 Temporal Rainfall Distribution Patterns used in this Study

Event	Time Step (min)	Rainfall Depth in mm for the Time Step Ending 1	2	3	4	5	6	7	8	9	10	11	12	Total Rain (mm)
SCS II	15	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	104
(24 h)		0.26	0.26	0.26	0.26	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	
(100 year)		0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.78	0.78	0.78	0.78	
		0.78	0.78	0.78	0.78	1.43	1.43	1.43	1.43	2.13	4.47	11.34	26.26	
		4.81	2.94	2.24	1.66	1.25	1.25	1.25	1.25	0.78	0.78	0.78	0.78	
		0.73	0.73	0.73	0.73	0.57	0.57	0.57	0.57	0.52	0.52	0.52	0.52	
		0.47	0.47	0.47	0.47	0.36	0.36	0.36	0.36	0.42	0.42	0.42	0.42	
		0.26	0.26	0.26	0.26	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	
SCS II	15	0.54	0.54	0.54	0.54	0.80	1.68	4.26	9.86	1.81	1.11	0.84	0.63	25
(4 hour)		0.47	0.47	0.47	0.47									

4.3 Computer Generated Flood Flows: Return Period Flows

The existing conditions watershed model was used to translate the 2 to 100 year return period flood flow estimates at the primary gauge station (Bronte Creek near Zimmerman) to all ungauged points of interest. This involved selecting a known event for which the model had already been set-up, and adjusting (scaling up or down) the model inputs (e.g. rainfall volume) until the model-generated flows matched (within +0.5%) the return period flows at the primary gauge site. The computational time step was set at 15 minutes (0.25 hours) for these applications.

The above procedure for distributing return period flood flows throughout a watershed has been applied in a number of hydrologic studies: the Speed and Eramosa Rivers Floodline Mapping Study (Ecologistics, 1988), the Grand River Hydrology Study Phase I (GRCA, 1988), the Ausable-Bayfield Watershed Hydrology Study (Schroeter & Associates, 1992), the Eramosa River Watershed Hydrology Study (Schroeter and Boyd, 1998), and the Torrance Creek Subwatershed Study (Schroeter & Associates, 1999). The flood flows generated by this technique tend to be more realistic than the design storm and intensity-duration-frequency (IDF) approach, because the frequency analysis utilizes extreme flows generated by mixed processes involving snowmelt events as well as rainfall. Moreover, the method is independent of initial conditions as they are the ones that accompany the ‘generating event’.

For the overall Bronte Creek watershed, the 48-hour regional storm (Hazel) pattern was selected as the return period flow generation base event (with the model parameters and initial conditions outlined in Section 3.3.2). It was chosen for three reasons: a) its large volume of rain (285 mm), b) its large spatial distribution meant that all parts of the watershed will be contributing flow at the outlet, and c) it was already set-up for the Bronte Creek watershed. Moreover, its two-day duration and volume are on the order of some very large rain-on-snowmelt events as well. **Table A 13** summarizes the rainfall scaling factor applied to the base event to match flows at the Zimmerman gauge, and the resulting 48 hour rainfall volume. For instance, the 50 year scaling factor is 0.406, which gives a 48 hour rainfall depth of 115.7 mm, and will cause the modelled discharge at the Zimmerman gauge to match the 50 year flood flow. These return period scaling factors applied to the Regional Storm pattern are comparable to those established for the Ausable-Bayfield Rivers (see Schroeter & Associates, 1992).

For the Indian Creek applications, particularly for establishing the SWM (stormwater management) pond volumes in Scenario 3 (which is Scenario 2, post-development with controls), it was decided to use the SCS Type II 24 hour pattern discretized into 15 minute intervals. This storm pattern (see **Table A 12**) gives higher rainfall intensities than are available in the Hazel pattern. Higher rainfall intensities govern flood flow estimates for urban areas. For this purpose, the SCS Type II 24 hour rainfall volumes were adjusted until a suitable value resulted in a match between the model generated peak flow and the one computed by frequency analyses for the Zimmerman gauge. **Table A 13** also gives the calibrated SCS 24 hour rain volumes for each return period. For comparison, the 24-hour rainfall volume for each return period at the Hamilton RBG rain gauge are also given in **Table A 13**.

In **Table A 13**, notice that for the longer return intervals (e.g. 50 and 100 year), the rainfall volumes for each method are comparable. For the shorter return intervals (e.g. 2 and 5 year), the 'calibrated' rainfall volumes are about 35 to 50% higher than those determined from rainfall intensity-duration-frequency analyses, because the 'calibrated' rainfalls are being matched to return period flows that were generated by mixed processes involving snowmelt or a combination of rainfall and snowmelt on frozen ground conditions. The calibrated 24-hour SCS volumes are about 15% smaller than the calibrated 48 hour 'base event (or Hazel)' volumes primarily due to difference in the maximum rainfall intensity. Recall, that for the Hazel pattern, the maximum rainfall intensity is 53 mm/h, whereas for the SCS 24 hour 100-year storm the maximum intensity is about 105 mm/h (see **Table A 12**).

The return period flood flow estimates for points of interest along the main stem of Bronte Creek are summarized in **Tables A 14** to **A 17** for each Scenario. Recall, that these flood flows were generated using the calibrated base event or the Hazel pattern. The return period flood flows estimates for locations within Indian Creek are displayed in **Tables A 18** to **A 20**, representing Scenarios 1 to 3 only. The reason Scenario 4 results are not given for Indian Creek is because Scenario 4 is exactly the same as Scenario 2. Recall, that the only difference between Scenario 2 and 4 is that Subcatchment 1340, which contributes flow to Bronte Creek downstream of Indian Creek, is the only element that changes.

Table A 13 Calibrated Rainfall Scaling Factors and Volumes that Match Return Period Flows

Return Period (Year)	Calibrated Base Event Rainfall Factor	Base Event 48 hour Volume (mm)	Calibrated SCS 24 hour Volume (mm)	Hamilton RBG 24 Hour Volume (mm)
2	0.267	76.1	68.3	50.2
5	0.319	90.9	77.0	69.4
10	0.350	99.8	84.0	82.1
20	0.376	107.2	90.1	n/a
25	0.383	109.2	92.2	97.0
50	0.406	115.7	98.3	109.0
100	0.427	121.7	104.0	120.0

Note: Base Event used the Regional Storm (Hazel) 48 hour pattern (with 285 mm).

Table A 14 Summary of Flood Flow Estimates: Bronte Creek Watershed Study Existing Conditions (Scenario 1)

No.	Point of Interest	Area km^2	Peak Flows (m^3/s) 1:2 yr	1:5	1:10	1:20	1:25	1:50	1:100
6013	Bronte Ck u/s Strabane Ck	36.500	2.900	3.760	4.320	4.820	4.970	5.450	5.900
2031	Strabane Creek Outlet	9.810	1.360	1.750	1.980	2.180	2.240	2.430	2.610
6031	Bronte Ck d/s Strabane Ck	46.310	4.220	5.460	6.230	6.930	7.130	7.810	8.430
6032	Bronte Ck u/s Mountsberg Ck	58.510	5.170	6.740	7.710	8.680	8.940	9.820	10.600
1050	Mountsberg Reservoir Inflow	37.100	1.720	2.180	2.460	2.720	2.790	3.020	3.220
5300	Mountsberg Reservoir	37.100	1.510	1.910	2.160	2.390	2.450	2.650	2.830
6080	Mountsberg Creek Outlet	57.700	8.980	11.700	13.600	15.500	16.000	18.000	19.800
2090	Bronte Ck at Carlisle	116.210	10.900	14.400	16.700	19.100	19.800	22.100	24.300
6100	Bronte Ck at Progreston	121.580	11.100	14.800	17.100	19.700	20.400	22.700	25.100
1120	Flamboro Ck Outlet	9.430	0.702	0.970	1.190	1.450	1.520	1.780	2.010
6120	Bronte Ck d/s Flamboro Ck	131.010	11.700	15.600	18.100	20.900	21.700	24.300	26.800
6165	Kilbride Creek Outlet	44.330	5.180	6.770	8.000	9.270	9.690	11.000	12.300
6160	Bronte Ck d/s Kilbride Ck	183.530	15.300	20.400	23.700	27.400	28.400	31.800	35.100
1180	Willoughby Creek	12.900	1.690	2.190	2.510	2.810	2.890	3.160	3.420
6180	Bronte Ck d/s Willoughby Ck	196.430	16.800	22.300	25.900	29.800	31.000	34.600	38.100
6222	Limestone Creek Outlet	40.000	10.200	13.000	14.800	16.300	16.700	18.100	19.500
6225	Bronte Ck d/s Limestone Ck	239.980	22.400	29.500	34.200	39.400	40.900	45.500	50.300
6240	Bronte Ck near Zimmerman	243.840	24.900	32.500	37.400	42.400	43.900	48.900	53.800
1260	Lowville Creek Outlet	9.100	2.830	3.660	4.220	4.730	4.870	5.340	5.770
6260	Bronte Ck d/s Lowville Ck	252.940	27.700	36.000	41.500	47.000	48.600	54.000	59.300
6302	Indian Ck outlet at Bronte	37.320	28.100	36.100	40.900	45.100	46.200	49.700	53.100
6310	Bronte Ck d/s Indian Creek	290.260	55.300	72.000	82.200	92.000	94.700	104.000	112.000
1320	Mount Nemo Creek outlet	4.790	2.230	2.890	3.340	3.770	3.890	4.290	4.640
6320	Bronte Ck d/s Mount Nemo Ck	296.390	57.900	75.300	86.100	96.400	99.200	109.000	118.000
1340	Bronte Subcatchment 1340	8.950	11.800	14.700	17.000	19.100	19.700	21.700	23.500
6340	Bronte Ck d/s Sub 1340	305.340	59.400	77.200	88.600	99.100	102.000	112.000	121.000
2360	Bronte Ck at QEW	305.340	59.100	76.900	88.200	98.700	102.000	111.000	120.000
2380	Bronte Ck at Lake Ontario	312.500	60.200	78.300	90.000	101.000	104.000	113.000	123.000

Table A 15 Summary of Flood Flow Estimates: Bronte Creek Watershed Study Post-Development Future 1 (Scenario 2)

No.	Point of Interest	Area km^2	Peak Flows (m^3/s) 1:2 yr	1:5	1:10	1:20	1:25	1:50	1:100
6013	Bronte Ck u/s Strabane Ck	36.500	2.900	3.760	4.320	4.820	4.970	5.450	5.900
2031	Strabane Creek Outlet	9.810	1.360	1.750	1.980	2.180	2.240	2.430	2.610
6031	Bronte Ck d/s Strabane Ck	46.310	4.220	5.460	6.230	6.930	7.130	7.810	8.430
6032	Bronte Ck u/s Mountsberg Ck	58.510	5.170	6.740	7.710	8.680	8.940	9.820	10.600
1050	Mountsberg Reservoir Inflow	37.100	1.720	2.180	2.460	2.720	2.790	3.020	3.220
5300	Mountsberg Reservoir	37.100	1.510	1.910	2.160	2.390	2.450	2.650	2.830
6080	Mountsberg Creek Outlet	57.700	8.980	11.700	13.600	15.500	16.000	18.000	19.800
2090	Bronte Ck at Carlisle	116.210	10.900	14.400	16.700	19.100	19.800	22.100	24.300
6100	Bronte Ck at Progreston	121.580	11.100	14.800	17.100	19.700	20.400	22.700	25.100
1120	Flamboro Ck Outlet	9.430	0.702	0.970	1.190	1.450	1.520	1.780	2.010
6120	Bronte Ck d/s Flamboro Ck	131.010	11.700	15.600	18.100	20.900	21.700	24.300	26.800
6165	Kilbride Creek Outlet	44.330	5.180	6.770	8.000	9.270	9.690	11.000	12.300
6160	Bronte Ck d/s Kilbride Ck	183.530	15.300	20.400	23.700	27.400	28.400	31.800	35.100
1180	Willoughby Creek	12.900	1.690	2.190	2.510	2.810	2.890	3.160	3.420
6180	Bronte Ck d/s Willoughby Ck	196.430	16.800	22.300	25.900	29.800	31.000	34.600	38.100
6222	Limestone Creek Outlet	40.000	10.200	13.000	14.800	16.300	16.700	18.100	19.500
6225	Bronte Ck d/s Limestone Ck	239.980	22.400	29.500	34.200	39.400	40.900	45.500	50.300
6240	Bronte Ck near Zimmerman	243.840	24.900	32.500	37.400	42.400	43.900	48.900	53.800

1260	Lowville Creek Outlet	9.100	2.830	3.660	4.220	4.730	4.870	5.340	5.770
6260	Bronte Ck d/s Lowville Ck	252.940	27.700	36.000	41.500	47.000	48.600	54.000	59.300
6302	Indian Ck outlet at Bronte	37.320	34.400	44.000	49.400	54.100	55.400	59.400	63.000
6310	Bronte Ck d/s Indian Creek	290.260	61.800	78.900	89.300	98.700	101.000	110.000	119.000
1320	Mount Nemo Creek outlet	4.790	2.230	2.890	3.340	3.770	3.890	4.290	4.640
6320	Bronte Ck d/s Mount Nemo Ck	296.390	64.800	82.800	93.800	104.000	107.000	116.000	125.000
1340	Bronte Subcatchment 1340	8.950	11.800	14.700	17.000	19.100	19.700	21.700	23.500
6340	Bronte Ck d/s Sub 1340	305.340	66.100	84.700	96.600	107.000	110.000	120.000	129.000
2360	Bronte Ck at QEW	305.340	65.100	83.700	95.400	106.000	109.000	118.000	128.000
2380	Bronte Ck at Lake Ontario	312.500	66.100	85.300	97.300	108.000	111.000	121.000	130.000

Table A 16 Summary of Flood Flow Estimates: Bronte Creek Watershed Study Post-Development Future 2 (Scenario 3)

		Area		Peak Flows (m^3/s)					
No.	**Point of Interest**	**km^2**	**1:2 yr**	**1:5**	**1:10**	**1:20**	**1:25**	**1:50**	**1:100**
6013	Bronte Ck u/s Strabane Ck	36.500	2.900	3.760	4.320	4.820	4.970	5.450	5.900
2031	Strabane Creek Outlet	9.810	1.360	1.750	1.980	2.180	2.240	2.430	2.610
6031	Bronte Ck d/s Strabane Ck	46.310	4.220	5.460	6.230	6.930	7.130	7.810	8.430
6032	Bronte Ck u/s Mountsberg Ck	58.510	5.170	6.740	7.710	8.680	8.940	9.820	10.600
1050	Mountsberg Reservoir Inflow	37.100	1.720	2.180	2.460	2.720	2.790	3.020	3.220
5300	Mountsberg Reservoir	37.100	1.510	1.910	2.160	2.390	2.450	2.650	2.830
6080	Mountsberg Creek Outlet	57.700	8.980	11.700	13.600	15.500	16.000	18.000	19.800
2090	Bronte Ck at Carlisle	116.210	10.900	14.400	16.700	19.100	19.800	22.100	24.300
6100	Bronte Ck at Progreston	121.580	11.100	14.800	17.100	19.700	20.400	22.700	25.100
1120	Flamboro Ck Outlet	9.430	0.702	0.970	1.190	1.450	1.520	1.780	2.010
6120	Bronte Ck d/s Flamboro Ck	131.010	11.700	15.600	18.100	20.900	21.700	24.300	26.800
6165	Kilbride Creek Outlet	44.330	5.180	6.770	8.000	9.270	9.690	11.000	12.300
6160	Bronte Ck d/s Kilbride Ck	183.530	15.300	20.400	23.700	27.400	28.400	31.800	35.100
1180	Willoughby Creek	12.900	1.690	2.190	2.510	2.810	2.890	3.160	3.420
6180	Bronte Ck d/s Willoughby Ck	196.430	16.800	22.300	25.900	29.800	31.000	34.600	38.100
6222	Limestone Creek Outlet	40.000	10.200	13.000	14.800	16.300	16.700	18.100	19.500
6225	Bronte Ck d/s Limestone Ck	239.980	22.400	29.500	34.200	39.400	40.900	45.500	50.300
6240	Bronte Ck near Zimmerman	243.840	24.900	32.500	37.400	42.400	43.900	48.900	53.800
1260	Lowville Creek Outlet	9.100	2.830	3.660	4.220	4.730	4.870	5.340	5.770
6260	Bronte Ck d/s Lowville Ck	252.940	27.700	36.000	41.500	47.000	48.600	54.000	59.300
6302	Indian Ck outlet at Bronte	37.320	27.300	34.800	39.100	42.900	44.000	47.900	51.600
6310	Bronte Ck d/s Indian Creek	290.260	54.700	70.700	80.600	89.800	92.600	102.000	111.000
1320	Mount Nemo Creek outlet	4.790	2.230	2.890	3.340	3.770	3.890	4.290	4.640
6320	Bronte Ck d/s Mount Nemo Ck	296.390	57.200	74.000	84.400	94.100	97.000	107.000	116.000
1340	Bronte Subcatchment 1340	8.950	11.800	14.700	17.000	19.100	19.700	21.700	23.500
6340	Bronte Ck d/s Sub 1340	305.340	58.700	75.900	86.800	96.800	99.800	110.000	119.000
2360	Bronte Ck at QEW	305.340	58.500	75.300	86.300	96.300	99.300	109.000	119.000
2380	Bronte Ck at Lake Ontario	312.500	59.500	76.700	88.000	98.200	101.000	111.000	121.000

Table A 17 Summary of Flood Flow Estimates: Bronte Creek Watershed Study Post-Development Future 3 (Scenario 4)

		Area		Peak Flows (m^3/s)					
No.	**Point of Interest**	**km^2**	**1:2 yr**	**1:5**	**1:10**	**1:20**	**1:25**	**1:50**	**1:100**
6013	Bronte Ck u/s Strabane Ck	36.500	2.900	3.760	4.320	4.820	4.970	5.450	5.900
2031	Strabane Creek Outlet	9.810	1.360	1.750	1.980	2.180	2.240	2.430	2.610
6031	Bronte Ck d/s Strabane Ck	46.310	4.220	5.460	6.230	6.930	7.130	7.810	8.430
6032	Bronte Ck u/s Mountsberg Ck	58.510	5.170	6.740	7.710	8.680	8.940	9.820	10.600
1050	Mountsberg Reservoir Inflow	37.100	1.720	2.180	2.460	2.720	2.790	3.020	3.220
5300	Mountsberg Reservoir	37.100	1.510	1.910	2.160	2.390	2.450	2.650	2.830
6080	Mountsberg Creek Outlet	57.700	8.980	11.700	13.600	15.500	16.000	18.000	19.800
2090	Bronte Ck at Carlisle	116.210	10.900	14.400	16.700	19.100	19.800	22.100	24.300

6100	Bronte Ck at Progreston	121.580	11.100	14.800	17.100	19.700	20.400	22.700	25.100
1120	Flamboro Ck Outlet	9.430	0.702	0.970	1.190	1.450	1.520	1.780	2.010
6120	Bronte Ck d/s Flamboro Ck	131.010	11.700	15.600	18.100	20.900	21.700	24.300	26.800
6165	Kilbride Creek Outlet	44.330	5.180	6.770	8.000	9.270	9.690	11.000	12.300
6160	Bronte Ck d/s Kilbride Ck	183.530	15.300	20.400	23.700	27.400	28.400	31.800	35.100
1180	Willoughby Creek	12.900	1.690	2.190	2.510	2.810	2.890	3.160	3.420
6180	Bronte Ck d/s Willoughby Ck	196.430	16.800	22.300	25.900	29.800	31.000	34.600	38.100
6222	Limestone Creek Outlet	40.000	10.200	13.000	14.800	16.300	16.700	18.100	19.500
6225	Bronte Ck d/s Limestone Ck	239.980	22.400	29.500	34.200	39.400	40.900	45.500	50.300
6240	Bronte Ck near Zimmerman	243.840	24.900	32.500	37.400	42.400	43.900	48.900	53.800
1260	Lowville Creek Outlet	9.100	2.830	3.660	4.220	4.730	4.870	5.340	5.770
6260	Bronte Ck d/s Lowville Ck	252.940	27.700	36.000	41.500	47.000	48.600	54.000	59.300
6302	Indian Ck outlet at Bronte	37.320	34.400	44.000	49.400	54.100	55.400	59.400	63.000
6310	Bronte Ck d/s Indian Creek	290.260	61.800	78.900	89.300	98.700	101.000	110.000	119.000
1320	Mount Nemo Creek outlet	4.790	2.230	2.890	3.340	3.770	3.890	4.290	4.640
6320	Bronte Ck d/s Mount Nemo Ck	296.390	64.800	82.800	93.800	104.000	107.000	116.000	125.000
1340	Bronte Subcatchment 1340	8.950	11.900	14.800	17.000	19.200	19.800	21.700	23.500
6340	Bronte Ck d/s Sub 1340	305.340	66.100	84.700	96.600	107.000	110.000	120.000	129.000
2360	Bronte Ck at QEW	305.340	65.100	83.700	95.400	106.000	109.000	118.000	128.000
2380	Bronte Ck at Lake Ontario	312.500	66.200	85.400	97.300	108.000	111.000	121.000	130.000

Table A 18 Summary of Flood Flow Estimates: Indian Creek Subwatershed Existing Conditions (Scenario 1)

No.	Point of Interest	Area km^2	Peak Flows (m^3/s) 1:2 yr	1:5	1:10	1:25	1:50	1:100	Reg 1.000
1281	W Indian Ck at Derry Rd	6.910	2.710	3.400	3.880	4.430	4.850	5.240	*17.100*
1282	W Indian Ck Catchment 1282	3.730	3.820	4.770	5.430	6.240	6.850	7.410	*19.400*
6282	W Indian Ck at Tremaine Rd	10.640	5.840	7.340	8.390	9.630	10.500	11.400	*34.400*
1283	Hydrograph 1283	3.420	1.500	1.890	2.160	2.470	2.700	2.920	9.210
6283	Hydrograph 6283	14.060	7.330	9.230	10.500	12.100	13.200	14.300	43.600
1284	Hydrograph 1284	3.720	5.290	6.580	7.460	8.530	9.360	10.100	23.800
6284	W Indian Ck at Britannia Rd	17.780	10.900	13.800	15.800	18.100	19.900	21.500	62.000
1285	W Indian Ck Catchment 1285	6.230	6.020	7.410	8.420	9.630	10.500	11.400	30.500
6285	W Indian Ck u/s East Indian	24.010	15.800	19.900	22.700	26.000	28.500	30.800	86.900
1291	E Indian Ck at Gartner Lee Gau	2.430	1.560	1.930	2.200	2.500	2.730	2.940	8.730
1292	E Indian Ck Catchment 1292	1.420	1.550	1.930	2.190	2.510	2.750	2.970	7.690
6292	E Indian Ck at CNR Culvert	3.850	2.970	3.690	4.210	4.800	5.250	5.670	16.000
1293	Hydrograph 1293	0.940	1.180	1.450	1.640	1.870	2.040	2.200	5.400
6293	E Indian Ck u/s West Indian	4.790	4.020	5.000	5.690	6.490	7.100	7.650	20.900
6294	Indian Ck d/s Confluence	28.800	19.400	24.400	27.900	32.000	35.100	37.900	107.000
6302	Indian Ck outlet at Bronte	37.320	25.200	31.800	36.300	41.700	45.800	49.400	137.000

Table A 19 Summary of Flood Flow Estimates: Indian Creek Subwatershed Study Post-Development Future 1 (Scenario 2)

No.	Point of Interest	Area km^2	Peak Flows (m^3/s) 1:2 yr	1:5	1:10	1:25	1:50	1:100	Reg 1.000
1281	W Indian Ck at Derry Rd	6.910	2.980	3.670	4.150	4.700	5.110	5.500	17.300
1282	W Indian Ck Catchment 1282	3.730	3.860	4.800	5.470	6.280	6.890	7.450	19.400
6282	W Indian Ck at Tremaine Rd	10.640	6.140	7.650	8.690	9.930	10.800	11.700	34.500
1283	Hydrograph 1283	3.420	1.500	1.890	2.160	2.470	2.700	2.920	9.210
6283	Hydrograph 6283	14.060	7.640	9.530	10.800	12.400	13.500	14.600	43.700
1284	Hydrograph 1284	3.720	5.290	6.580	7.460	8.530	9.360	10.100	23.800
6284	W Indian Ck at Britannia Rd	17.780	11.200	14.100	16.100	18.400	20.200	21.800	62.200
1285	W Indian Ck Catchment 1285	6.230	6.410	7.800	8.800	10.000	10.900	11.700	30.700
6285	W Indian Ck u/s East Indian	24.010	16.300	20.400	23.300	26.600	29.100	31.400	87.100
1291	E Indian Ck at Gartner Lee Gau	2.430	44.900	51.900	56.700	62.300	66.800	70.700	35.600
1292	E Indian Ck Catchment 1292	1.420	24.400	28.700	31.700	35.200	38.100	40.500	20.700
6292	E Indian Ck at CNR Culvert	3.850	38.600	45.000	49.400	54.500	58.600	62.200	53.300
1293	Hydrograph 1293	0.940	1.180	1.450	1.640	1.870	2.040	2.200	5.400
6293	E Indian Ck u/s West Indian	4.790	34.200	40.400	44.600	49.400	53.200	56.600	55.800
6294	Indian Ck d/s Confluence	28.800	40.900	48.800	54.300	60.700	65.700	70.200	123.000
6302	Indian Ck outlet at Bronte	37.320	35.700	43.700	49.300	55.900	60.600	65.300	159.000

Table A 20 Summary of Flood Flow Estimates: Indian Creek Subwatershed Study Post-Development Future 2 (Scenario 3)

Area No.	Peak Flows (m^3/s) Point of Interest	km^2	1:2 yr	1:5	1:10	1:25	1:50	1:100	Reg 1.000
5281	W Indian Ck at Derry Rd	6.910	2.730	3.410	3.870	4.410	4.810	5.210	17.200
1282	W Indian Ck Catchment 1282	3.730	3.860	4.800	5.470	6.280	6.890	7.450	19.400
6282	W Indian Ck at Tremaine Rd	10.640	4.430	5.790	6.690	7.740	8.590	9.300	34.100
1283	Hydrograph 1283	3.420	1.500	1.890	2.160	2.470	2.700	2.920	9.210
6283	Hydrograph 6283	14.060	5.700	7.440	8.600	9.970	11.000	12.000	43.300
1284	Hydrograph 1284	3.720	5.290	6.580	7.460	8.530	9.360	10.100	23.800
6284	W Indian Ck at Britannia Rd	17.780	9.610	12.100	13.700	15.800	17.300	18.700	61.500
1285	W Indian Ck Catchment 1285	6.230	6.030	7.440	8.470	9.680	10.400	11.300	30.100
6285	W Indian Ck u/s East Indian	24.010	15.000	18.900	21.500	24.500	27.100	29.000	87.700
1291	E Indian Ck at Gartner Lee Gau	2.430	1.570	1.940	2.220	2.510	2.740	2.950	13.100
1292	E Indian Ck Catchment 1292	1.420	1.560	1.940	2.200	2.520	2.760	2.980	9.040

6292	E Indian Ck at CNR Culvert	3.850	2.970	3.740	4.270	4.860	5.320	5.740	21.600
1293	Hydrograph 1293	0.940	1.180	1.450	1.640	1.870	2.040	2.200	5.400
6293	E Indian Ck u/s West Indian	4.790	4.040	5.070	5.780	6.580	7.190	7.760	26.600
6294	Indian Ck d/s Confluence	28.800	18.800	23.700	27.000	30.800	33.900	36.400	113.000
6302	Indian Ck outlet at Bronte	37.320	24.600	31.200	35.600	40.700	44.900	48.400	143.000

4.4 Comparison of Flood Flow Estimates: Results and Discussion

The 'reasonableness' or credibility of the flood flows generated in this study for existing conditions was established by comparing them with previous estimates (e.g. Triton, 1991; Moin and Shaw, 1985; 1986) and regional analyses for selected points of interest. To this end, **Tables A 21** and **A 22** give various flood flow estimates for the area. The steps taken to produce these flows are summarized below.

1. Return period flood flows, 2 to 100 year, for the Carlisle and Zimmerman gauges were established by frequency analysis in Section 4.3 of the Appendix A and presented in **Table A 11**.

2. Return period flood flows generated through computer application of a specified storm pattern and rainfall volumes calibrated to the frequency flows are explained in Section 3 of the report, and listed in **Table A 14** for existing conditions.

3. For comparison with Steps 1, and 2, additional estimates were obtained as follows:

   A. Previous studies: Crysler and Latham (1979) produced flood flow estimates resulting from the application return period events for Indian Creek. In a similar manner, Proctor and Redfern (1986) supplied flood flow estimates for selected location within the Bronte Creek watershed for floodline mapping purposes.

   B. Index Flood Method: Moin and Shaw (1986) developed regional flood flow estimates based on regression analyses of observed index floods (e.g. 2 year) for the whole province. For their Region 7, which contains the Bronte Creek watershed, the index flood is computed as:

   [3.3.1] $Q_2 = C\ (\text{drainage area})^N$

   where Q_2 is the index flood (in m^3/s), the drainage area is in km^2, C=0.40 and N=0.696. For Region 7, the mean C value was found to be 1.13, with a minimum of 0.40 (as shown earlier), and a maximum of 1.61. The remaining return period flood flows (5 through 100 year) are taken as ratios of the Index Flood. The applicable ratios for Region 7 are given below.

Index	Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}
Ratio	**1.00**	**1.32**	**1.58**	**1.82**	**2.15**	**2.41**

   C. Transfer of results from one site to another: Flows at one site where results of a frequency analysis are available can be transposed to another site using:

   [3.3.2] $Q_Y = Q_X\ (A_Y/A_X)^n$

   where Q_Y is the flow (in m^3/s) at site Y with drainage area (in km^2) A_Y, and Q_X and A_X are the corresponding quantities at site X, and n is an exponent (taken as n=0.696, from Step B above).

   For example, suppose Q_X represents the flows at the Zimmerman gauge (Hydrograph 6240, with area=243.8 km^2), and Q_Y denotes the flows in Bronte Creek immediately upstream of the Strabane Creek outlet (Hydrograph 6013, area=36.5 km^2). Now if the 100 year flow at the Zimmerman is 53.8 m^3/s, the corresponding estimated flow at hydrograph 6013 becomes

   [3.3.3] $Q_{100} = 53.8\ (36.5/243.8)^{0.696} = 14.3\ m^3/s$

   Results of the frequency analysis were 'indexed' or 'transposed' for to other parts of Bronte Creek in the same manner for each point of interest listed in **Table A 14**. The SSFA results for the Carlisle and Zimmer gauges were used directly in **Tables A 21** and **A 22**.

D. Continuous Simulation Generated Peak Flows: In the previous section , we discussed the application of the hydrologic model to a 39 year meteorological data sequence for each scenario in the Bronte Creek watershed. This exercise is required for assessing the long-term water balance and predicting low flows in the study watershed. From this application, it is possible to obtain return period flood flows estimates by conducting frequency analyses on the generated annual maximum flow series. The 2 and 100 year flows estimated using the continuous simulation approach for existing conditions at each location are also given in **Tables A 21** and **A 22**. The noted 2 and 100 year flood flows were obtained by fitting a LN3P distribution (moments fit) to the series of generated annual maximum flows.

Comparative estimates for the 2 year flow are given in **Table A 21** and **A 22** for the 100 year flow. From a brief glance at these Tables, one can see that there is acceptable agreement (less than ±15%) for many of the flows, particularly at the three long-term gauge locations (e.g. Carlisle, Progreston, Zimmerman). For the 2 and 100 year flood flow estimates, this is expected because the method involved was 'calibrated' or adjusted to match the value computed from single station frequency analyses (SSFA). The computed flows for the two Index Methods are inconsistent, where it is really a hit or miss situation, that is some agree and some don't. But in other places (e.g. West Branch Indian Creek, Hydrograph 6285), the disparities are higher than 70%. In general, the greatest discrepancies occur when the results of the present study are compared with the 1986 FDRP study prepared by Proctor & Redfern. At the Zimmerman gauge, the 100 year flow from the FDRP study is more than 3 times higher than the value produced in the present study, but the 2 year value differs by less than 20%. For the 100 year flows, the agreement between the two studies are closer for the upper parts of the watershed (e.g., at Progreston), but widens as the comparisons move downstream.

According to Watt and Paine (1992), describing uncertainty considerations in flood risk mapping, some of these discrepancies are not surprising. Watt and Paine suggest that hydrologic uncertainty for the 1:100 year flood estimates using single station frequency analyses or calibrated watershed models are about 25 to 40%. Using an uncalibrated model, this range of uncertainties widens to 50%. Therefore, it is likely that variations less than the normal or typical uncertainty may be difficult to explain, because they proceed as a natural consequence of accepted practice in available methodology. Nevertheless, where the differences are much higher than the normal uncertainty, logical explanations may be possible. In this regard, any noted differences are primarily attributed to modelling approach used. The major differences between the event and continuous simulation modelling lies in the computational time step used. In the event modelling, a 15 minute time step is used, whereas a 60 minute step is used in the continuous simulation work. Because of differences in runoff intensity, this can easily result in peak flow differences greater than 10 to 25%. The fact the Proctor and Redfern 100 year flows at Zimmerman gauge are more than 3 times higher than those determined in the present study is still a mystery, because Proctor and Redfern had essentially the same length of streamflow records (more than 20 years) from which to do their SSFA. The disparities between the Index Flood Method and other estimates is likely because the Index Flood formula developed for this region used flow data from watersheds dominated by open fields and clay-type soils. The general soil types in Bronte Creek are more pervious than this.

In addition, we offer the following comments on the differences between the results of this study and other methodologies:

1. Previous HYMO modelling did not include any calibration.

2. In the FDRP study, return period flood flows estimates were not checked against an Index Flood Method.

3. The FDRP study stated that there was 'insufficient' streamflow data to do any model calibration work. However, a frequency analysis with the available Zimmerman data could have been completed assuming that they would have only the 1964 to 1983 (perhaps to 1984) data available. Nineteen or twenty peak flow values could have been used in a single

station frequency analysis. A frequency analysis using the 1964 to 1983 data (19 values), results in a 100-year flow of 40.4 m^3/s at the Zimmerman gauge. The FDRP study computed a 100-year flow at the Zimmerman gauge of 105 m^3/s, which is 2.6 times higher than the one developed in the frequency analysis.

4. The current study results and the FDRP study would be in better agreement if the 100-year values (in **Table A 14**) were adjusted by the factor calculator above in Item 3.

5. In the new model, only 4% of the Bronte Creek watershed has hummocky topography. The Hummocky topography influence on peak flows is exactly the same as removing drainage area from the computations. Therefore, if you reduce the drainage area by about 10%, you'll reduce the peakflow by 10%.

In general, there is enough agreement between the different methods to 'bound' the actual results, which suggests that the formulated model predicts flood flows in the Bronte Creek watershed reasonably well.

Table A 21 Comparison of Flood Flow estimates for the Study Area: 2 Year Flow

No.	Location	Drainage Area (km^2)	This Study Event Model	This Study Cont. Model	This Study SSFA	Other Studies *	Index# Flood Method Region 7	Indexed This Study
6013	Bronte Creek u/s Strabane Creek	36.5	2.90	2.39			4.89	6.66
2031	Strabane Creek outlet	29.9	2.05	0.950			4.26	5.80
6032	Bronte Creek u/s Mountsberg Ck	58.5	5.17	4.15			6.79	9.25
1050	Mountsberg Reservoir Inflow	37.1	1.72	1.70			4.95	6.74
5300	Mountsberg Reservoir Outflow	37.1	1.51	1.37				
6080	Mountsberg Creek outlet	57.7	8.98	5.27			6.73	9.16
2090	Bronte Creek at Carlisle	116.2	10.9	7.95	10.2		11.0	14.9
6100	Bronte Creek at Progreston	121.6	11.1	8.34			11.3	15.4
1120	Flamboro Creek Outlet	9.43	0.702	0.540			1.91	2.60
6165	Kilbride Creek Outlet	44.3	5.18	3.48			5.60	7.63
6160	Bronte Creek d/s Kilbride Creek	183.5	15.3	11.9			15.1	20.5
6222	Limestone Creek Outlet	40.0	10.2	6.01			5.21	7.11
6240	Bronte Creek near Zimmerman	243.8	24.9	18.4	25.0		18.3	25.0
6285	West Branch Indian Creek Outlet	24.0	15.8	9.14		8.19	3.65	4.98
6293	East Branch Indian Creek Outlet	4.79	4.02	2.43		1.14	1.19	1.62
6302	Indian Creek Outlet at Bronte Ck	37.3	25.2	14.0		13.0	4.97	6.77
6310	Bronte Creek d/s Indian Creek	290.3	55.3	33.3			20.71	28.2
2380	Bronte Creek at Lake Ontario	312.5	60.2	35.9			21.8	29.7

Notes:*Denotes the 1986 FDRP Study by Proctor & Redfern Ltd, and 1979 Indian Creek Study by Crysler & Lathem Ltd.
Index Flood Method of Moin and Shaw (1985, 1986) Region 7
SSFA Single Station Frequency Analysis

Table A 22 Comparison of Flood Flow estimates for the Study Area: 100 Year Flow								
No.	**Location**	**Drainage Area (km^2)**	**This Study Event Model**	**This Study Cont Model**	**This Study SSFA**	**Other Studies ***	**Index# Flood Method Region 7**	**Indexed This Study**
6013	Bronte Creek u/s Strabane Creek	36.5	5.90	4.99			11.8	14.3
2031	Strabane Creek outlet	29.9	4.12	4.87			10.3	12.5
6032	Bronte Creek u/s Mountsberg Ck	58.5	10.6	8.64			16.4	19.9
1050	Mountsberg Reservoir Inflow	37.1	3.22	3.25			11.9	14.5
5300	Mountsberg Reservoir Outflow	37.1	2.83	3.08				
6080	Mountsberg Creek outlet	57.7	19.8	15.7			16.2	19.7
2090	Bronte Creek at Carlisle	116.2	24.3	20.5	22.7		26.4	32.1
6100	Bronte Creek at Progreston	121.6	25.1	21.4			27.2	33.1
1120	Flamboro Creek Outlet	9.43	2.01	1.85			4.6	5.59
6165	Kilbride Creek Outlet	44.3	12.3	9.91			13.5	16.4
6160	Bronte Creek d/s Kilbride Creek	183.5	35.1	30.3			36.3	44.1
6222	Limestone Creek Outlet	40.0	19.5	14.2			12.6	15.3
6240	Bronte Creek near Zimmerman	243.8	53.8	45.8	53.8		44.2	53.8
6285	West Branch Indian Creek Outlet	24.0	30.8	22.9		33.7	8.81	10.7
6293	East Branch Indian Creek Outlet	4.79	7.65	5.95		5.10	2.87	3.48
6302	Indian Creek Outlet at Bronte Ck	37.3	49.4	34.5		55.0	12.0	14.6
6310	Bronte Creek d/s Indian Creek	290.3	112	80.8			49.9	60.7
2380	Bronte Creek at Lake Ontario	312.5	123	85.9			52.5	63.9

Notes:*Denotes the 1986 FDRP Study by Proctor & Redfern Ltd, and 1979 Indian Creek Study by Crysler & Lathem Ltd.
Index Flood Method of Moin and Shaw (1985, 1986) Region 7
SSFA Single Station Frequency Analysis

APPENDIX B

FLUVIAL GEOMORPHOLOGY

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APPENDIX B1

SITE DESCRIPTION AND ROSGEN CLASSIFICATION

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Table B1 - Bronte Creek Morphology Assessment Site Descriptions and Rosgen Classification

Site Location	Characteristic Description	Rosgen Class
Bronte 1	This site represents the lowest measured point within the Bronte Creek Watershed. It is located just down the slope from the Bronte Creek Provincial Park Maintenance Yard just prior to a bend in the river. Site one is a riffle within the pool riffle sequence with bank heights ranging from 0.16 metres to 0.23 metres and with bank angles from 6^{0} to 20^{0}. On the outside bend there is considerable erosion on the banks, resulting in fallen trees. The inside bank is exhibiting very little erosion.	F3
Bronte 2	Site 2 is nested within a floodplain that is dominated by grasses just upstream of the bridge and the brick factory on Dundas Street. Banks at this site range in height from 0.24 metres to 0.38 metres with bank angles in the vicinity of 17^{0} to 30^{0}. The down-left bank is undergoing considerable erosion with the observed stretch being approximately 60% eroded. The down-right bank is more stable but still experiencing roughly 10% erosion through the loss of its silt layer.	F4
Bronte 3	The most distinguishing feature of site three is the extreme meander. It is located on the point of an abnormally long meander bend just down from highway 407. The down-left bank is 0.22 metres tall while the down-right bank was not measurable due to its height. The down-right bend consists of the original shale and bedrock of the area while the down-left is made up of cobbles.	F1
Bronte 4	Site 4 is immediately after the input of Mount Nemo by the scout camp. The down-left of this site is dominated by grasses while the down-right is near void of vegetation. The vegetation on the down-left is growing right in to the channel resulting in a relatively stable bank with a height of 0.65 metres and an angle of 30^{0}. The down-right is subject to more failure, approximately 60 % of the observed section was eroding. The down-right is more in the vicinity of 15 metres high with an angle of 35^{0}.	F3
Bronte 5	Site 5 is located off of Appleby Line accessed through the Latvian Children's Camp, downstream of Indian Creek. Site 5's floodplain is dominated by grasses that grow right down in to the water. The banks in this area are ranging in height from 0.325 metres to 0.48 metres with bank angles ranging from 12^{0} to 20^{0}. Less than 15 % erosion was observed at this site, most of which was on the down-right. The down-left exhibited very little erosion.	F4
Bronte 6	Site 6 is located before a riffle downstream of Lowville Creek's mouth within a fish sanctuary. At this point the floodplain is dominated by shrubs that are growing down to the water. The down-left bank is experiencing considerable erosion of approximately 35 % with a height of 0.58 metres and an angle upwards of 65^{0}. The down-right bank is slightly more stable, roughly 25 % eroded with a bank height of 0.306 metres and a more shallow angle of 12^{0}.	F5
Bronte 7	This site is located just downstream of the 4^{th} Line Sideroad bridge. Grasses that are able to grow down in to the water dominate this site. The down-left bank has a shallow angle of 12^{0} with a height of 0.225 metres. The down-right bank's angle is closer to that of 90^{0} with a height of 0.46 metres and is exhibiting undercutting. The undercutting is 0.08 metres deep with a height of 0.15 metres.	F4
Bronte 8	Site 8 is located off of 4^{th} line side road accessed through the Campbell farm. It is situated just below the mouth of Limestone Creek. The floodplain is a large pastor made of grasses that is actively used for livestock. The down-left bank is experiencing undercutting of depth 0.26 metres with a height of 0.27 metres. The bank itself is 0.845 metres high with an angle of 43^{0}. The down-right bank is experiencing roughly 15 % erosion with a height of 0.57 metres and a bank angle of 15^{0}.	A

Site Location	Characteristic Description	Rosgen Class
Bronte 9	This site is situated within a park just downstream of Guelph Line, just after a smaller bridge accessing a house on a hill. The floodplain is made up of grasses that are securing the banks to the point that no erosion was visible. The banks range in height from 0.646 metres to 0.451 metres with bank angles of 22^0.	F4
Bronte 10	This site is within the Cedar Springs Community off of Cedar Springs Road. Site 10 is upstream of a swimming hole dam, at the time of the measurement the dam was wide open and no pool was formed. The floodplain is a mix between the park on the down-left being grasses and the bank leading up to the road on the down-right being trees. The down-left bank had a height of 1.19 metres with an angle of 15^0. The down-right bank was closer to 4 metres with an angle of 20^0. Only the down-left bank exhibited erosion, which was around 20 %.	F3
Bronte 11	This site is situated between the Cedar Springs Road bridge and a dam further upstream where Kilbride Creek enters Bronte. The vegetation is primarily grasses with scrub growing in to the water. The banks range in height from 0.17 metres to 0.21 metres with angles ranging from 20^0 to 30^0. Very little erosion is evident due to the cobble banks secured further by an established root system.	F5
Bronte 12	Site 12 is located just down from the mouth of Flamborough Creek. This area of the channel has sections of channel that cut off and rejoin downstream further. The down-left of the channel is sheltered by deadfall leaving a bank that is 0.224 metres high and on an angle of 49^0. The down-right bank is 0.421 metres high with an angle of 52^0. The down-right is exhibiting slow erosion shown by the sloping trees.	F3
Bronte 13	Site 13 is located within the city of Carlisle downstream of Center Avenue just after a footbridge. The floodplain consists of shrubs but mainly grasses. On the down-left the bank is angled at 85^0 with a height of 0.58 metres. The down-right bank is shallower at 30^0 with a height of 0.48 metres. Neither bank is exhibiting much erosion, less than 5 %. There is some scouring out of the bank behind the bridge footings but very little.	F5
Bronte 14	Site 14 is inside of Courtcliffe Park downstream of both Mountsberg Creek mouths. The floodplain is primarily grasses with trees on the down-left. Neither bank is exhibiting any significant erosion. The down-right bank has a height of 0.435 metres with an angle of 45^0. The down left bank is higher at 0.70 metres with an angle of 30^0.	B4
Bronte 15	This site is just after Strabane Creek enters in to the main channel of Bronte Creek, north of Strabane Road. Smaller shrubs and trees dominate the area. The down-left bank is very gradual with an angle of 8^0 and a height of 0.164 metres. The down-right is steeper at an angle of 57^0 and 0.41 metres high. Very little erosion was observed but arced trees indicate a slow retreat of the banks as well as the presence of exposed roots.	G5
Bronte 16	This site is downstream of a minor tributary input as well as within an odd shaped meander sequence downstream of 11th concession east off of Hwy 6. Ferns dominate the floodplain. The bank on the down-right is 0.418 metres high with an angle of 26^0. On the down-left the bank is 0.288 metres high with an angle of 14^0. The only erosion observed was over an area of 15 % where no shrubs are present to slow the flow. At these points the bank is slowly retreating.	F3
Bronte 17	This site is located upstream of 11th concession off of Hwy 6 within a marsh land. The banks as well as the bed are extremely silty making moving in this area extremely difficult. The banks are quite low ranging in height from 0.108 metres to 0.253 metres. On the down-right there is undercutting with a depth of 0.17 metres and a height of 0.26 metres. At the time of measurement the undercutting was completely underwater.	A6

Site Location	Characteristic Description	Rosgen Class

Indian 1	This site is at the mouth of Indian Creek accessed through a Children's Latvian Camp off of Appleby Line. The floodplain is dominated by deciduous forest. The down-left bank has a height of 1.19 metres with undercutting that is 0.81 metres deep and 0.85 metres high. On this bank trees are growing straight out showing rapid erosion. The downright bank is 0.25 metres high with an angle of 22° and well vegetated.	F4
Indian 2	This site is on the property of the Children's Camp off of Appleby Line just after Indian Creek's first tributary input. The superintendent's house located roughly 150 metres from this site experiences flooding in its basement regularly during high flow and is a concern to the landowner. The down-right bank has a height of 0.23 metres with an angle pushing 90°. This bank is made up of parent material that is slowly being undercut. The down-left bank is 0.38 metres high with undercutting that is 0.12 metres deep and 0.22 metres high.	G3
Indian 3	This site is just upstream of Bell School Lane. At the time of study this site was without water. Downstream of this site at the road the channel cuts through two culverts roughly 3.5 metres tall. The down-right bank is highly vegetated with a height of 0.30 metres and an angle of 51°. The down-left bank is exposed parent material with a height of 1.5 metres and an angle of 41 °. There is approximately 20% erosion on the down-left.	G1
Indian 4	This site is accessed through a farm off of Tremaine Road just up stream of an extremely sharp meander. This area is predominantly grasses around the channel. The only obvious erosion shows up on the down-left bank which is in the form of toppled trees and undercutting which is just up from the measured site that is 0.55 metres deep and 1.06 metres high. This bank is 0.437 metres high with an angle of 20°.	F4
Indian 5	This site is within the same cow farm as site 4 off of Tremaine Road. Pastor dominates the entire area. The bank heights are 0.45 metres for the down-left and 0.64 metres for the down-right. The bank angles tend to be around 90° or greater as many sections of the banks are actually tumbling in to the channel.	G4
Indian 6	This site is on the same farm as the previous two sites. This section of the creek appeared to be more heavily used by the cattle as depicted in the picture below. This results in further bank erosion as well as worn paths. The banks are 0.604 metres high on the down-left and 0.716 metres high on the down-right. The down-left bank is subject to undercutting that is 0.21 metres deep and 0.26 metres high. 90 % of the down-right bank is slumping.	G5
Indian 7	This site is located further north on Tremaine road from sites 4-6, just below the input of the second tributary recorded on Indian Creek. The flood plain is made up of primarily grass. Both banks had heights of 0.69 metres with angles around 90°. The down-left bank is subject to undercutting of depth 0.30 metres and a height of 0.31 metres.	F4
Indian 8	This site is just downstream of the third tributary recorded as entering Indian Creek, off of Tremaine Road. Site 8 is situated on a straight section of the channel that is just prior to where Indian Creek is forced to meander due to Tremaine Road. Here the down-left bank was found to be 0.235 metres high with the down-right being 0.575 metres high. As with the other sites in this section the banks were near 90°.	G4
Indian 9	This site is at the intersection of Bell School Lane and Britannia, downstream of the overpass. The vegetation here is thick and grows throughout the channel it self. The down-right bank has an angle of 25° while the down-left has an angle of 61°.	G4

Site Location	Characteristic Description	Rosgen Class
Indian 10	This site lies along a straightened section of the channel between Derry Road and Britannia. The banks are all well vegetated with woody shrubs and grasses. Bank angles are consistent from 51° on the down-right to 46° on the down-left. There is no obvious signs of erosion at this site.	B4

Site Location	Characteristic Description	Rosgen Class
Indian Tributary 1	This site is located on the first recorded tributary on Indian Creek. This site is located on the Children's Camp off of Appleby Line. The banks consist of mixed gravel deposits that seem active with signs of slumping. The banks are 0.25 metres high with angles of 30°. Above the bank on the down-right bankfull bank there is undercutting of 0.28 metres deep and 0.61 metres high. This channel continues on through a culvert then hits a point of unconsolidated gravel and is force to make a hard right before entering Bronte.	G4
Indian Tributary 2	This site is located at the mouth of the second recorded tributary entering Indian Creek. It passes through two culverts under Tremaine road and enters in to Indian Creek on a very gentle angle. The down-right bank is 0.847 metres high and exhibits undercutting of depth 0.27 metres and height 0.55 metres for the entire length of the bank. The down-left bank appears to be relatively stable and is 0.27 metres high.	B4
Indian Tributary 3	This tributary is the third to be recorded. It runs perfectly straight and enters Indian Creek at a 90° angle just up from Tremaine Road. The floodplain for this channel consists of a manicured lawn as well as a small orchard. The banks along this tributary are being subjected to undercutting but in a pattern that would indicate the channel is trying to assume a meandering form. The banks along this channel are 0.68 metres high.	B6
Limestone 1	This is the first site in Limestone Creek up from Bronte Creek. It is accessed through the Campbell Farm off of 4th side road. The floodplain around this site is an active pastor with paths cutting through the stream. The down-left bank is 0.43 metres high with undercutting which is 0.20 metres deep and 0.21 metres high. The down right bank is 0.58 metres high with undercutting which is 0.45 metres deep and 0.46 metres high.	G4
Limestone 2	This site is located upstream from the Campbell farm within a large valley which is dominated by open grass fields. Just down from the site is a sharp 90° turn in the channel. The down-right bank is 0.645 metres high with undercutting which is 0.10 metres deep and 0.285 metres high. The down-left bank is slumping and is 0.879 metres high.	B5
Limestone 3	This site is approximately 300 metres down from Britannia Road just after a small tributary input. The site is located on a large meander with the down-right bank on the outside edge. The down-right bank is 0.66 metres high with an angle close to 90°. This bank is subject to undercutting which is 0.26 metres deep and 0.49 metres high, as well as slumping. The down-left bank has a forming point bar and is 0.285 metres high with an angle of 15°.	G4
Limestone 4	This site was accessed from a house off of Walker's Line just up from Britannia. Site 5 is located within a farmer's field after a sharp diversion of the flow. Prior to the site there is a number of I-beams placed within the channel on angles. Above this site the trees are toppling in to the flow but at the site the banks are exhibiting no erosion.	A4
Limestone 5	This site is within a field that appears to be unused accessed through the same property off of Walker's Line as site 5. Upstream from this site on the same property is two ponds and one smaller tributary. The banks here are showing no signs of erosion with their 70° angles and heights ranging from 0.685 metres on the down-left to 0.651 metres on the down-right.	A4

Site Location	**Characteristic Description**	**Rosgen Class**
Limestone 6	Site 6 was accessed via a property that is beside where Limestone crosses under Derry Road. It is situated within an open grass field just down from a tributary input. The banks look quite stable except for a small area which has been trampled by wildlife accessing the creek. The down-right bank is the taller of the two with a height of 0.579 metres and an angle of 64°. The down-left bank is 0.248 metres high with an angle similar to that of the down-right.	A5
Limestone Tributary	This tributary is just upstream of site 6. It enters in to Limestone as Limestone is making a turn down to site 6. The floodplain around this site is low lying marsh land dominated by grasses. The banks along this stretch	F5

	appeared to be stable. The down-left bank has a height of 0.21 metres with an angle of 8° while the down-right bank is 0.487 metres high with an angle of 24°.	
Lowville 1	Site is located at the mouth of Lowville Creek off of 4th side road. Various sorts of trees dominate the area. Over the past couple years the landowner has planted close to 300 trees to try and "naturalize" the area. Bank heights are ranging from 0.31 on the down-right bank to 0.288 metres on the down-left bank. The only erosion that stood out was on the down-right where tree roots are exposed and the trees are arced.	A4
Lowville 2	This site is located on private property off of 4th side road. The floodplain is mainly shrubs with trees. Upstream from this location there is an apparatus that is assumed to be used to draw water for the use of the golf course. The bank on the down-right is 0.248 metres high with an angle of 32°. This bank is experiencing slight undercutting. The down-left bank is much lower at 0.05 metres and with an angle of 6°. Up from the banks on the down-right there is considerable slumping.	A4
Kilbride 1	This site is at the mouth of Kilbride Creek as it enters Bronte Creek. Where Kilbride enters in to Bronte is just upstream of a dam that is pooling Bronte Creek. The banks are ranging in height from 0.33 metres to 0.38 metres with angles ranging from 66° to 69°. Along the banks is exposed roots and toppling trees showing rapid erosion.	F4
Kilbride 2	This site is located upstream of Kilbride Street downstream of a small tributary. The area is dominated by ferns. Trees are indicating by their slope that there is rapid retreat of the banks. The down-left bank is 0.427 metres high with an angle of 40° while the down-right bank is 0.35 metres high with an angle of 22°.	A5
Kilbride 3	This site is located upstream of a 90° turn forced on Kilbride Creek by Derry Road. The landowner of this site is complaining of trees falling and increased erosion since construction in the summer of 2000 on Derry road which narrowed the down-right bank after the bend in the creek. The down-right bank at the measured site was 0.37 metres high with an angle of 76°. On this bank there is trees growing that are arced indicating a slow retreat. The down-left bank is 0.28 metres high with an angle of 26° adjacent to a manicured lawn.	A4
Kilbride 4	This site is located just downstream of a 90° bend in the main channel of Kilbride Creek. At this bend a tributary that is 7.2 kilometres long enters in to the main channel straight in to the turn. The banks along this section of the channel consist of large limestone boulders resulting in no bank erosion. The banks range in height from 0.422 metres on the down-left to 0.459 on the down-right.	A4
Kilbride 5	This site is prior to the input of the tributary and prior to the 90° bend in the main channel. There is very little sign of erosion. The banks consist of manicured lawn right up until the water. The down-left bank is 0.244 metres high with an angle of 38°. The down-right bank is 0.309 metres high with an angle of 40°. Upstream of the site there is a bridge used to access a house that has been fortified by large stones.	F4

Site Location	Characteristic Description	Rosgen Class
Mountsberg 1A	This site is representing the original channel of Mountsberg Creek which enters in to the Bronte within Courtcliffe Park. The floodplain's main component is grasses with some trees on either side of the channel. The down-left bank appears to be stable with a height of 0.77 metres and an angle of 38°. The down-right bank is 0.82 metres high and is exhibiting undercutting of depth 0.20 metres and 0.17 metres high.	A5
Mountsberg 1B	This site is representing the new channel of Mountsberg, which enters in to the Bronte downstream of where the original channel entered. The floodplain is much like that of MB1A where it is dominated by the grasses of the park. The down-right bank in this case is stable with its height of 0.537 metres and angle of 20°. The down-left bank is 0.714 metres high and is	A5

	experiencing undercutting, which is 0.14 metres deep and 0.20 metres high.	
Mountsberg 3	This site is upstream of 11th concession just after the input of a small tributary. This area is entirely marshland with pockets of vegetation and soil breaking up the floodplain. The down-right has no obvious height to it or angle, it is grass that distinguishes the channel. The down-left has a height of 0.244 metres. The bank consists of clumps of vegetation that are jutting and collapsing in to the main part of the channel.	A5
Mountsberg 4	This site is just below the dam that is creating the Mountsberg reservoir off of concession 14. The floodplain is managed by the conservation authority with manicured lawns and dogwoods lining the banks. There is little activity on the banks. The down-left bank is 0.073 metres high with an angle of 10°. The down-right bank is 0.17 metres high with an angle of 6°.	F4
Mt Nemo 1	This site is located off of 2nd side road via the scout camp. The site itself is located approximately 300 metres up from the mouth of Mount Nemo Creek at the end of a pool. Shrubs mainly dominate the area. Both banks have a height of 0.18 metres with angles ranging from 31° to 42°. There is exposed roots and suspended rocks providing evidence of erosion. Up from the flow at the time of measurement there is undercutting of the bankfull notch.	F4
Willoughby 1	This site is located at the mouth of Willoughby Creek down from a dam. Above the dam there is ponded water controlling the discharge on the lower reaches of Willoughby. The down-right bank is 0.09 metres high with an angle of 19°. The down-left bank is less defined, there is no difference between the channel bank and the bankfull bank resulting in a bank height of 0.824 metres and a bank angle of 68°. Erosion is evident through downed trees as well as trees that are arced.	A4
Flamborough 1	This site is accessed from a private quarry across from a Golf Course on Carlisle Road. Site 1 is situated right at the mouth of Flamborough Creek. This area is made up of primarily ferns and pines. Both banks are comparable at heights ranging from 0.354 metres to 0.355 metres and angles ranging from 64° to 70°. Slow erosion is evident from trees that have become arced as well as roots that have become exposed.	G4
Strabane 1	This site is located at the mouth of the Strabane Creek in close proximity to BC14 off of Strabane road. The floodplain is typical deciduous forest. Both banks have a height of 0.27 metres but the down-right bank has an angle of 45° while the down-left bank has an angle of 12°. There is slow erosion on both banks over approximately 15 % of the area.	G6

Appendix B2

General fluvial geomorphology concepts

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1.0 CHANNEL MAINTENANCE AND ALLUVIAL RIVER BEHAVIOUR

The concept of channel maintenance derives from an understanding of the behaviour 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 (i.e. locations where water taking occurs), 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 threshold streamflow is the minimum amount necessary to transport all of the bedload sediment through reaches where water taking has been realised. 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 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 threshold low flows will temporarily accumulate in the channels, higher flows, where claimed flows have not been realised or have minimal impact, 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 generalised 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 generalisation 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 armour 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 gravel-bed channels is composed of sand and fine gravel 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 coarse 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 armoured 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.

2.0 SEDIMENT MONITORING

Bed Material Transport: Alluvial river channels are dynamic, constantly changing to reach some form of equilibrium through erosion and deposition processes within the basin. Equilibrium may be reached if there are no new 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. Factors considered were 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.

Studies have concerned themselves with the amount of material that is actually moved by rivers. Middleton (1976) noted 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.

There have been a number of different theories regarding the movement of material over a river bed. 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 (1950) 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 concluded 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 and not simply fluid velocity determined the rate of transport, (a reaffirmation of the work of Laronne and Carson, 1976 and others). Kuhnle and Southard 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 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) postulated that transport rates are more dependent on whether or not the channel reaches in question are in equilibrium with the water flow. 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 and Church (1991) identified three 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 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 (ripple-marks) or so stable as to last for a considerable period of time (gravel bars). Since considerable work has been done in this area, this review will touch on those studies which 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 by creating resistance to movement due to armouring. These structures are offered as proof of movement of bed material. The presence of imbricated structures further proves the notion of bedload transport. Because imbricate structures are characterised 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.

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. 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 among the data points he used and the fact that different velocities will produce different results.

Numerous authors have looked into this problem since Hjulstrom. Nevin (1946) investigated the flows necessary to transport concrete blocks weighing 10,000 tons, a phenomenon caused by the failure of the St. Francis Dam in California. He determined that particle shape is important in the evaluation of flow competence. He also expanded on the idea of critical tractive force being a determinant of competency. Menard (1950) concurred, stating that the critical tractive force and critical tractive velocity are important parameters for the initiation of motion, and that they are applicable in both the laboratory and in the field. Lane and Carlson (1954) found in their study on the effect of particle shape on the movement of coarse sediments that, on average, disks are of the same susceptibility to movement as spheres 2.5 times their weight.

This introduced a new problem into the theories of flow competence. Menard was able to show that larger particles than were initially imagined would be able to be transported by rivers. In the past, it was assumed that larger particles were placed on the river bed by forces other than fluvial, for instance glacial. Krumbein and Lieblein (1956) were able to show, using extreme value theory, that a number of these particles were actually part of the local deposits, and that it is unnecessary to "call upon extraneous processes to account for their occurrence in the deposit".

Sundborg (1956) presented a refined competency diagram for fine sediments (<2 cm. diameter). Although his work correlated closely with Hjulstrom's, it was considered to be a starting rather than finishing point. Ljunggren and Sundborg (1968) noted that competency curves for uniform materials (such as Sundborg's 1956 curve) could not be used to determine stream competence when particles with different densities, shapes and sizes were present in the same deposit. The interaction between grains with different densities will be influential in the process, and the 'hiding effect' of larger particles is important in the process of sorting and enrichment.

Investigators started to question the use of velocity as the determining force that entrained particles, because of the fact that near-bed velocities approached zero and that the use of mean, surface or other velocities was not indicative of the actual processes at the bed. Novak (1973) attempted to draw a relationship between critical tractive force and mean velocity using a synthesis of published works in this area. In doing so, he was able to create a situation where either measurement could be used, and then related to other works that may have used either. Novak also plotted his results against the standard Hjulstrom curve, and noted that for coarse particle transport different velocities were required than would be predicted by the Hjulstrom curve. He found that a curve of mean velocity for overturning and a curve of bottom velocity for sliding defines a zone that predicts coarse sediment transport better than the Hjulstrom-type curves (including Sundborg, 1956).

Church and Gilbert (1975) suggested that a non-cohesive bed exists in three states: normal, where materials are resting in a non-dispersed state; overloose, where materials are resting in a dispersed 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 four times the fluctuation in lift and drag forces at the bed, allowing for particles up to four times in size to be moved than would be predicted (Church and Gilbert, 1975).

Baker and Ritter (1975) used mean shear stresses to predict competence. Bagnold (1977) suggested that hydraulic properties of the flow need to be determined through the measurement of hydraulic 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 important factors in competency. Bradley and Mears (1980) determined that macroturbulent or other flow conditions 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 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, 1986), 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., 1990).

For the purposes of evaluating velocities needed to carry bed material in this study, the work of Komar (1987) will be used. His attempt to formulate a competency relationship for coarse-grained sediments on a mixed bed was a synthesis of previous works, re-evaluated so that all calculations would be uniform between the studies. His resulting competent velocity,

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

where U_c = mean fluid velocity (cm $sec.^{-1}$) and D = particle diameter (cm) appears to be the best compilation of the variables needed to entrain bed material.

The introduction of sediment into an alluvial river channel, caused by either the failure of river banks, scouring of the bed due to either the introduction of a `foreign' object that alters flow or a rapid increase in fluid velocity from storm events, or by overland flow can affect the stability of the channel.

Sediment yields from watershed sources are continual over time, due to the constantly changing nature of watersheds under human influence (Anderson, 1957). Despite that statement, suspended sediment concentrations are directly dependent on such factors as the base flow level (longer periods between rainstorms generally mean that more sediment is available for transport: Wood, 1977; Ongley et al., 1981). There is also a distinct seasonal component to suspended sediment concentrations, being higher (50% of the annual load) in the spring during snowmelt and lower in the summer and winter (Dickenson and Scott, 1975), although there is some disagreement on this claim (Grimshaw and Lewin, 1980).

Suspended Sediment Transport: Suspended sediment concentrations, by nature of the fact that they vary considerably over time, are difficult to extrapolate over a stream for a period of time. Because of these problems, suspended sediment rating curves have been developed to estimate suspended sediment loads from small to medium catchments (Walling, 1977). There is still a great deal of error involved in the use of these curves, and one should be careful not to use the information contained within them blindly (Walling, 1977).

Verhoff and Melfi (1978) and Verhoff et al. (1979) studied the movement of suspended sediment through a system. They found that suspended sediment moves through the system in a series of discrete steps of deposition and resuspension, rather than moving through completely in one event. This means that there is some storage of sediment within the channel at different periods of the flow, an important implication for use of the channel by fish.

Novotny (1980) suggests that the storage of sediment in the channel is of little significance due to the fact that suspended sediment only deposits under very low flow conditions or in impoundments. Lambert and Walling (1988) found that under periods of base flow and at the tail end of storm hydrographs, fine sediments settle from suspension onto the bed surface forming deposits 5-10mm thick. Depending on the proximity to flow of that layer, it may be resuspended or it may remain, where it is added to under the next depositional condition.

3.0 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 localised 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.

4.0 USING SHEAR STRESS AS AN INDICATOR OF SEDIMENT TRANSPORT POTENTIAL

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 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 analyse 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.

Appendix B3

Site summary sheets

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LANDSCAPE
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Bronte Creek

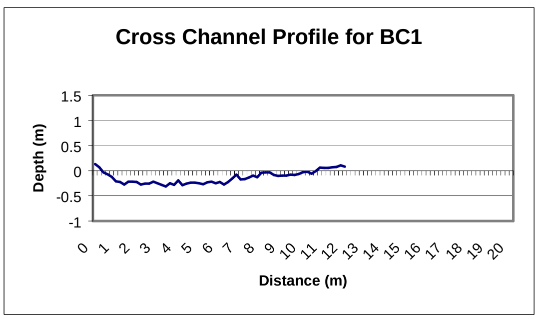
Site 1

Site Characteristics:

This site represents the lowest measured point within the Bronte Creek Watershed. It is located just down the slope from the Bronte Creek Provincial Park Maintenance Yard just prior to a bend in the river. Site one is a riffle within the pool riffle sequence with bank heights ranging from 0.16 metres to 0.23 metres and with bank angles from 6^0 to 20^0. On the outside bend there is considerable erosion on the banks, resulting in fallen trees. The inside bank is exhibiting very little erosion.

Width:	10.2 m	Top of Bank Width: 10.58 m
Mean Depth:	0.17 m	Bankfull Width: 10.58 m
Mean Velocity:	1.074 m/s	Bankfull Depth: 0.37 m
Discharge:	1.86 m^3/s	Torvane: 0.09 kg/cm^2
D_{50}:	20.25 mm	

Channel Profile: Grain Size Curve:



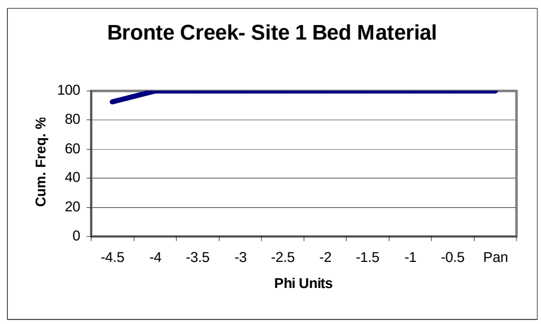


Photo Looking Downstream:

Bronte Creek

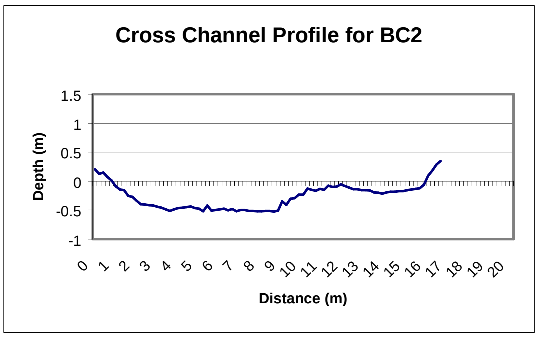
Site 2

Site Characteristics:

Site 2 is nested within a floodplain that is dominated by grasses just upstream of the bridge and the brick factory on Dundas Street. Banks at this site range in height from 0.24 metres to 0.38 metres with bank angles in the vicinity of 17^0 to 30^0. The down-left bank is undergoing considerable erosion with the observed stretch being approximately 60% eroded. The down-right bank is more stable but still experiencing roughly 10% erosion through the loss of its silt layer.

Width:	15.05 m	Top of Bank Width:	16.01m
Mean Depth:	0.31 m	Bankfull Width:	16.01 m
Mean Velocity:	0.41 m/s	Bankfull Depth:	0.67 m
Discharge:	1.91 m^3/s	Torvane:	0.28 kg/cm^2
D_{50}:	12.25 mm	Pavement:	>20.25 mm

Channel Profile: Grain Size Curve:



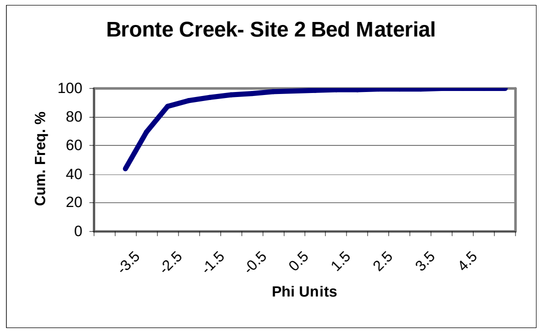


Photo Looking Downstream:

Bronte Creek

Site 3

Site Characteristics:

The most distinguishing feature of site three is the extreme meander. It is located on the point of an abnormally long meander bend just down from highway 407. The down-left bank is 0.22 metres tall while the down-right bank was not measurable due to its height. The down-right bend consists of the original shale and bedrock of the area while the down-left is made up of cobbles.

Width:	10.6 m	Top of Bank Width:	11.83 m
Mean Depth:	0.19 m	Bankfull Width:	11.83 m
Mean Velocity:	0.68 m/s	Bankfull Depth:	0.48 m
Discharge:	1.37 m^3/s	Torvane: DR	Shale
D_{50}:	Bedrock	DL	Cobble

Channel Profile: Grain Size Curve:

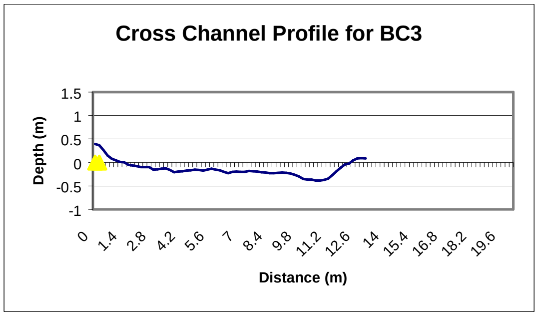


Photo Looking Downstream:

Bronte Creek

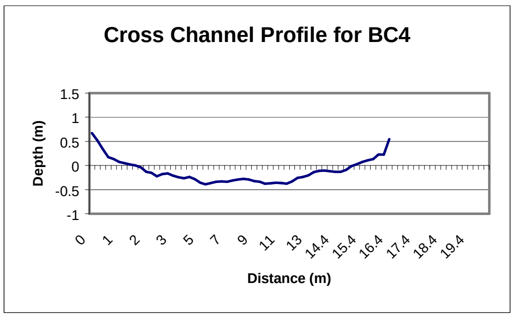
Site 4

Site Characteristics:

Site 4 is immediately after the input of Mount Nemo by the scout camp. The down-left of this site is dominated by grasses while the down-right is near void of vegetation. The vegetation on the down-left is growing right in to the channel resulting in a relatively stable bank with a height of 0.65 metres and an angle of 30^0. The down-right is subject to more failure, approximately 60 % of the observed section was eroding. The down-right is more in the vicinity of 15 metres high with an angle of 35^0.

Width:	13.2 m	Top of Bank Width:	15.31 m
Mean Depth:	0.24 m	Bankfull Width:	15.31 m
Mean Velocity:	0.47 m/s	Bankfull Depth:	0.57 m
Discharge:	1.49 m^3/s	Torvane:	0.6 kg/cm^2
D_{50}:	12.25 mm	Pavement:	> 20.25 mm

Channel Profile:



Grain Size Curve:

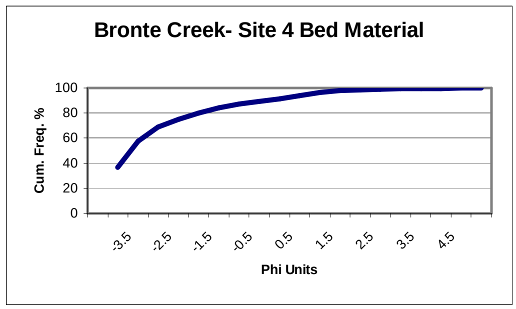


Photo Looking Downstream:

Bronte Creek

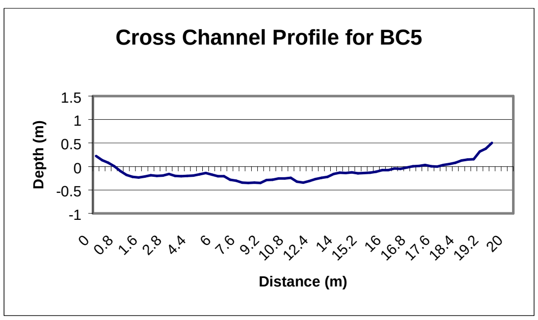
Site 5

Site Characteristics:

Site 5 is located off of Appleby Line accessed through the Latvian Children's Camp, downstream of Indian Creek. Site 5's floodplain is dominated by grasses that grow right down in to the water. The banks in this area are ranging in height from 0.325 metres to 0.48 metres with bank angles ranging from 12^0 to 20^0. Less than 15 % erosion was observed at this site, most of which was on the down-right. The down-left exhibited very little erosion.

Width:	15.8 m	Top of Bank Width:	18.65 m
Mean Depth:	0.20 m	Bankfull Width:	18.65 m
Mean Velocity:	0.38 m/s	Bankfull Depth:	0.51 m
Discharge:	1.20 m^3/s	Torvane:	0.29 kg/cm^2
D_{50}:	9.00 mm	Pavement:	> 12.25 mm

Channel Profile: Grain Size Curve:



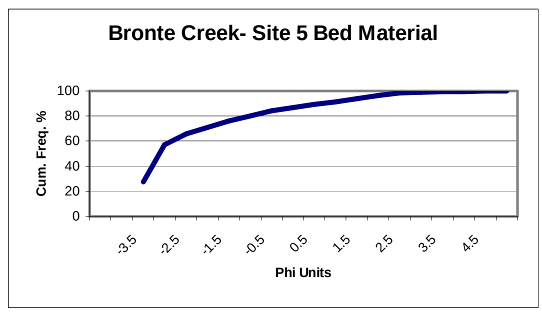


Photo Looking Downstream:

Bronte Creek

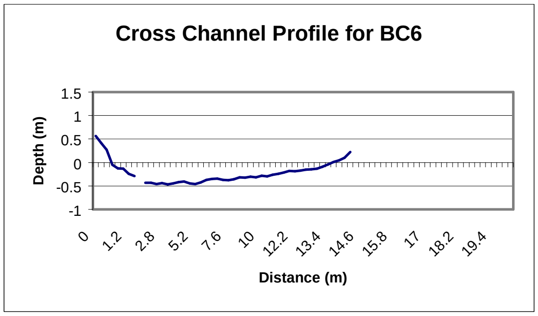
Site 6

Site Characteristics:

Site 6 is located before a riffle downstream of Lowville Creek's mouth within a fish sanctuary. At this point the floodplain is dominated by shrubs that are growing down to the water. The down-left bank is experiencing considerable erosion of approximately 35 % with a height of 0.58 metres and an angle upwards of 65^0. The down-right bank is slightly more stable, roughly 25 % eroded with a bank height of 0.306 metres and a more shallow angle of 12^0.

Width:	11.8 m	Top of Bank Width:	13.77 m
Mean Depth:	0.30 m	Bankfull Width:	13.77 m
Mean Velocity:	0.30 m/s	Bankfull Depth:	0.69 m
Discharge:	1.06 m^3/s	Torvane:	0.45 kg/cm^2
D_{50}:	0.71 mm	Pavement:	> 16.00 mm

Channel Profile:



Grain Size Curve:

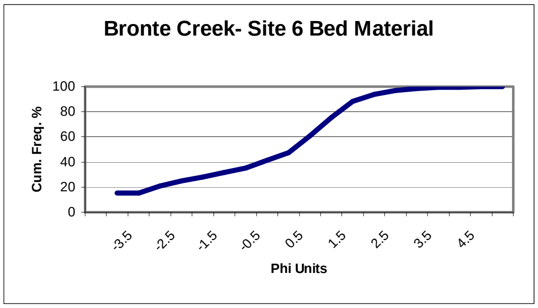


Photo Looking Downstream:

Bronte Creek

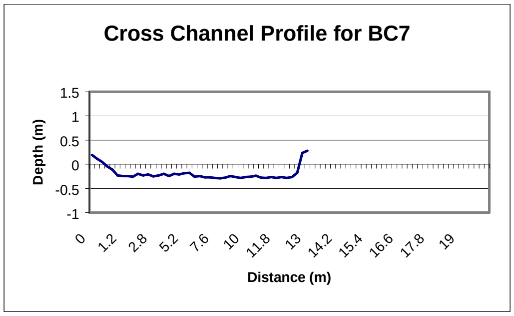
Site 7

Site Characteristics:

This site is located just downstream of the 4th Line Sideroad bridge. Grasses that are able to grow down in to the water dominate this site. The down-left bank has a shallow angle of 12^0 with a height of 0.225 metres. The down-right bank's angle is closer to that of 90^0 with a height of 0.46 metres and is exhibiting undercutting. The undercutting is 0.08 metres deep with a height of 0.15 metres.

Width:	12.0 m	Top of Bank Width:	12.78 m
Mean Depth:	0.24 m	Bankfull Width:	12.78 m
Mean Velocity:	0.41 m/s	Bankfull Depth:	0.48 m
Discharge:	1.18 m^3/s	Torvane:	0.28 kg/cm^2
D_{50}:	16.00 mm	Pavement:	> 16.00 mm

Channel Profile: Grain Size Curve:



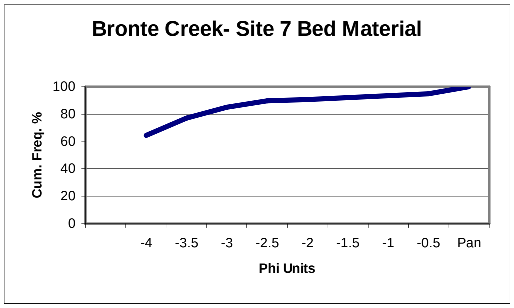


Photo Looking Downstream:

Bronte Creek

Site 8

Site Characteristics:

Site 8 is located off of 4th line sideroad accessed through the Campbell farm. It is situated just below the mouth of Limestone Creek. The floodplain is a large pasture made of grasses that is actively used for livestock. The down-left bank is experiencing undercutting of depth 0.26 metres with a height of 0.27 metres. The bank itself is 0.845 metres high with an angle of 43^0. The down-right bank is experiencing roughly 15 % erosion with a height of 0.57 metres and a bank angle of 15^0.

Width:	10.6 m	Top of Bank Width:	11.2 m
Mean Depth:	0.41 m	Bankfull Width:	11.59 m
Mean Velocity:	0.52 m/s	Bankfull Depth:	0.67 m
Discharge:	2.26 m^3/s	Torvane:	0.27 kg/cm^2
D_{50}:			

Channel Profile:

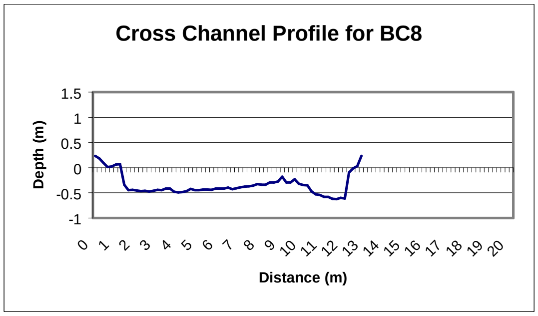


Photo Looking Downstream:

Bronte Creek

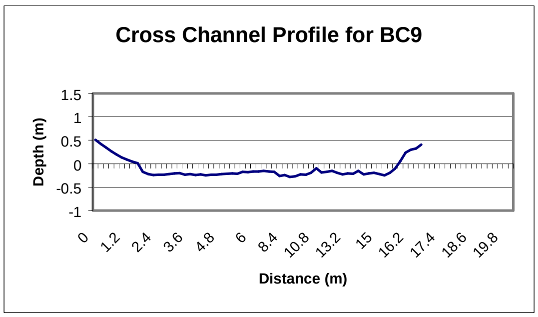
Site 9

Site Characteristics:

This site is situated within a park just downstream of Guelph Line, just after a smaller bridge accessing a house on a hill. The floodplain is made up of grasses that are securing the banks to the point that no erosion was visible. The banks range in height from 0.646 metres to 0.451 metres with bank angles of 22^0.

Width:	14.0 m	Top of Bank Width:	14.82 m
Mean Depth:	0.21 m	Bankfull Width:	14.82 m
Mean Velocity:	0.48 m/s	Bankfull Depth:	0.40 m
Discharge:	1.41 m^3/s	Torvane:	0.38 kg/cm^2
D_{50}:	16.00 mm	Pavement:	> 16.00 mm

Channel Profile:



Grain Size Curve:

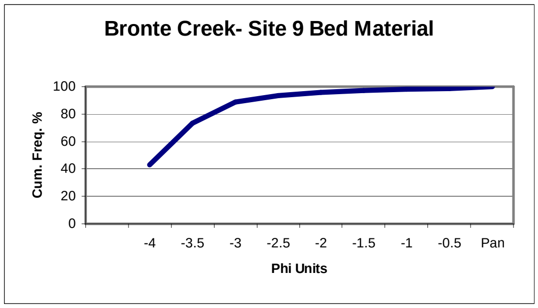


Photo Looking Downstream:

Bronte Creek

Site 10

Site Characteristics:

This site is within the Cedar Springs Community off of Cedar Springs Road. Site 10 is upstream of a swimming hole dam, at the time of the measurement the dam was wide open and no pool was formed. The floodplain is a mix between the park on the down-left being grasses and the bank leading up to the road on the down-right being trees. The down-left bank had a height of 1.19 metres with an angle of 15^0. The down-right bank was closer to 4 metres with an angle of 20^0. Only the down-left bank exhibited erosion, which was around 20 %.

Width:	8.7 m	Top of Bank Width:	11.87 m
Mean Depth:	0.27 m	Bankfull Width:	11.87 m
Mean Velocity:	0.48 m/s	Bankfull Depth:	0.72 m
Discharge:	1.13 m^3/s	Torvane: DR	Not able to measure due to
D_{50}:	Bedrock + Cobbles	DL	rocky banks.

Channel Profile:

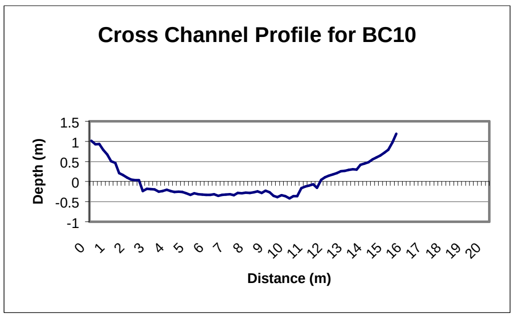


Photo Looking Downstream:

Bronte Creek

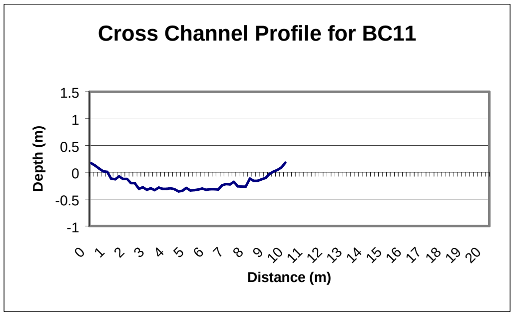
Site 11

Site Characteristics:

This site is situated between the Cedar Springs Road bridge and a dam further upstream where Kilbride Creek enters Bronte. The vegetation is primarily grasses with scrub growing in to the water. The banks range in height from 0.17 metres to 0.21 metres with angles ranging from 20^0 to 30^0. Very little erosion is evident due to the cobble banks secured further by an established root system.

Width:	8.1 m	Top of Bank Width:	9.72 m
Mean Depth:	0.24 m	Bankfull Width:	9.72 m
Mean Velocity:	0.49 m/s	Bankfull Depth:	0.51 m
Discharge:	0.95 m^3/s	Torvane:	0.43 kg/cm^2
D_{50}:	0.25 mm		

Channel Profile: Grain Size Curve:



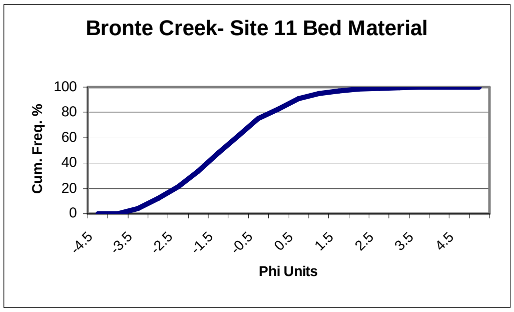


Photo Looking Downstream:

Bronte Creek

Site 12

Site Characteristics:

Site 12 is located just down from the mouth of Flamborough Creek. This area of the channel has sections of channel that cut off and rejoin downstream further. The down-left of the channel is sheltered by deadfall leaving a bank that is 0.224 metres high and on an angle of 49^{0}. The down-right bank is 0.421 metres high with an angle of 52^{0}. The down-right is exhibiting slow erosion shown by the sloping trees.

Width:	8.6 m	Top of Bank Width:	9.10 m
Mean Depth:	0.26 m	Bankfull Width:	9.10 m
Mean Velocity:	0.35 m/s	Bankfull Depth:	0.47
Discharge:	0.78 m^3/s	Torvane:	0.22 kg/cm^2
D_{50}:	> 20.25 mm		

Channel Profile: Grain Size Curve:

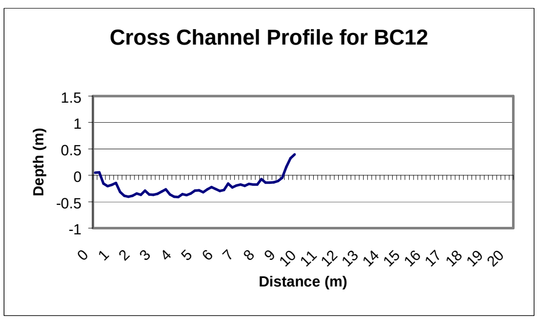


Photo Looking Downstream:

Bronte Creek

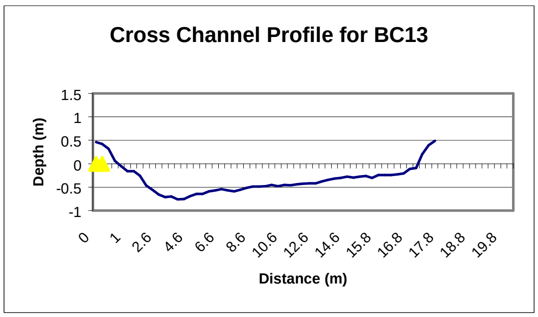
Site 13

Site Characteristics:

Site 13 is located within the city of Carlisle downstream of Center Avenue just after a footbridge. The floodplain consists of shrubs but mainly grasses. On the down-left the bank is angled at 85^0 with a height of 0.58 metres. The down-right bank is shallower at 30^0 with a height of 0.48 metres. Neither bank is exhibiting much erosion, less than 5 %. There is some scouring out of the bank behind the bridge footings but very little.

Width:	16.24 m	Top of Bank Width:	17.4 m
Mean Depth:	0.42 m	Bankfull Width:	17.40 m
Mean Velocity:	0.076 m/s	Bankfull Depth:	1.20 m
Discharge:	0.52 m^3/s	Torvane:	0.10 kg/cm^2
D_{50}:	0.25 mm		

Channel Profile: Grain Size Curve:



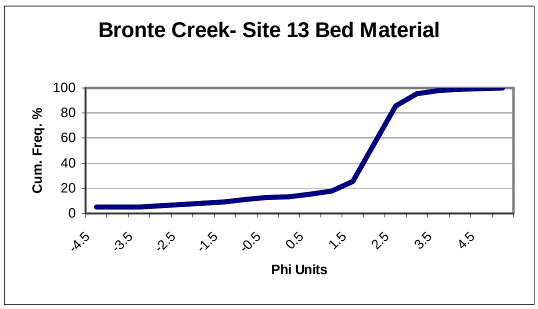


Photo Looking Downstream:

Bronte Creek

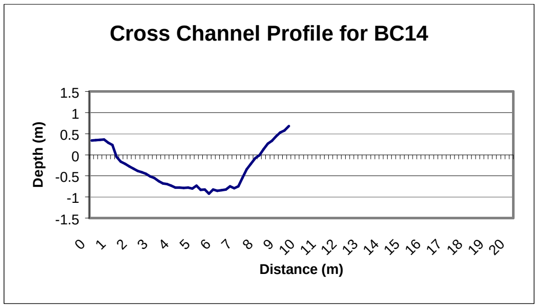
Site 14

Site Characteristics:

Site 14 is inside of Courtcliffe Park downstream of both Mountsberg Creek mouths. The floodplain is primarily grasses with trees on the down-left. Neither bank is exhibiting any significant erosion. The down-right bank has a height of 0.435 metres with an angle of 45^0. The down left bank is higher at 0.70 metres with an angle of 30^0.

Width:	6.62 m	Top of Bank Width:	8.64 m
Mean Depth:	0.58 m	Bankfull Width:	8.64 m
Mean Velocity:	0.12 m/s	Bankfull Depth:	1.27 m
Discharge:	0.46 m^3/s	Torvane: DR	0.18 kg/cm^2
D_{50}:	6.25 mm	DL	Cobble

Channel Profile: Grain Size Curve:



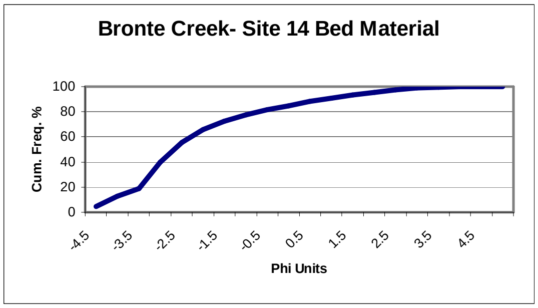


Photo Looking Downstream:

Bronte Creek

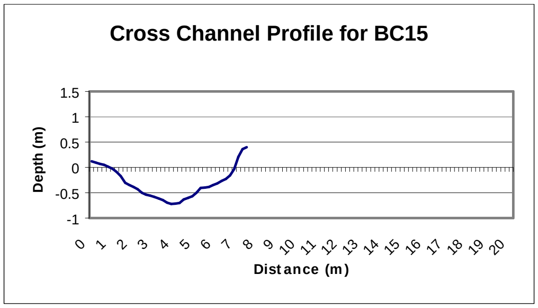
Site 15

Site Characteristics:

This site is just after Strabane Creek enters in to the main channel of Bronte Creek, north of Strabane Road. Smaller shrubs and trees dominate the area. The down-left bank is very gradual with an angle of 8^0 and a height of 0.164 metres. The down-right is steeper at an angle of 57^0 and 0.41 metres high. Very little erosion was observed but arced trees indicate a slow retreat of the banks as well as the presence of exposed roots.

Width:	5.9 m	Top of Bank Width:	6.93 m
Mean Depth:	0.43 m	Bankfull Width:	6.93 m
Mean Velocity:	0.14 m/s	Bankfull Depth:	0.84 m
Discharge:	0.36 m^3/s	Torvane:	0.08 kg/cm^2
D_{50}:	0.42 mm		

Channel Profile: Grain Size Curve:



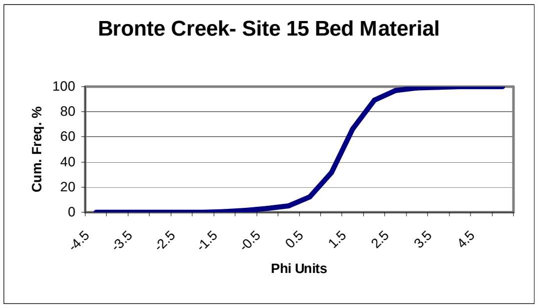


Photo Looking Downstream:

Bronte Creek

Site 16

Site Characteristics:

This site is downstream of a minor trib input as well as within an odd shaped meander sequence downstream of 11th concession east off of Hwy 6. Ferns dominate the floodplain. The bank on the down-right is 0.418 metres high with an angle of 26^0. On the down-left the bank is 0.288 metres high with an angle of 14^0. The only erosion observed was over an area of 15 % where no shrubs are present to slow the flow. At these points the bank is slowly retreating.

Width:	9.4 m	Top of Bank Width:	10.3 m
Mean Depth:	0.20 m	Bankfull Width:	10.3 m
Mean Velocity:	0.074 m/s	Bankfull Depth:	0.40 m
Discharge:	0.14 m^3/s	Torvane:	0.24 kg/cm^2
D_{50}:	Cobbles		

Channel Profile:

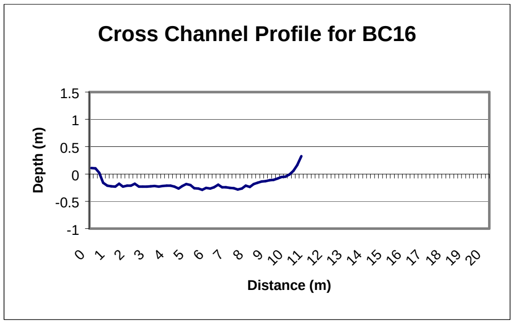


Photo Looking upstream:

Bronte Creek

Site 17

Site Characteristics:

This site is located upstream of 11th concession off of Hwy 6 within a marsh land. The banks as well as the bed are extremely silty making moving in this area extremely difficult. The banks are quite low ranging in height from 0.108 metres to 0.253 metres. On the down-right there is undercutting with a depth of 0.17 metres and a height of 0.26 metres. At the time of measurement the undercutting was completely underwater.

Width:	7.20 m	Top of Bank Width:	7.94 m
Mean Depth:	0.32 m	Bankfull Width:	7.94 m
Mean Velocity:	0.032 m/s	Bankfull Depth:	0.76 m
Discharge:	0.074 m^3/s	Torvane:	0.28 kg/cm^2
D_{50}:	silts/organics		

Channel Profile:

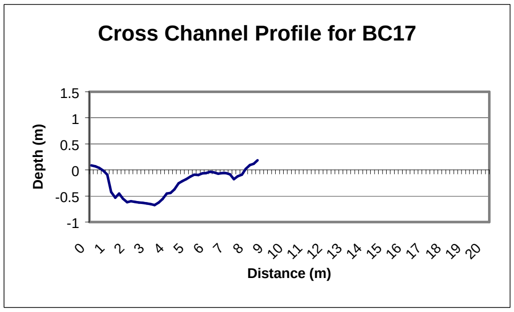


Photo Looking Downstream:

Indian Creek

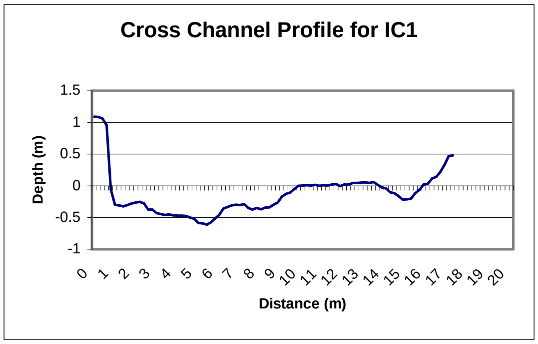
Site 1

Site Characteristics:

This site is at the mouth of Indian Creek accessed through a Children's Latvian Camp off of Appleby Line. The floodplain is dominated by deciduous forest. The down-left bank has a height of 1.19 metres with undercutting that is 0.81 metres deep and 0.85 metres high. On this bank trees are growing straight out showing rapid erosion. The downright bank is 0.25 metres high with an angle of 22^{o} and well vegetated.

Width:	9.31 m	Top of Bank Width:	10.6 m
Mean Depth:	0.359 m	Bankfull Width:	15.67 m
Mean Velocity:	0.392 m/s	Bankfull Depth:	0.76 m
Discharge:	1.31 m^3/s	Torvane:	0.20 kg/cm^2
D_{50}:	4 mm	Pavement:	> 12.25 mm

Channel Profile: Grain Size Curve:



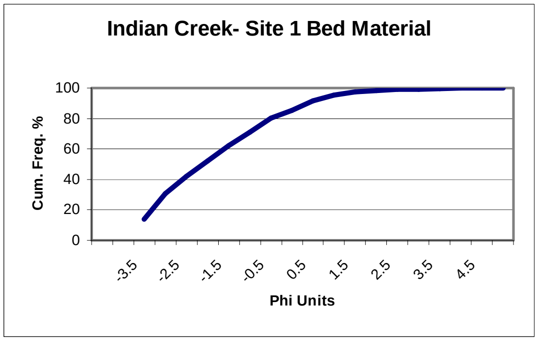


Photo Looking Downstream:

Indian Creek

Site 2

Site Characteristics:

This site is on the property of the Children's Camp off of Appleby Line just after Indian Creek's first tributary input. The superintendent's house located roughly 150 metres from this site experiences flooding in its basement regularly during high flow and is a concern to the landowner. The down-right bank has a height of 0.23 metres with an angle of 42°. This bank is made up of parent material that is slowly being undercut. The down-left bank is 0.38 metres high with undercutting that is 0.12 metres deep and 0.22 metres high at an angle of 25°.

Width:	8.6 m	Top of Bank Width: 8.95 m
Mean Depth:	0.29 m	Bankfull Width: 8.95 m
Mean Velocity:	0.28 m/s	Bankfull Depth: 0.82 m
Discharge:	0.70 m^3/s	Torvane: DR Bedrock
D_{50}:	Bed is 0.20 m clasts.	DL 0.26 kg/cm^2

Channel Profile:

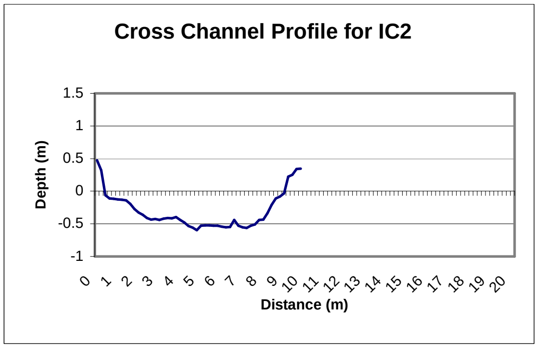


Photo Looking Downstream:

Indian Creek

Site 3

Site Characteristics:

This site is just upstream of Bell School Lane. At the time of study this site was without water. Downstream of this site at the road the channel cuts through two culverts roughly 3.5 meters tall. The down-right bank is highly vegetated with a height of 0.30 metres and an angle of 51°. The down-left bank is exposed parent material with a height of 1.5 metres and an angle of 41 °. There is approximately 20% erosion on the down-left.

Width:	N/A	Top of Bank Width:	4.6 m
Mean Depth:	0.0 m	Bankfull Width:	4.6 m
Mean Velocity:	0.0 m/s	Bankfull Depth:	0.41 m
Discharge:	0.0 m^3/s	Torvane:	0.28 kg/cm^2
D_{50}:	Bedrock		

Channel Profile:

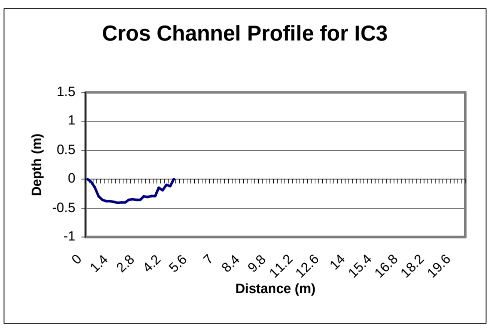


Photo Looking Upstream:

Indian Creek

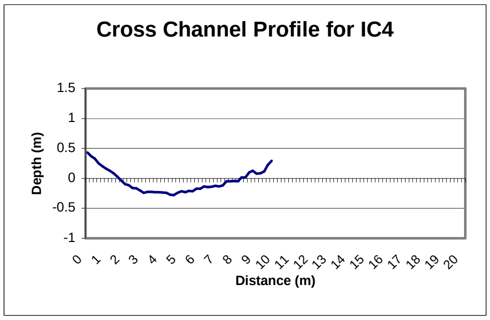
Site 4

Site Characteristics:

This site is accessed through a farm off of Tremaine Road just up stream of an extremely sharp meander. This area is predominantly grasses around the channel. The only obvious erosion shows up on the down-left bank which is in the form of toppled trees and undercutting which is just up from the measured site that is 0.55 metres deep and 1.06 metres high. This bank is 0.437 metres high with an angle of 20°. The downright bank is angled at 46°.

Width:	3.18 m	Top of Bank Width:	8.22 m
Mean Depth:	0.17 m	Bankfull Width:	8.22 m
Mean Velocity:	0.20 m/s	Bankfull Depth:	0.41 m
Discharge:	0.11 m^3/s	Torvane:	0.14 kg/cm^2
D_{50}:	16 mm	Pavement:	> 16 mm

Channel Profile: Grain Size Curve:



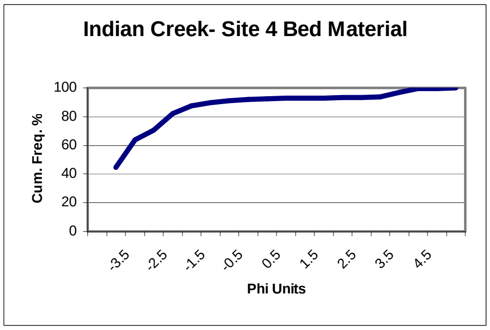


Photo Looking Downstream:

Indian Creek

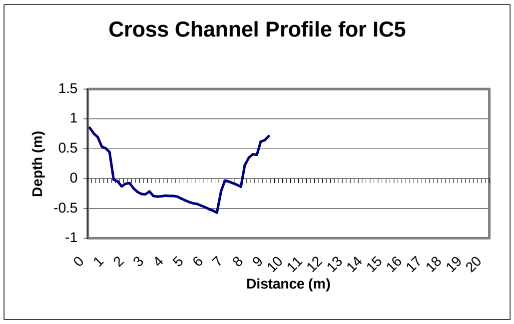
Site 5

Site Characteristics:

This site is within the same cow farm as site 3 off of Tremaine Road. Pasture dominates the entire area. The bank heights are 0.45 metres for the down-left and 0.64 metres for the down-right. The bank angles tend to be around 90° or greater as many sections of the banks are actually tumbling in to the channel.

Width:	6.60 m	Top of Bank Width:	7.18 m
Mean Depth:	0.26 m	Bankfull Width:	7.18 m
Mean Velocity:	0.11 m/s	Bankfull Depth:	0.97 m
Discharge:	0.19 m^3/s	Torvane:	0.24 kg/cm^2
D_{50}:	9.00 mm	Pavement:	>16.00 mm

Channel Profile:



Grain Size Curve:

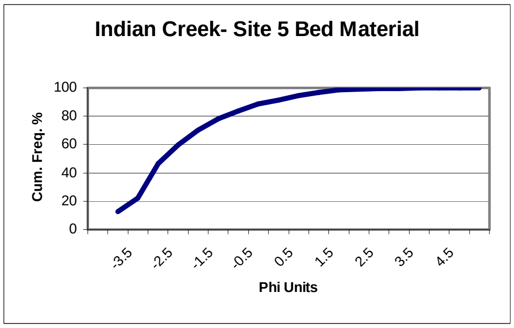


Photo Looking Downstream:

Indian Creek

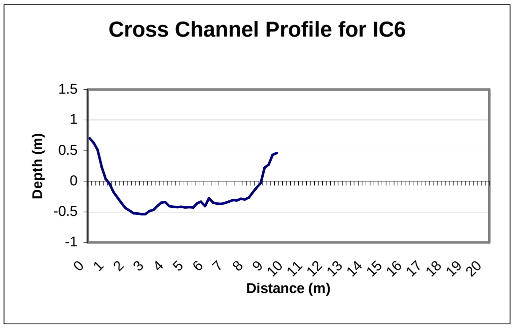
Site 6

Site Characteristics:

This site is on the same farm as the previous two sites. This section of the creek appeared to be more heavily used by the cattle as depicted in the picture below. This results in further bank erosion as well as worn paths. The banks are 0.604 metres high on the down-left and 0.716 metres high on the down-right. The down-left bank is subject to undercutting that is 0.21 metres deep and 0.26 metres high with an angle of 64°. 90 % of the down-right bank is slumping averaging an angle of 55°.

Width:	7.82 m	Top of Bank Width:	8.19 m
Mean Depth:	0.35 m	Bankfull Width:	8.19 m
Mean Velocity:	0.062 m/s	Bankfull Depth:	0.76 m
Discharge:	0.17 m^3/s	Torvane:	0.23 kg/cm^2
D_{50}:	2.83 mm		

Channel Profile: Grain Size Curve:



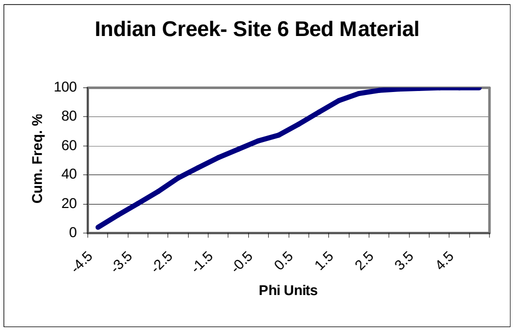


Photo Looking Downstream:

Indian Creek

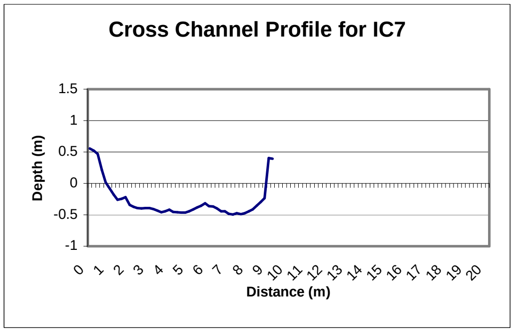
Site 7

Site Characteristics:

This site is located further north on Tremaine road from sites 3-5 just below the input of the second tributary recorded on Indian Creek. The flood plain is made up of primarily grass. Both banks had heights of 0.69 metres with angles of 25^{o}. The down-left bank is subject to undercutting of depth 0.30 metres and a height of 0.31 metres.

Width:	8.07 m	Top of Bank Width:	8.75 m
Mean Depth:	0.38 m	Bankfull Width:	8.75 m
Mean Velocity:	0.070 m/s	Bankfull Depth:	0.51 m
Discharge:	0.21 m^3/s	Torvane:	0.22 kg/cm^2
D_{50}:	5.06 mm	Pavement:	>12.25 mm

Channel Profile: Grain Size Curve:



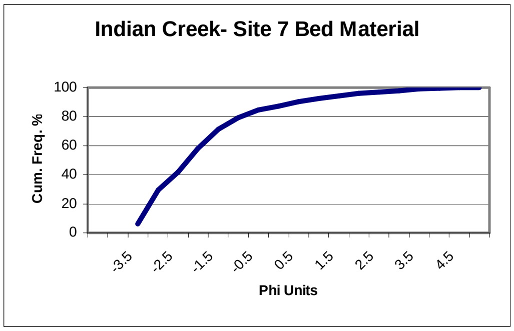


Photo Looking Downstream:

Indian Creek

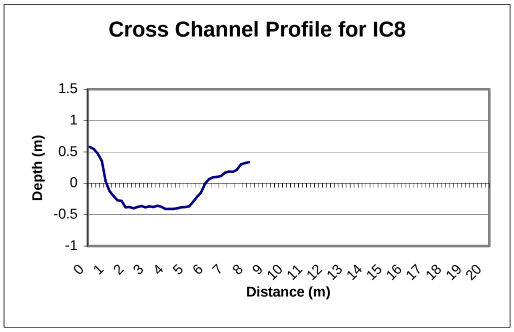
Site 8

Site Characteristics:

This site is just downstream of the third tributary recorded as entering Indian Creek, off of Tremaine Road. Site 7 is situated on a straight section of the channel that is just prior to where Indian Creek is forced to meander due to Tremaine Road. Here the down-left bank was found to be 0.235 metres high with an angle of 38^o with the down-right being 0.575 metres high at an angle of 35^o.

Width:	4.93 m	Top of Bank Width:	5.44 m
Mean Depth:	0.32 m	Bankfull Width:	5.44 m
Mean Velocity:	0.090 m/s	Bankfull Depth:	0.51 m
Discharge:	0.14 m^3/s	Torvane:	0.35 kg/cm^2
D_{50}:	4.00 mm	Pavement:	>12.25 mm

Channel Profile:



Grain Size Curve:

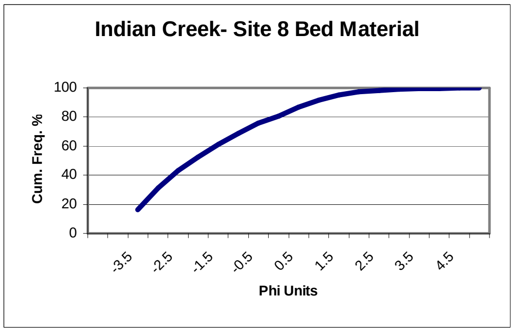


Photo Looking Downstream:

Indian Creek

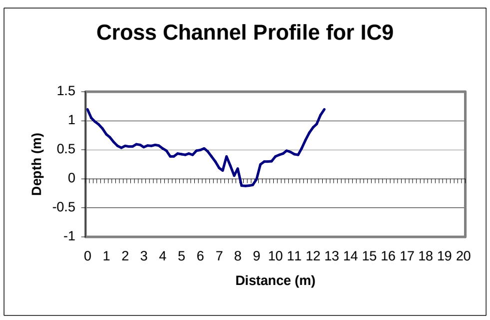
Site 9

Site Characteristics:

This site is at the intersection of Bell School Lane and Brittania, downstream of the overpass. The vegetation here is thick and grows throughout the channel it self. The down-right bank has an angle of 25° while the down-left has an angle of 61°.

Width:	0.90 m	Top of Bank Width:	10.01 m
Mean Depth:	0.093 m	Bankfull Width:	10.01 m
Mean Velocity:	0.0 m/s	Bankfull Depth:	0.73 m
Discharge:	0.0 m^3/s	Torvane:	0.40 kg/cm^2
D_{50}:	6.25 mm		

Channel Profile: Grain Size Curve:



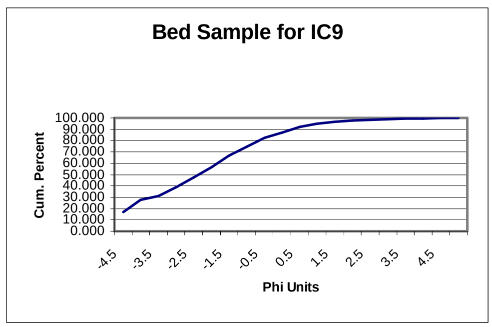


Photo Looking Upstream:

Indian Creek

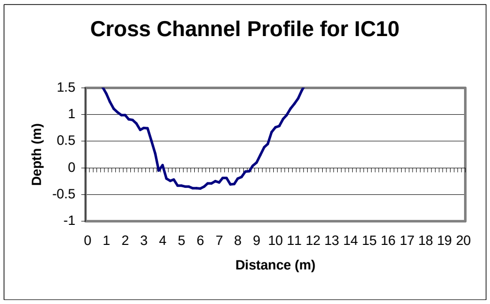
Site 10

Site Characteristics:

This site lies along a straightened section of the channel between Derry Road and Brittania. The banks are all well vegetated with woody shrubs and grasses. Bank angles are consistent from 51^o on the down-right to 46^o on the down-left. There is no obvious signs of erosion at this site.

Width:	4.8 m	Top of Bank Width:	4.81 m
Mean Depth:	0.24 m	Bankfull Width:	4.81 m
Mean Velocity:	0.0 m/s	Bankfull Depth:	0.39 m
Discharge:	0.0 m^3/s	Torvane:	0.16 kg/cm^2
D_{50}:	3.36 mm		

Channel Profile: Grain Size Curve:



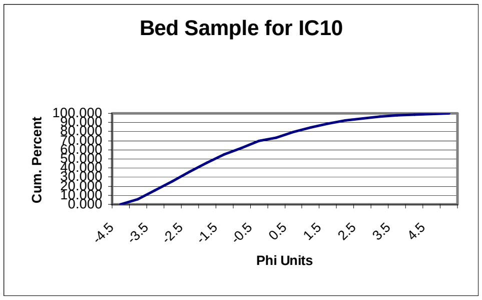


Photo Looking Downstream:

Indian Creek

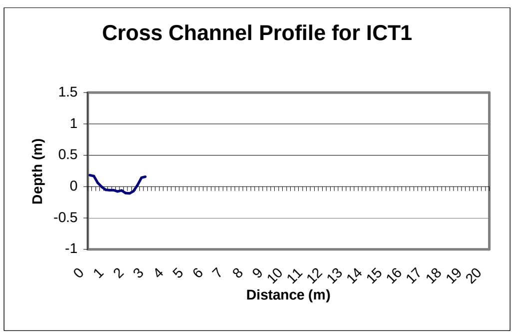
Site ICT1

Site Characteristics:

This site is located on the first recorded tributary on Indian Creek. This site is located on the Children's Camp off of Appleby Line. The banks consist of mixed gravel deposits that seem active with signs of slumping. The banks are 0.25 metres high with angles of 30°. Above the bank on the down-right bankfull bank there is undercutting of 0.28 metres deep and 0.61 metres high. This channel continues on through a culvert then hits a point of unconsolidated gravel and is force to make a hard right before entering Bronte.

Width:	1.90 m	Top of Bank Width:	2.35 m
Mean Depth:	0.066 m	Bankfull Width:	2.35 m
Mean Velocity:	0.16 m/s	Bankfull Depth:	0.25 m
Discharge:	0.020 m^3/s	Torvane:	0.43 kg/cm^2
D_{50}:	5.06 mm	Pavement:	>12.25 mm

Channel Profile: Grain Size Curve:



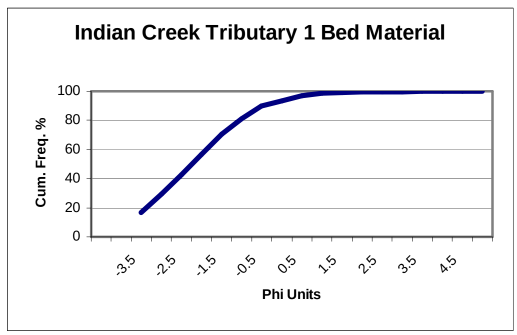


Photo Looking Downstream:

Indian Creek

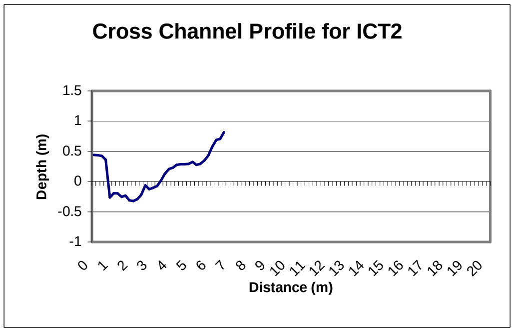
Site ICT2

Site Characteristics:

This site is located at the mouth of the second recorded tributary entering Indian Creek. It passes through two culverts under Tremaine road and enters in to Indian Creek on a very gentle angle. The down-right bank is 0.847 metres high with an angle of 33 ^{o} and exhibits undercutting of depth 0.27 metres and height 0.55 metres for the entire length of the bank. The down-left bank appears to be relatively stable and is 0.27 metres high with an angle of 44^{o}.

Width:	3.00 m	Top of Bank Width:	3.71 m
Mean Depth:	0.20 m	Bankfull Width:	3.71 m
Mean Velocity:	0.17 m/s	Bankfull Depth:	0.60 m
Discharge:	0.10 m^3/s	Torvane:	0.23 kg/cm^2
D_{50}:	9.00 mm		

Channel Profile: Grain Size Curve:



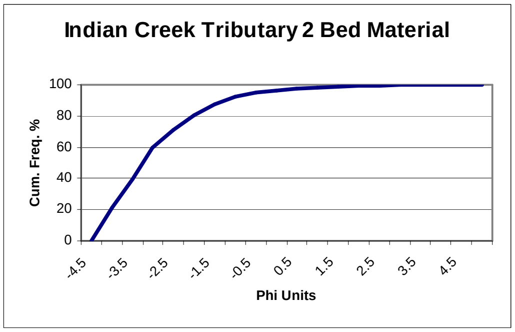


Photo Looking Downstream:

Indian Creek

Site ICT3

Site Characteristics:

This tributary is the third to be recorded. It runs perfectly straight and enters Indian Creek at a 90^o angle just up from Tremaine Road. The floodplain for this channel consists of a manicured lawn as well as a small orchard. The banks along this tributary are being subjected to undercutting but in a pattern that would indicate the channel is trying to assume a meandering form. The banks along this channel are 0.68 metres high with an angle of 28^o on the down-left and 55^o on the down-right.

Width:	3.18 m	Top of Bank Width:	3.75 m
Mean Depth:	0.42 m	Bankfull Width:	3.75 m
Mean Velocity:	0.11 m/s	Bankfull Depth:	0.90 m
Discharge:	0.15 m^3/s	Torvane:	0.20 kg/cm^2
D_{50}:			

Channel Profile: Grain Size Curve:

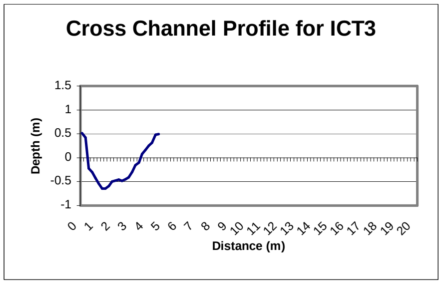


Photo Looking Downstream:

Limestone Creek

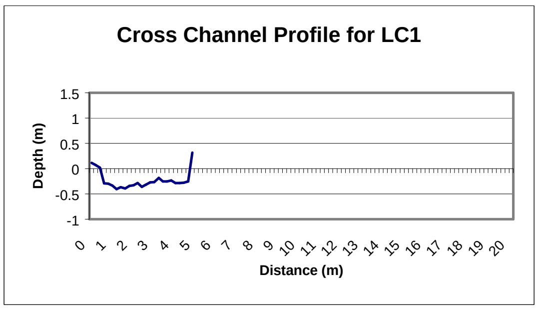
Site 1

Site Characteristics:

This is the first site in Limestone Creek up from Bronte Creek. It is accessed through the Campbell Farm off of 4th side road. The floodplain around this site is an active pasture with paths cutting through the stream. The down-left bank is 0.43 metres high with undercutting which is 0.20 metres deep and 0.21 metres high. The down right bank is 0.58 metres high with undercutting which is 0.45 metres deep and 0.46 metres high.

Width:	4.2 m	Top of Bank Width:	4.71 m
Mean Depth:	0.30 m	Bankfull Width:	4.71 m
Mean Velocity:	0.36 m/s	Bankfull Depth:	0.52 m
Discharge:	0.45 m^3/s	Torvane:	0.25 kg/cm^2
D_{50}:	4.00 mm		

Channel Profile: Grain Size Curve:



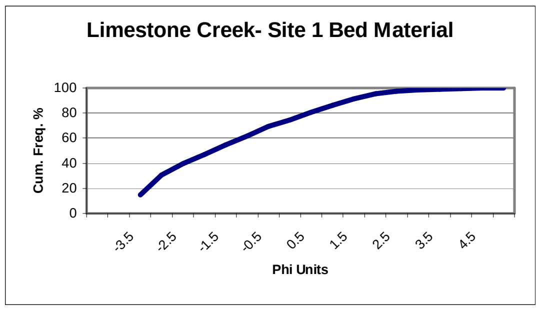


Photo Looking Downstream:

Limestone Creek

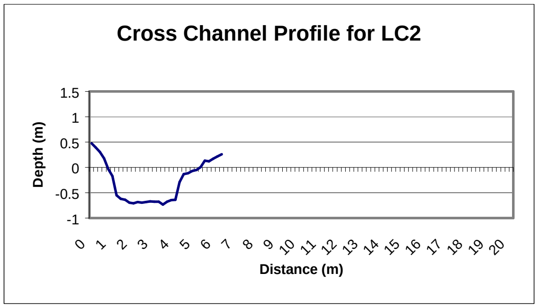
Site 2

Site Characteristics:

This site is located upstream from the Campbell farm within a large valley which is dominated by open grass fields. Just down from the site is a sharp 90^0 turn in the channel. The down-right bank is 0.645 metres high with undercutting which is 0.10 metres deep and 0.285 metres high. The down-left bank is slumping and is 0.879 metres high.

Width:	3.5 m	Top of Bank Width:	4.5 m
Mean Depth:	0.49 m	Bankfull Width:	4.99 m
Mean Velocity:	0.20 m/s	Bankfull Depth:	0.87 m
Discharge:	0.34 m^3/s	Torvane:	N/A
D_{50}:	2 mm	Pavement:	> 12.25 mm

Channel Profile: Grain Size Curve:



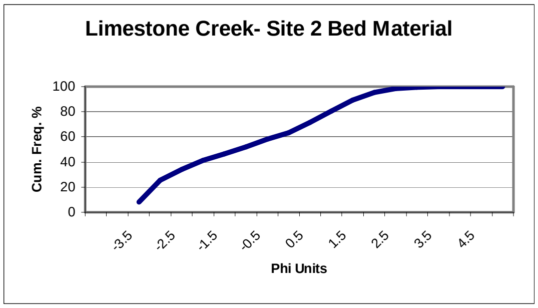


Photo Looking Downstream:

Limestone Creek

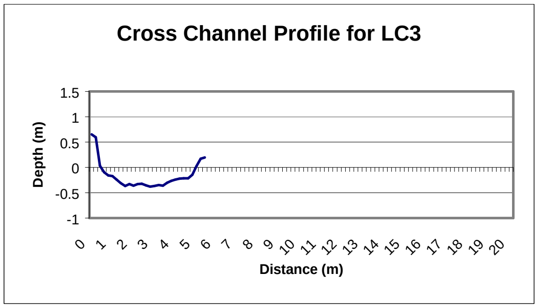
Site 3

Site Characteristics:

This site is approximately 300 metres down from Brittania Road just after a small tributary input. The site is located on a large meander with the down-right bank on the outside edge. The down-right bank is 0.66 metres high with an angle close to 90°. This bank is subject to undercutting which is 0.26 metres deep and 0.49 metres high, as well as slumping. The down-left bank has a forming point bar and is 0.285 metres high with an angle of 15°.

Width:	4.6 m	Top of Bank Width:	5.06 m
Mean Depth:	0.28 m	Bankfull Width:	5.06 m
Mean Velocity:	0.28 m/s	Bankfull Depth:	0.58 m
Discharge:	0.36 m^3/s	Torvane:	0.38 kg/cm^2
D_{50}:	6.25 mm	Pavement:	> 12.25 mm

Channel Profile: Grain Size Curve:



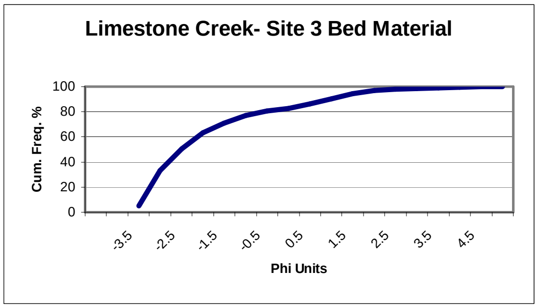


Photo Looking Downstream:

Limestone Creek

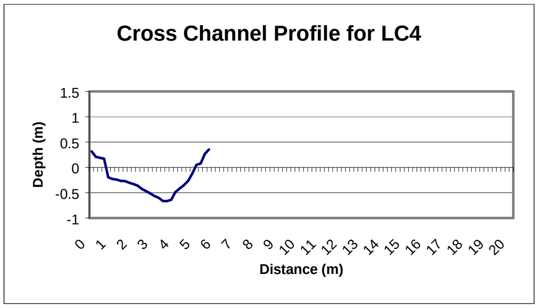
Site 4

Site Characteristics:

This site was accessed from a house off of Walker's Line just up from Brittania. Site 5 is located within a farmer's field after a sharp diversion of the flow. Prior to the site there is a number of I-beams placed within the channel on angles. Above this site the trees are toppling in to the flow but at the site the banks are exhibiting no erosion.

Width:	4.23 m	Top of Bank Width:	4.81 m
Mean Depth:	0.40 m	Bankfull Width:	4.81 m
Mean Velocity:	0.15 m/s	Bankfull Depth:	0.85 m
Discharge:	0.25 m^3/s	Torvane:	0.66 kg/cm^2
D_{50}:	4.00 mm	Pavement:	> 16.00 mm

Channel Profile:



Grain Size Curve:

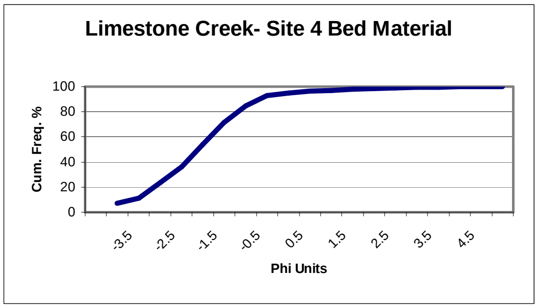


Photo Looking Upstream:

Limestone Creek

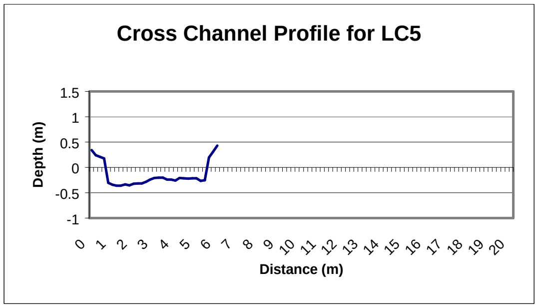
Site 5

Site Characteristics:

This site is within a field that appears to be unused, accessed through the same property off of Walker's Line as site 5. Upstream from this site on the same property is two ponds and one smaller tributary. The banks here are showing no signs of erosion with their 70^{o} angles and heights ranging from 0.685 metres on the down-left to 0.651 metres on the down-right.

Width:	4.7 m	Top of Bank Width:	5.04 m
Mean Depth:	0.27 m	Bankfull Width:	5.04 m
Mean Velocity:	0.28 m/s	Bankfull Depth:	0.54 m
Discharge:	0.36 m^3/s	Torvane:	0.72 kg/cm^2
D_{50}:	9.00 mm		

Channel Profile: Grain Size Curve:



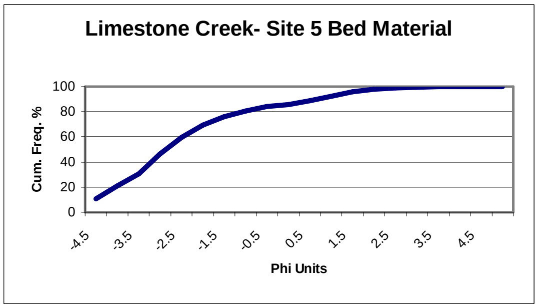


Photo Looking Downstream:

Limestone Creek

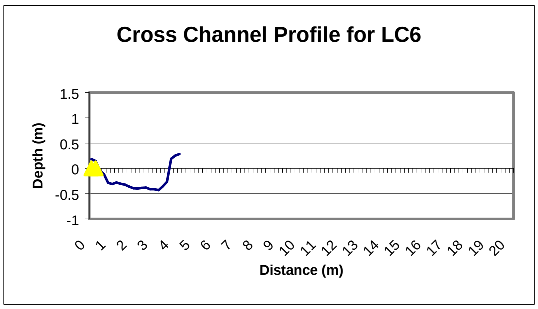
Site 6

Site Characteristics:

Site 7 was accessed via a property that is beside where Limestone crosses under Derry Road. It is situated within an open grass field just down from a tributary input. The banks look quite stable except for a small area which has been trampled by wildlife accessing the creek. The down-right bank is the taller of the two with a height of 0.579 metres and an angle of 64°. The down-left bank is 0.248 metres high with an angle similar to that of the down-right.

Width:	3.25 m	Top of Bank Width:	3.58 m
Mean Depth:	0.32 m	Bankfull Width:	3.58 m
Mean Velocity:	0.29 m/s	Bankfull Depth:	0.58 m
Discharge:	0.30 m^3/s	Torvane:	0.47 kg/cm^2
D_{50}:	2.00 mm		

Channel Profile: Grain Size Curve:



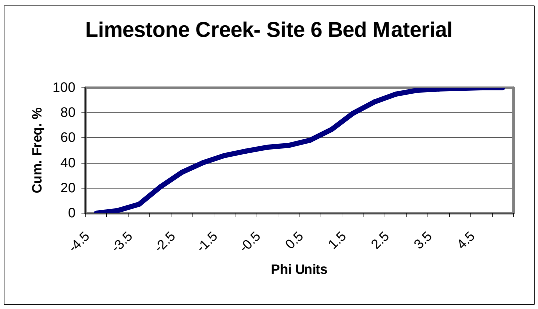


Photo Looking Downstream:

Limestone Creek Tributary

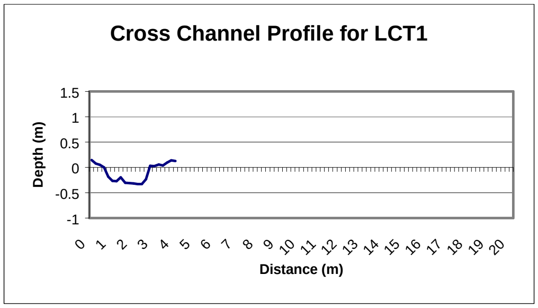
Site LCT1

Site Characteristics:

This tributary is just upstream of site 7. It enters in to Limestone as Limestone is making a turn down to site 7. The floodplain around this site is low lying marsh land dominated by grasses. The banks along this stretch appeared to be stable. The down-left bank has a height of 0.21 metres with an angle of 8^o while the down-right bank is 0.487 metres high with an angle of 24^o.

Width:	1.90 m	Top of Bank Width:	3.13 m
Mean Depth:	0.25 m	Bankfull Width:	3.13 m
Mean Velocity:	0.11 m/s	Bankfull Depth:	0.039 m
Discharge:	0.052 m^3/s	Torvane:	0.11 kg/cm^2
D_{50}:	0.5 mm		

Channel Profile: Grain Size Curve:



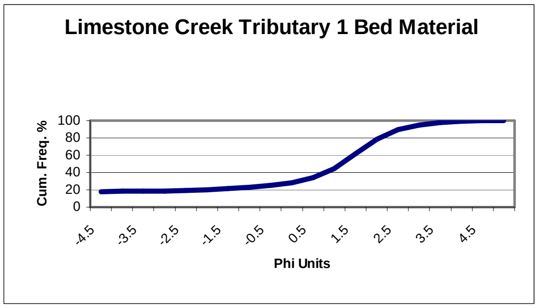


Photo Looking Upstream:

Kilbride Creek

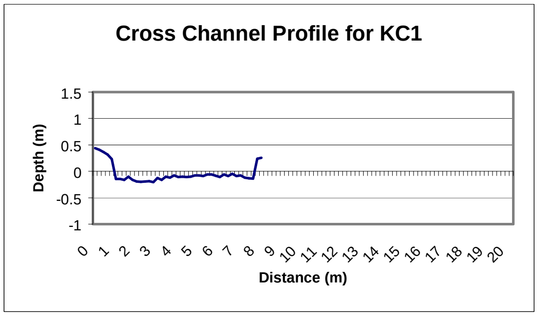
Site 1

Site Characteristics:

This site is at the mouth of Kilbride Creek as it enters Bronte Creek. Where Kilbride enters in to Bronte is just upstream of a dam that is pooling Bronte Creek. The banks are ranging in height from 0.33 metres to 0.38 metres with angles ranging from 66^{o} to 69^{o}. Along the banks is exposed roots and toppling trees showing rapid erosion.

Width:	6.72 m	Top of Bank Width:	7.27 m
Mean Depth:	0.12 m	Bankfull Width:	7.27 m
Mean Velocity:	0.18 m/s	Bankfull Depth:	0.47 m
Discharge:	0.15 m^3/s	Torvane:	0.19 kg/cm^2
D_{50}:	4.00 mm	Pavement:	> 12.25 mm

Channel Profile: Grain Size Curve:



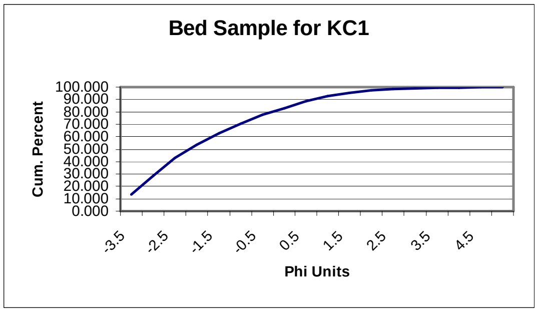


Photo Looking Downstream:

Kilbride Creek

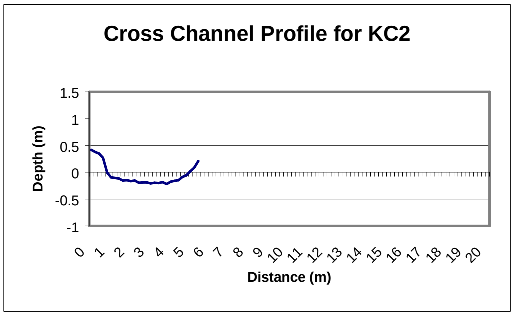
Site 2

Site Characteristics:

This site is located upstream of Kilbride Street downstream of a small tributary. The area is dominated by ferns. Trees are indicating by their slope that there is rapid retreat of the banks. The down-left bank is 0.427 metres high with an angle of 40^o while the down-right bank is 0.35 metres high with an angle of 22^o.

Width:	4.1 m	Top of Bank Width:	4.76 m
Mean Depth:	0.15 m	Bankfull Width:	4.76 m
Mean Velocity:	0.13 m/s	Bankfull Depth:	0.43 m
Discharge:	0.079 m^3/s	Torvane:	0.17 kg/cm^2
D_{50}:	2.00 mm	Pavement:	> 12.25 mm

Channel Profile: Grain Size Curve:



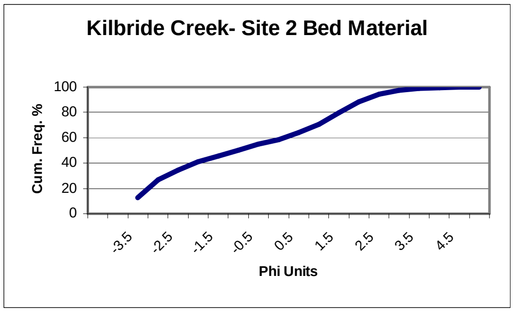


Photo Looking Downstream:

Kilbride Creek

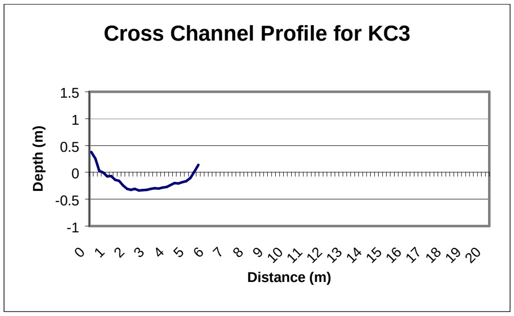
Site 3

Site Characteristics:

This site is located upstream of a 90^{o} turn forced on Kilbride Creek by Derry Road. The landowner of this site is complaining of trees falling and increased erosion since construction in the summer of 2000 on Derry road which narrowed the down-right bank after the bend in the creek. The down-right bank at the measured site was 0.37 metres high with an angle of 76^{o}. On this bank there is trees growing that are arced indicating a slow retreat. The down-left bank is 0.28 metres high with an angle of 26^{o} adjacent to a manicured lawn.

Width:	4.69 m	Top of Bank Width:	5.10 m
Mean Depth:	0.23 m	Bankfull Width:	5.10 m
Mean Velocity:	0.054 m/s	Bankfull Depth:	0.48 m
Discharge:	0.058 m^3/s	Torvane:	0.24 kg/cm^2
D_{50}:	16.00 mm	Pavement:	> 16.00 mm

Channel Profile: Grain Size Curve:



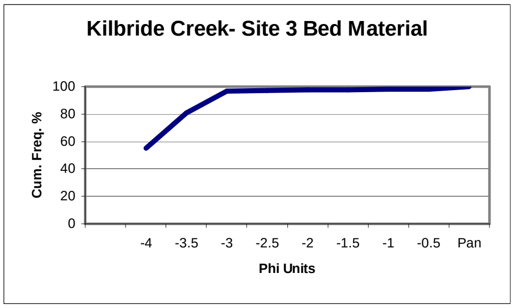


Photo Looking Downstream:

Kilbride Creek

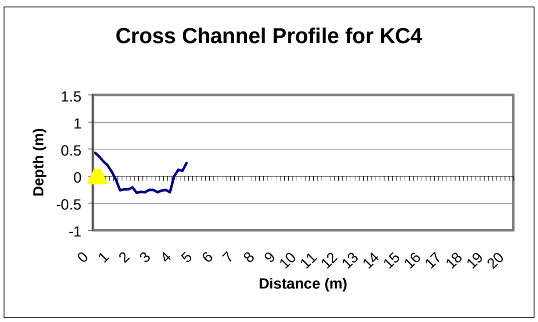
Site 4

Site Characteristics:

This site is located just downstream of a 90° bend in the main channel of Kilbride Creek. At this bend a tributary that is 7.2 kilometres long enters in to the main channel straight in to the turn. The banks along this section of the channel consist of large limestone boulders resulting in no bank erosion. The banks range in height from 0.422 metres on the down-left to 0.459 on the down-right.

Width:	2.85 m	Top of Bank Width:	3.50 m
Mean Depth:	0.24 m	Bankfull Width:	3.50 m
Mean Velocity:	0.14 m/s	Bankfull Depth:	0.43 m
Discharge:	0.096 m^3/s	Torvane: Not measurable due to size of material.	
D_{50}:	14.06 mm	Pavement:	>16.00 mm

Channel Profile: Grain Size Curve:



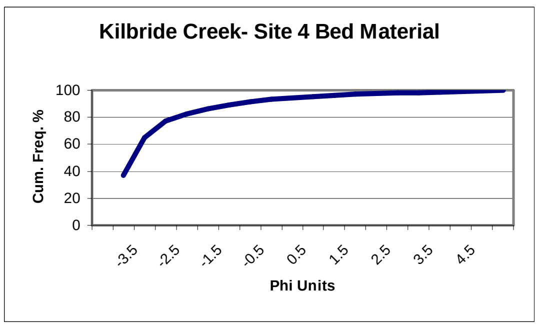


Photo Looking Downstream:

Kilbride Creek

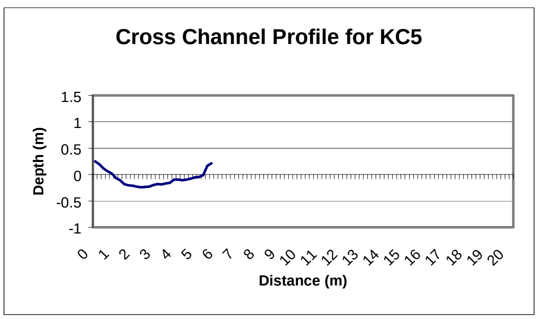
Site 5

Site Characteristics:

This site is prior to the input of the tributary and prior to the 90° bend in the main channel. There is very little sign of erosion. The banks consist of manicured lawn right up until the water. The down-left bank is 0.244 metres high with an angle of 38°. The down-right bank is 0.309 metres high with an angle of 40^0. Upstream of the site there is a bridge used to access a house that has been fortified by large stones.

Width:	4.1 m	Top of Bank Width:	5.08 m
Mean Depth:	0.14 m	Bankfull Width:	5.08 m
Mean Velocity:	0.17 m/s	Bankfull Depth:	0.39 m
Discharge:	0.098 m^3/s	Torvane:	0.12 kg/cm^2
D_{50}:	6.25 mm	Pavement:	> 12.25 mm

Channel Profile:



Grain Size Curve:

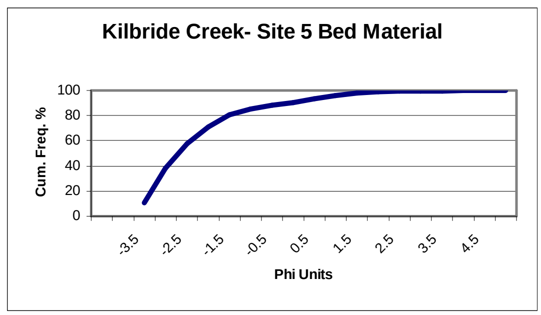


Photo Looking Downstream:

Lowville Creek

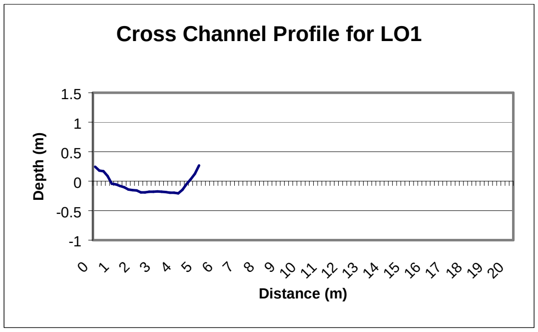
Site 1

Site Characteristics:

Site is located at the mouth of Lowville Creek off of 4th side road. Various sorts of trees dominate the area. Over the past couple years the landowner has planted close to 300 trees to try and "naturalize" the area. Bank heights are ranging from 0.31metres on the down-right bank to 0.288 metres on the down-left bank. The down-right bank has an angle of 30 ° while the down-left bank is angled at 52 °. The only erosion that stood out was on the down-right where tree roots are exposed and the trees are arced.

Width:	3.6 m	Top of Bank Width:	4.47 m
Mean Depth:	0.15 m	Bankfull Width:	4.47 m
Mean Velocity:	0.11 m/s	Bankfull Depth:	0.38 m
Discharge:	0.059 m^3/s	Torvane:	0.07 kg/cm^2
D_{50}:	2.83 mm		

Channel Profile: Grain Size Curve:



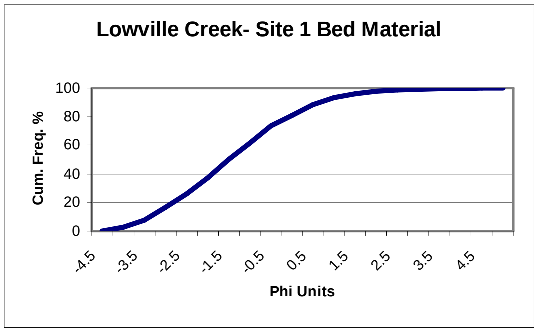


Photo Looking Downstream:

Lowville Creek

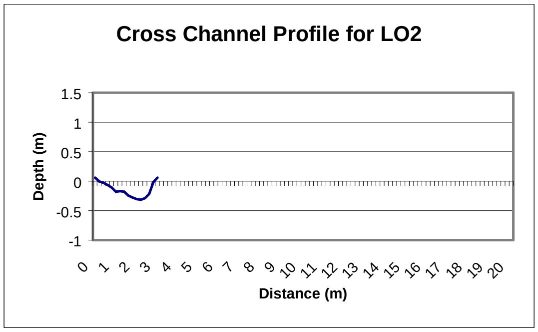
Site 2

Site Characteristics:

This site is located on private property off of 4th side road. The floodplain is mainly shrubs with trees. Upstream from this location there is an apparatus that is assumed to be used to draw water for the use of the golf course. The bank on the down-right is 0.248 metres high with an angle of 32°. This bank is experiencing slight undercutting. The down-left bank is much lower at 0.05 metres and with an angle of 6°. Up from the banks on the down-right there is considerable slumping.

Width:	2.0 m	Top of Bank Width:	2.97 m
Mean Depth:	0.17 m	Bankfull Width:	2.97 m
Mean Velocity:	0.19 m/s	Bankfull Depth:	0.37 m
Discharge:	0.065 m^3/s	Torvane:	0.42 kg/cm^2
D_{50}:	3.36 mm	Pavement:	> 12.25 mm

Channel Profile:



Grain Size Curve:

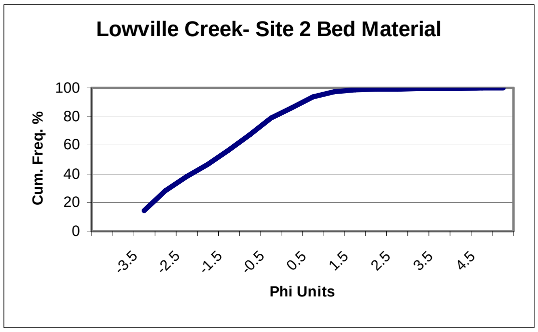


Photo Looking Downstream:

Flamboro Creek

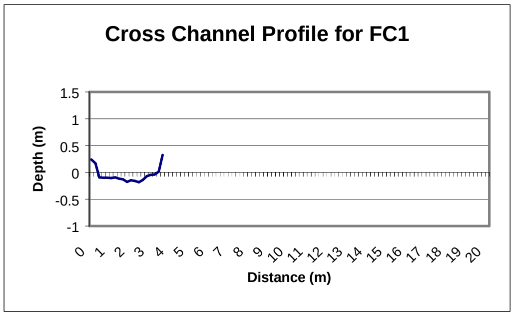
Site 1

Site Characteristics:

This site is accessed from a private quarry across from a Golf Course on Carlisle Road. Site 1 is situated right at the mouth of Flamboro Creek. This area is made up of primarily ferns and pines. Both banks are comparable at heights ranging from 0.354 metres to 0.355 metres and angles ranging from 64° to 70°. Slow erosion is evident from trees that have become arced as well as roots that have become exposed.

Width:	2.85 m	Top of Bank Width:	3.30 m
Mean Depth:	0.11 m	Bankfull Width:	3.30 m
Mean Velocity:	0.14 m/s	Bankfull Depth:	0.35 m
Discharge:	0.044 m^3/s	Torvane:	0.53 kg/cm^2
D_{50}:	7.56 mm		

Channel Profile: Grain Size Curve:



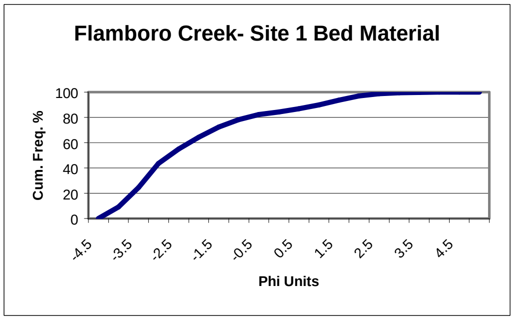


Photo Looking Upstream:

Mount Nemo

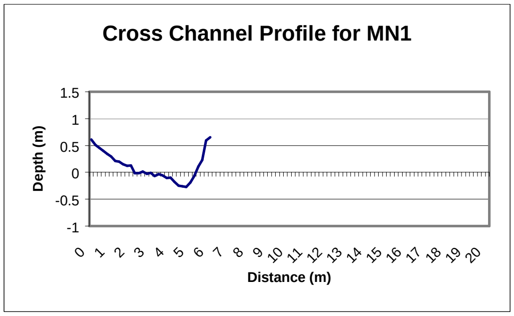
Site 1

Site Characteristics:

This site is located off of 2nd side road via the scout camp. The site itself is located approximately 300 metres up from the mouth of Mount Nemo Creek at the end of a pool. Shrubs mainly dominate the area. Both banks have a height of 0.18 metres with angles ranging from 31^0 to 42^0. There is exposed roots and suspended rocks providing evidence of erosion. Up from the flow at the time of measurement there is undercutting of the bankfull notch.

Width:	2.7 m	Top of Bank Width:	3.70 m
Mean Depth:	0.10 m	Bankfull Width:	3.70 m
Mean Velocity:	0.068 m/s	Bankfull Depth:	0.40 m
Discharge:	0.018 m^3/s	Torvane:	0.28 kg/cm^2
D_{50}:	6.25 mm	Pavement:	> 12.25 mm

Channel Profile: Grain Size Curve:



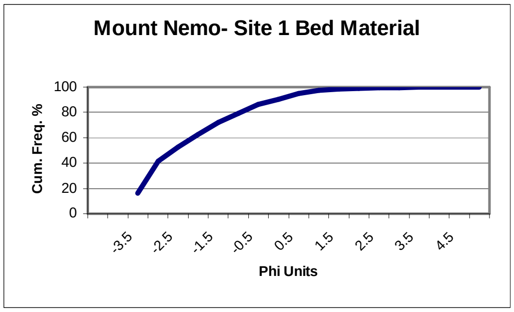


Photo Looking Downstream:

Willoughby Creek

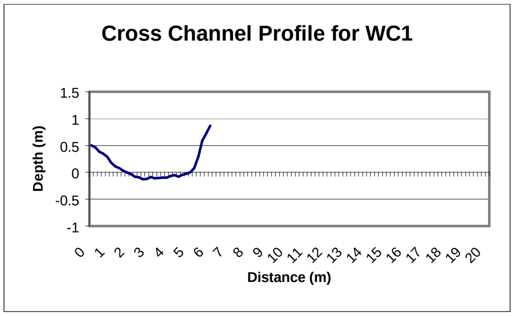
Site 1

Site Characteristics:

This site is located at the mouth of Willoughby Creek down from a dam. Above the dam there is ponded water controlling the discharge on the lower reaches of Willoughby. The down-right bank is 0.09 metres high with an angle of 19°. The down-left bank is less defined, there is no difference between the channel bank and the bankfull bank resulting in a bank height of 0.824 metres and a bank angle of 68°. Erosion is evident through downed trees as well as trees that are arced.

Width:	2.9 m	Top of Bank Width:	3.95 m
Mean Depth:	0.078 m	Bankfull Width:	3.95 m
Mean Velocity:	0.26 m/s	Bankfull Depth:	0.23 m
Discharge:	0.059 m^3/s	Torvane:	0.40 kg/cm^2
D_{50}:	9.00 mm	Pavement:	> 12.25 mm

Channel Profile: Grain Size Curve:



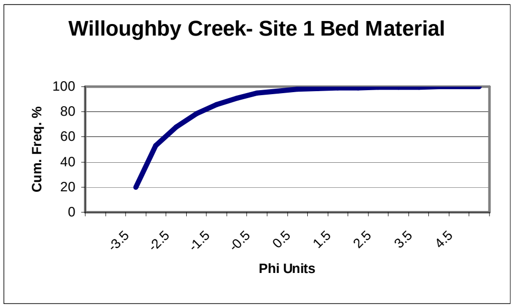


Photo Looking Downstream:

Strabane Creek

Site 1

Site Characteristics:

This site is located at the mouth of the Strabane Creek in close proximity to BC14 off of Strabane road. The floodplain is typical deciduous forest. Both banks have a height of 0.27 metres but the down-right bank has an angle of 45^o while the down-left bank has an angle of 12^o. There is slow erosion on both banks over approximately 15 % of the area.

Width:	5.0 m	Top of Bank Width:	6.18 m
Mean Depth:	0.27 m	Bankfull Width:	6.18 m
Mean Velocity:	0.06 m/s	Bankfull Depth:	0.64 m
Discharge:	0.081 m^3/s	Torvane:	0.17 kg/cm^2
D_{50}:	organics		

Channel Profile:

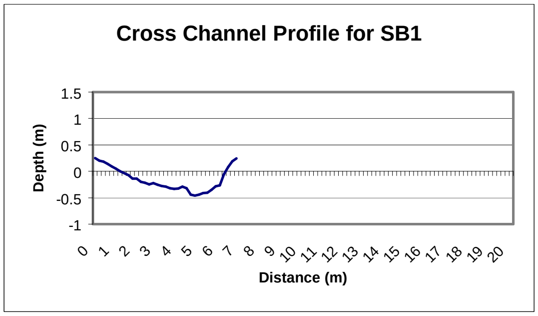


Photo Looking at Mouth of Strabane (left channel – main channel is Bronte site 15):

Strabane Creek

Site 2

Site Characteristics:

This site is accessed through private property off of Strabane road. The site is downstream of a series of ponds that appear to be kept up by the landowner as a bird sanctuary. The floodplain of the creek in this area is a large swamp made up of mainly ferns. The banks are barely distinguishable at 0.14 metres to 0.168 metres with angles of 6^o and 8^o. No erosion was observed as the water was not moving at this point. This area appears to be a point of deposition with greater than 0.15 metres of humic material built up on the bed.

Width:	5.4 m	Top of Bank Width:	6.4 m
Mean Depth:	0.42 m	Bankfull Width:	Large low lying marsh
Mean Velocity:	N/A	Bankfull Depth:	N/A
Discharge:	Still Water	Torvane:	0.24 kg/cm^2
D_{50}:	silt/organics		

Channel Profile: Grain Size Curve:

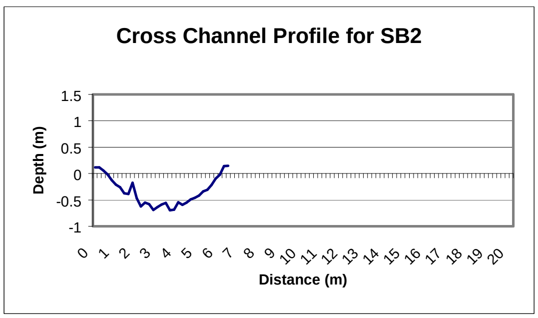


Photo Looking Downstream:

Mountsberg Creek

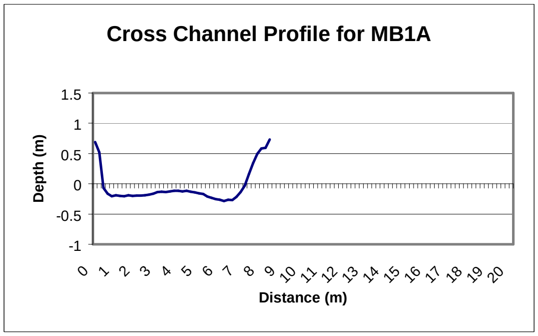
Site 1A

Site Characteristics:

This site is representing the original channel of Mountsberg Creek which enters in to the Bronte within Courtcliffe Park. The floodplain's main component is grasses with some trees on either side of the channel. The down-left bank appears to be stable with a height of 0.77 metres and an angle of 38°. The down-right bank is 0.82 metres high and is exhibiting undercutting of depth 0.20 metres and 0.17 metres high.

Width:	6.6 m	Top of Bank Width:	8.13 m
Mean Depth:	0.18 m	Bankfull Width:	8.13 m
Mean Velocity:	0. 10/s	Bankfull Depth:	0.90 m
Discharge:	0.12 m^3/s	Torvane:	0.10 kg/cm^2
D_{50}:	0.50 mm		

Channel Profile: Grain Size Curve:



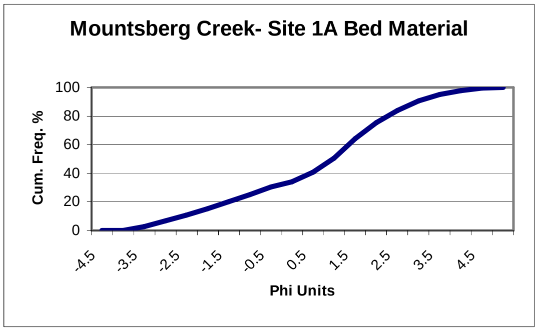


Photo Looking Downstream:

Mountsberg Creek

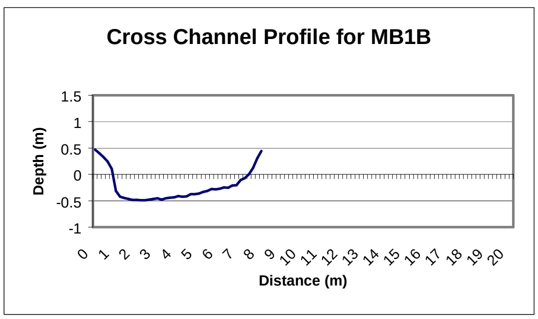
Site 1B

Site Characteristics:

This site is representing the new channel of Mountsberg, which enters in to the Bronte downstream of where the original channel entered. The floodplain is much like that of MB1A where it is dominated by the grasses of the park. The down-right bank in this case is stable with its height of 0.537 metres and angle of 20^{o}. The down-left bank is 0.714 metres high and is experiencing undercutting, which is 0.14 metres deep and 0.20 metres high.

Width:	6.40 m	Top of Bank Width:	7.87 m
Mean Depth:	0.37 m	Bankfull Width:	7.87 m
Mean Velocity:	0.12 m/s	Bankfull Depth:	0.92 m
Discharge:	0.28 m^3/s	Torvane:	0.28 kg/cm^2
D_{50}:	0.35 mm		

Channel Profile: Grain Size Curve:



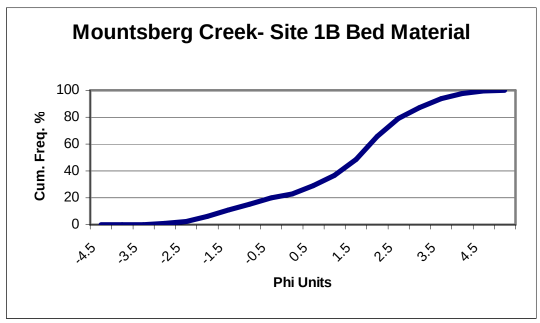


Photo Looking Downstream:

Mountsberg Creek

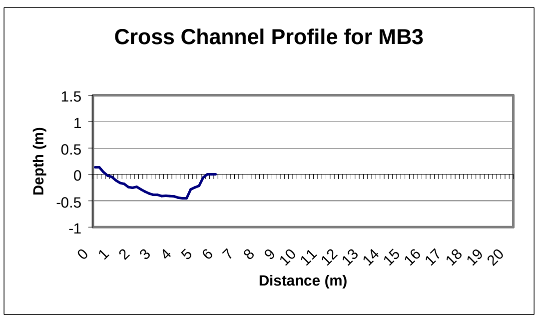
Site 3

Site Characteristics:

This site is upstream of 11th concession just after the input of a small tributary. This area is entirely marshland with pockets of vegetation and soil breaking up the floodplain. The down-right has no obvious height to it or angle, it is grass that distinguishes the channel. The down-left has a height of 0.244 metres. The bank consists of clumps of vegetation that are jutting and collapsing in to the main part of the channel.

Width:	4.5 m	Top of Bank Width:	N/A
Mean Depth:	0.28 m	Bankfull Width:	N/A
Mean Velocity:	0.048 m/s	Bankfull Depth:	N/A
Discharge:	0.060 m^3/s	Torvane:	0.50 kg/cm^2
D_{50}:	0.30 mm		

Channel Profile: Grain Size Curve:



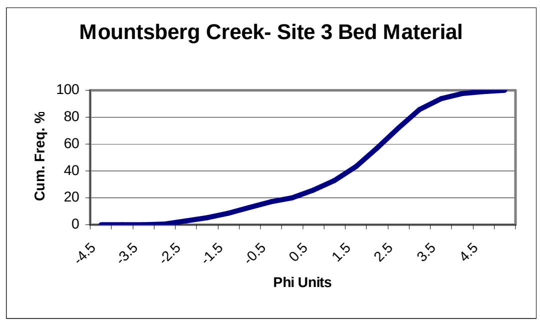


Photo Looking Upstream:

Mountsberg Creek

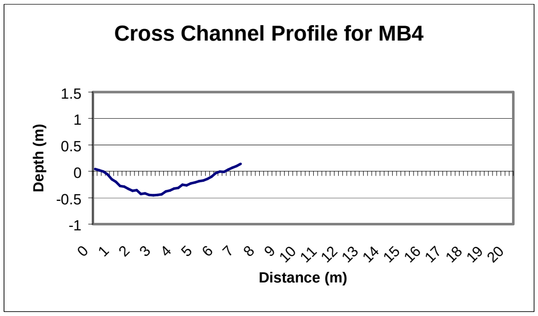
Site 4

Site Characteristics:

This site is just below the dam that is creating the Mountsberg reservoir off of concession 14. The floodplain is managed by the conservation authority with manicured lawns and dogwoods lining the banks. There is little activity on the banks. The down-left bank is 0.073 metres high with an angle of 10^o. The down-right bank is 0.17 metres high with an angle of 6^o.

Width:	5.51 m	Top of Bank Width:	6.48 m
Mean Depth:	0.26 m	Bankfull Width:	6.48 m
Mean Velocity:	0.046 m/s	Bankfull Depth:	0.50 m
Discharge:	0.066 m^3/s	Torvane:	0.80 kg/cm^2
D_{50}:	12.25 mm	Pavement:	> 12.25 mm

Channel Profile: Grain Size Curve:



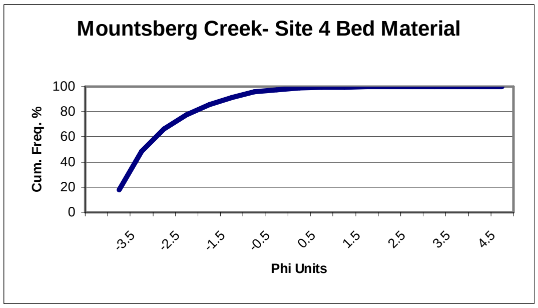


Photo Looking Downstream:

APPENDIX C

TARGET HYDROGRAPHS

PEIL

PLANNERS
CONSULTING
ENGINEERS &
LANDSCAPE
ARCHITECTS

APPENDIX C

HYDROGRAPH DUMPS FOR INDIAN CREEK

Every individual subcatchment hydrograph, as well as all those at the addition points or nodes, were dumped out for the return period events and the Regional storm in the Indian Creek watershed model under existing conditions. There are three general methods of dumping the ordinates for computed hydrographs in the GAWSER program, but in this particular case the KEEP HYD command was used exclusively because it puts the hydrograph ordinates in the traditional HYMO STORE HYD command. For each return period and Regional Storm event, the hydrographs are stored in files whose names are summarized in **Table C 1**. Its obvious from the file names what event was used to generate the hydrographs that are stored in that particular file. For example, IC25MM.HYD contains the hydrographs generated using the SCS four hour 25 mm storm, whereas IC100YR.HYD has the hydrographs for the 100 year 24 hour SCS Storm. All these files have been assembled in a single zipped file, called INDIAN.ZIP and provided to Conservation Halton. The file ICREG100.HYD represents those hydrographs generated using no areal adjustment to the Regional Storm rainfall totals, whereas ICREG971.HYD represents those hydrographs generated by applying the 0.971 areal adjustment factor. Due to extreme file sizes, only the 100 year hydrographs have been appended. Conservation Halton can provide additional information on other storm hydrographs.

Table C 2 illustrates a section of the Indian Creek watershed model file with two major GAWSER commands, the COMPUTE FLOWRATE for generating subcatchments total outflow hydrographs, and an ADD HYD command for a typical addition node. Notice how the KEEP HYD commands have been inserted into the file, with ICODE=0 to get the STORE HYD command format. Although CUTOFF=24 in each example, the actual time base of the dumped hydrographs is specified in the START command, which in each of these cases is 144 hours. Remember, output from the KEEP HYD commands are always printed to the GAWSKEEP.DAT file. In this example, the GAWSKEEP.DAT files generated after each event run were renamed as summarized in **Table C 1**. Below the sample ADD HYD command, are two other examples of dumping computed hydrograph ordinates, using the PRINT HYD and ERROR ANALYSIS commands. Output from these two commands are printed to the main listing file in a more column like structure.

Table C 1 Summary of hydrograph dump filenames

IC25MM.HYD
IC2YR.HYD
IC5YR.HYD
IC10YR.HYD
IC25YR.HYD
IC50YR.HYD
IC100YR.HYD

Table 2 Summary of how GAWSER commands are inserted to dump hydrographs

```
COMPUTE FLOWRATE    ID=2 NHD=1285 AREA=   6.2300 Sq km  L=  1560 m  W=
779 m
            SOIL ZONE I    II  III    IV    V    VI  VII  VIII   IX
                   2.0   0.0  0.0  94.2  0.0   0.0  0.0   3.8  0.0
                 RATING CURVES: IDMC=1 IDOC=5 QRMC=  0.25 QROC=
0.05
                 ROUTING MODEL=2 CONSTANTS: OVERLAND FTB= 2.0 TLO=
0.0
```

```
                    SUBSURFACE: KSS= 5.0 KGW= 384 h PCODE=1 WQPCODE=1
                    RBASIN=0 IDA=0 IDB=0 IDC=0 IDD=0 RBDUMP=0
                    GWFACT=0.00 GWON=0
*
KEEP HYD            ID=2 CUTOFF=24 ICODE=0 ISTEP=1 IFORM=0
*
* West Indian Creek u/s Confluence East Branch
*
ADD HYD             ID=3 HYD NO=6285 IDA=2 IDB=1
*
* Prints required hydrograph in GAWSKEEP.DAT file in traditional HYMO
* STORE HYD command format ready
*
KEEP HYD            ID=3 CUTOFF=24 ICODE=0 ISTEP=1 IFORM=0
*
* Puts hydrograph print-outs of each ordinate in output listing file
*
PRINT HYD           ID=3 PCODE=0 MODE=0
*
ERROR ANALYSIS      FIRST ID=2 SECOND ID=3 PCODE=0
```

```
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                        AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=1281DT= 0.2500 HRS  DA=   6.910 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0330
                        0.033    0.033    0.033    0.033    0.033    0.033
                        0.033    0.033    0.033    0.033    0.033    0.034
                        0.034    0.035    0.035    0.036    0.036    0.037
                        0.037    0.038    0.039    0.040    0.041    0.042
                        0.043    0.044    0.045    0.046    0.046    0.047
                        0.048    0.049    0.050    0.051    0.053    0.055
                        0.057    0.060    0.062    0.065    0.068    0.074
                        0.095    0.140    0.210    0.340    0.590    1.210
                        2.260    3.360    4.190    4.720    4.970    5.070
                        5.140    5.180    5.210    5.230    5.240    5.230
                        5.230    5.220    5.200    5.190    5.180    5.160
                        5.140    5.120    5.090    5.060    5.040    5.010
                        4.980    4.950    4.920    4.890    4.850    4.820
                        4.780    4.740    4.710    4.670    4.630    4.600
                        4.560    4.530    4.490    4.440    4.400    4.360
                        4.320    4.270    4.230    4.190    4.160    4.120
                        4.080    4.030    3.990    3.940    3.890    3.840
                        3.790    3.740    3.690    3.640    3.590    3.550
                        3.500    3.460    3.410    3.370    3.320    3.280
                        3.240    3.190    3.150    3.110    3.070    3.030
                        2.990    2.950    2.920    2.880    2.840    2.800
                        2.770    2.730    2.700    2.660    2.630    2.590
                        2.560    2.530    2.490    2.460    2.430    2.400
                        2.370    2.340    2.310    2.280    2.250    2.220
                        2.190    2.160    2.130    2.110    2.080    2.050
                        2.030    2.000    1.980    1.950    1.930    1.900
                        1.880    1.850    1.830    1.810    1.780    1.760
                        1.740    1.720    1.690    1.670    1.650    1.630
                        1.610    1.590    1.570    1.550    1.530    1.510
                        1.490    1.470    1.450    1.430    1.420    1.400
                        1.380    1.360    1.350    1.330    1.310    1.300
                        1.280    1.260    1.250    1.230    1.220    1.200
                        1.190    1.170    1.160    1.140    1.130    1.110
                        1.100    1.090    1.070    1.060    1.050    1.030
                        1.020    1.010    1.000    0.980    0.970    0.960
                        0.950    0.940    0.920    0.910    0.900    0.890
                        0.880    0.870    0.860    0.850    0.840    0.830
                        0.820    0.810    0.800    0.790    0.780    0.770
                        0.760    0.750    0.740    0.730    0.720    0.720
                        0.710    0.700    0.690    0.680    0.670    0.670
                        0.660    0.650    0.640    0.630    0.630    0.620
                        0.610    0.610    0.600    0.590    0.580    0.580
                        0.570    0.560    0.560    0.550    0.540    0.540
                        0.530    0.530    0.520    0.510    0.510    0.500
                        0.500    0.490    0.490    0.480    0.470    0.470
                        0.460    0.460    0.450    0.450    0.440    0.440
                        0.430    0.430    0.420    0.420    0.410    0.410
                        0.400    0.400    0.400    0.390    0.390    0.380
                        0.380    0.370    0.370    0.370    0.360    0.360
                        0.350    0.350    0.350    0.340    0.340    0.340
                        0.330    0.330    0.330    0.320    0.320    0.320
                        0.310    0.310    0.310    0.300    0.300    0.300
                        0.290    0.290    0.290    0.280    0.280    0.280
                        0.280    0.270    0.270    0.270    0.260    0.260
                        0.260    0.260    0.250    0.250    0.250    0.250
                        0.240    0.240    0.240    0.240    0.230    0.230
                        0.230    0.230    0.230    0.220    0.220    0.220
                        0.220    0.220    0.210    0.210    0.210    0.210
                        0.210    0.200    0.200    0.200    0.200    0.200
                        0.200    0.190    0.190    0.190    0.190    0.190
                        0.190    0.180    0.180    0.180    0.180    0.180
                        0.180    0.170    0.170    0.170    0.170    0.170
                        0.170    0.170    0.160    0.160    0.160    0.160
                        0.160    0.160    0.160    0.160    0.150    0.150
                        0.150    0.150    0.150    0.150    0.150    0.150
                        0.150    0.140    0.140    0.140    0.140    0.140
```

```
                         0.140    0.140    0.140    0.140    0.140    0.130
                         0.130    0.130    0.130    0.130    0.130    0.130
                         0.130    0.130    0.130    0.130    0.120    0.120
                         0.120    0.120    0.120    0.120    0.120    0.120
                         0.120    0.120    0.120    0.120    0.120    0.120
                         0.110    0.110    0.110    0.110    0.110    0.110
                         0.110    0.110    0.110    0.110    0.110    0.110
                         0.110    0.110    0.110    0.110    0.100    0.100
                         0.100    0.100    0.100    0.100    0.100    0.100
                         0.100    0.100    0.100    0.099    0.099    0.098
                         0.098    0.097    0.097    0.097    0.096    0.096
                         0.095    0.095    0.094    0.094    0.094    0.093
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                         0.089    0.088    0.088    0.088    0.087    0.087
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                         0.085    0.085    0.084    0.084    0.084    0.084
                         0.083    0.083    0.083    0.083    0.082    0.082
                         0.082    0.082    0.081    0.081    0.081    0.081
                         0.080    0.080    0.080    0.080    0.080    0.079
                         0.079    0.079    0.079    0.079    0.078    0.078
                         0.078    0.078    0.078    0.077    0.077    0.077
                         0.077    0.077    0.076    0.076    0.076    0.076
                         0.076    0.076    0.075    0.075    0.075    0.075
                         0.075    0.075    0.075    0.074    0.074    0.074
                         0.074    0.074    0.074    0.074    0.073    0.073
                         0.073    0.073    0.073    0.073    0.073    0.073
                         0.072    0.072    0.072    0.072    0.072    0.072
                         0.072    0.072    0.071    0.071    0.071    0.071
                         0.071    0.071    0.071    0.071    0.071    0.069
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                           AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=1282DT= 0.2500 HRS  DA=   3.730 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0180
                         0.018    0.018    0.018    0.018    0.018    0.018
                         0.018    0.018    0.018    0.019    0.020    0.021
                         0.021    0.022    0.023    0.023    0.024    0.026
                         0.027    0.029    0.030    0.031    0.032    0.033
                         0.034    0.035    0.036    0.037    0.038    0.039
                         0.040    0.041    0.042    0.046    0.052    0.057
                         0.062    0.067    0.072    0.076    0.084    0.120
                         0.230    0.370    0.560    0.970    2.020    4.830
                         7.080    7.350    7.410    7.360    7.250    7.100
                         6.970    6.840    6.680    6.490    6.320    6.150
                         5.980    5.820    5.660    5.510    5.360    5.200
                         5.050    4.910    4.760    4.620    4.490    4.360
                         4.230    4.110    3.980    3.870    3.750    3.630
                         3.520    3.410    3.300    3.210    3.120    3.030
                         2.940    2.840    2.740    2.650    2.560    2.480
                         2.400    2.330    2.260    2.190    2.120    2.060
                         1.990    1.900    1.830    1.750    1.680    1.610
                         1.540    1.480    1.420    1.360    1.300    1.250
                         1.200    1.150    1.100    1.060    1.010    0.970
                         0.930    0.900    0.860    0.820    0.790    0.760
                         0.730    0.700    0.670    0.640    0.620    0.590
                         0.570    0.550    0.530    0.500    0.480    0.470
                         0.450    0.430    0.410    0.400    0.380    0.370
                         0.350    0.340    0.330    0.310    0.300    0.290
                         0.280    0.270    0.260    0.250    0.240    0.230
                         0.220    0.210    0.210    0.200    0.190    0.190
                         0.180    0.170    0.170    0.160    0.160    0.150
                         0.150    0.140    0.140    0.130    0.130    0.120
                         0.120    0.120    0.110    0.110    0.110    0.100
                         0.100    0.097    0.094    0.092    0.089    0.087
                         0.084    0.082    0.080    0.078    0.076    0.075
                         0.073    0.071    0.070    0.068    0.067    0.065
                         0.064    0.063    0.061    0.060    0.059    0.058
                         0.057    0.056    0.055    0.054    0.053    0.053
                         0.052    0.051    0.050    0.050    0.049    0.048
                         0.048    0.047    0.047    0.046    0.046    0.045
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                         0.045    0.044    0.044    0.044    0.043    0.043
                         0.043    0.042    0.042    0.042    0.041    0.041
                         0.041    0.041    0.040    0.040    0.040    0.040
                         0.040    0.040    0.039    0.039    0.039    0.039
                         0.039    0.039    0.039    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.037    0.037    0.037    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.038    0.038    0.038    0.038    0.038    0.037
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                        AND=BRONTE.WAT
STORE HYD           ID=3 HYD NO=6282DT= 0.2500 HRS  DA=  10.640 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0510
                         0.051    0.051    0.051    0.051    0.051    0.051
                         0.051    0.051    0.051    0.052    0.053    0.053
                         0.054    0.055    0.056    0.057    0.059    0.061
                         0.062    0.064    0.066    0.068    0.070    0.072
                         0.074    0.076    0.078    0.079    0.081    0.083
                         0.085    0.086    0.089    0.093    0.099    0.110
```

0.110	0.120	0.120	0.130	0.140	0.180
0.280	0.420	0.610	1.010	2.040	4.830
7.080	7.630	8.410	9.280	10.100	10.700
11.100	11.300	11.400	11.400	11.300	11.200
11.100	11.000	10.900	10.700	10.600	10.400
10.300	10.100	9.940	9.780	9.620	9.470
9.320	9.170	9.020	8.880	8.730	8.580
8.440	8.290	8.160	8.030	7.900	7.780
7.650	7.510	7.380	7.250	7.130	7.010
6.890	6.770	6.660	6.550	6.440	6.340
6.220	6.100	5.990	5.870	5.760	5.640
5.530	5.420	5.310	5.200	5.090	4.990
4.890	4.790	4.700	4.610	4.520	4.430
4.350	4.260	4.180	4.110	4.030	3.960
3.880	3.810	3.740	3.680	3.610	3.550
3.490	3.430	3.370	3.310	3.250	3.200
3.150	3.090	3.040	2.990	2.940	2.890
2.850	2.800	2.760	2.710	2.670	2.630
2.590	2.550	2.510	2.470	2.430	2.400
2.360	2.320	2.290	2.250	2.220	2.190
2.160	2.120	2.090	2.060	2.030	2.000
1.980	1.950	1.920	1.890	1.870	1.840
1.810	1.790	1.760	1.740	1.720	1.690
1.670	1.650	1.620	1.600	1.580	1.560
1.540	1.520	1.500	1.480	1.460	1.440
1.420	1.400	1.380	1.370	1.350	1.330
1.310	1.300	1.280	1.260	1.250	1.230
1.220	1.200	1.180	1.170	1.150	1.140
1.130	1.110	1.100	1.080	1.070	1.060
1.040	1.030	1.020	1.010	0.990	0.980
0.970	0.960	0.950	0.940	0.920	0.910
0.900	0.890	0.880	0.870	0.860	0.850
0.840	0.830	0.820	0.810	0.800	0.790
0.780	0.770	0.760	0.760	0.750	0.740
0.730	0.720	0.710	0.700	0.700	0.690
0.680	0.670	0.670	0.660	0.650	0.640
0.640	0.630	0.620	0.620	0.610	0.600
0.600	0.590	0.580	0.580	0.570	0.560
0.560	0.550	0.550	0.540	0.530	0.530
0.520	0.520	0.510	0.510	0.500	0.500
0.490	0.490	0.480	0.480	0.470	0.470
0.460	0.460	0.450	0.450	0.440	0.440
0.430	0.430	0.420	0.420	0.420	0.410
0.410	0.400	0.400	0.400	0.390	0.390
0.380	0.380	0.380	0.370	0.370	0.370
0.360	0.360	0.360	0.350	0.350	0.350
0.340	0.340	0.340	0.330	0.330	0.330
0.320	0.320	0.320	0.320	0.310	0.310
0.310	0.300	0.300	0.300	0.300	0.290
0.290	0.290	0.290	0.280	0.280	0.280
0.280	0.270	0.270	0.270	0.270	0.270
0.260	0.260	0.260	0.260	0.260	0.250
0.250	0.250	0.250	0.250	0.240	0.240
0.240	0.240	0.240	0.230	0.230	0.230
0.230	0.230	0.230	0.220	0.220	0.220
0.220	0.220	0.220	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.180	0.180	0.180
0.180	0.180	0.180	0.180	0.180	0.180
0.170	0.170	0.170	0.170	0.170	0.170
0.170	0.170	0.170	0.170	0.170	0.160
0.160	0.160	0.160	0.160	0.160	0.160
0.160	0.160	0.160	0.160	0.160	0.160
0.150	0.150	0.150	0.150	0.150	0.150
0.150	0.150	0.150	0.150	0.150	0.150
0.150	0.150	0.150	0.150	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140

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                         0.130    0.130    0.130    0.130    0.130    0.130
                         0.130    0.130    0.130    0.130    0.130    0.130
                         0.130    0.130    0.130    0.130    0.130    0.130
                         0.130    0.130    0.130    0.130    0.130    0.130
                         0.130    0.130    0.130    0.120    0.120    0.120
                         0.120    0.120    0.120    0.120    0.120    0.120
                         0.120    0.120    0.120    0.120    0.120    0.120
                         0.120    0.120    0.120    0.120    0.120    0.120
                         0.120    0.120    0.120    0.120    0.120    0.120
                         0.120    0.120    0.120    0.120    0.120    0.120
                         0.120    0.120    0.120    0.120    0.120    0.120
                         0.120    0.120    0.110    0.110    0.110    0.110
                         0.110    0.110    0.110    0.110    0.110    0.110
                         0.110    0.110    0.110    0.110    0.110    0.110
                         0.110    0.110    0.110    0.110    0.110    0.110
                         0.110    0.110    0.110    0.110    0.110    0.110
                         0.110    0.110    0.110    0.110    0.110    0.110
                         0.110    0.110    0.110    0.110    0.110    0.110
                         0.110    0.110    0.110    0.110    0.110    0.110
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                    AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=1283DT= 0.2500 HRS  DA=   3.420 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0160
                         0.016    0.016    0.016    0.016    0.016    0.016
                         0.016    0.016    0.016    0.016    0.017    0.017
                         0.017    0.017    0.018    0.018    0.018    0.019
                         0.019    0.020    0.020    0.021    0.021    0.022
                         0.022    0.023    0.023    0.024    0.024    0.025
                         0.025    0.026    0.026    0.027    0.029    0.032
                         0.035    0.038    0.042    0.045    0.049    0.055
                         0.071    0.100    0.150    0.230    0.390    0.800
                         1.490    2.170    2.610    2.810    2.870    2.900
                         2.910    2.920    2.920    2.920    2.900    2.890
                         2.870    2.850    2.830    2.810    2.790    2.770
                         2.750    2.720    2.700    2.670    2.650    2.620
                         2.590    2.570    2.540    2.510    2.490    2.460
                         2.430    2.400    2.370    2.340    2.320    2.290
                         2.260    2.240    2.210    2.180    2.150    2.120
                         2.090    2.060    2.030    2.000    1.980    1.950
                         1.930    1.900    1.870    1.830    1.800    1.770
                         1.740    1.710    1.680    1.650    1.620    1.590
                         1.560    1.530    1.510    1.480    1.460    1.430
                         1.400    1.380    1.360    1.330    1.310    1.290
                         1.260    1.240    1.220    1.200    1.180    1.160
                         1.140    1.120    1.100    1.080    1.060    1.040
                         1.020    1.010    0.990    0.970    0.950    0.940
                         0.920    0.910    0.890    0.870    0.860    0.840
                         0.830    0.820    0.800    0.790    0.770    0.760
                         0.750    0.740    0.720    0.710    0.700    0.690
                         0.680    0.660    0.650    0.640    0.630    0.620
                         0.610    0.600    0.590    0.580    0.570    0.560
                         0.550    0.540    0.530    0.520    0.520    0.510
                         0.500    0.490    0.480    0.470    0.470    0.460
                         0.450    0.440    0.440    0.430    0.420    0.420
                         0.410    0.400    0.400    0.390    0.380    0.380
                         0.370    0.370    0.360    0.350    0.350    0.340
                         0.340    0.330    0.330    0.320    0.320    0.310
                         0.310    0.300    0.300    0.290    0.290    0.280
                         0.280    0.280    0.270    0.270    0.260    0.260
                         0.260    0.250    0.250    0.240    0.240    0.240
                         0.230    0.230    0.230    0.220    0.220    0.220
                         0.210    0.210    0.210    0.210    0.200    0.200
                         0.200    0.190    0.190    0.190    0.190    0.180
                         0.180    0.180    0.180    0.170    0.170    0.170
                         0.170    0.170    0.160    0.160    0.160    0.160
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.140    0.140    0.140    0.140    0.140    0.140
                         0.130    0.130    0.130    0.130    0.130    0.130
                         0.120    0.120    0.120    0.120    0.120    0.120
                         0.120    0.120    0.110    0.110    0.110    0.110
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                                  0.110    0.110    0.110    0.110    0.100    0.100
                                  0.100    0.100    0.100    0.100    0.099    0.098
                                  0.097    0.096    0.095    0.094    0.093    0.092
                                  0.092    0.091    0.090    0.089    0.088    0.088
                                  0.087    0.086    0.086    0.085    0.084    0.083
                                  0.083    0.082    0.082    0.081    0.080    0.080
                                  0.079    0.079    0.078    0.077    0.077    0.076
                                  0.076    0.075    0.075    0.074    0.074    0.073
                                  0.073    0.072    0.072    0.071    0.071    0.071
                                  0.070    0.070    0.069    0.069    0.068    0.068
                                  0.068    0.067    0.067    0.067    0.066    0.066
                                  0.066    0.065    0.065    0.065    0.064    0.064
                                  0.064    0.063    0.063    0.063    0.063    0.062
                                  0.062    0.062    0.061    0.061    0.061    0.061
                                  0.060    0.060    0.060    0.060    0.060    0.059
                                  0.059    0.059    0.059    0.059    0.058    0.058
                                  0.058    0.058    0.058    0.057    0.057    0.057
                                  0.057    0.057    0.057    0.056    0.056    0.056
                                  0.056    0.056    0.056    0.055    0.055    0.055
                                  0.055    0.055    0.055    0.055    0.054    0.054
                                  0.054    0.054    0.054    0.054    0.054    0.054
                                  0.054    0.053    0.053    0.053    0.053    0.053
                                  0.053    0.053    0.053    0.053    0.053    0.052
                                  0.052    0.052    0.052    0.052    0.052    0.052
                                  0.052    0.052    0.052    0.052    0.052    0.052
                                  0.051    0.051    0.051    0.051    0.051    0.051
                                  0.051    0.051    0.051    0.051    0.051    0.051
                                  0.051    0.051    0.051    0.051    0.051    0.050
                                  0.050    0.050    0.050    0.050    0.050    0.050
                                  0.050    0.050    0.050    0.050    0.050    0.050
                                  0.050    0.050    0.050    0.050    0.050    0.050
                                  0.050    0.050    0.050    0.050    0.050    0.049
                                  0.049    0.049    0.049    0.049    0.049    0.049
                                  0.049    0.049    0.049    0.049    0.049    0.049
                                  0.049    0.049    0.049    0.049    0.049    0.049
                                  0.049    0.049    0.049    0.049    0.049    0.049
                                  0.049    0.049    0.049    0.049    0.049    0.049
                                  0.049    0.049    0.049    0.049    0.049    0.049
                                  0.049    0.049    0.049    0.049    0.049    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.048
                                  0.048    0.048    0.048    0.048    0.048    0.047
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                             AND=BRONTE.WAT
STORE HYD            ID=2 HYD NO=6283DT= 0.2500 HRS  DA=  14.060 SQ KM
                       HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0670
                                  0.067    0.067    0.067    0.067    0.067    0.067
                                  0.067    0.067    0.067    0.068    0.069    0.070
                                  0.071    0.073    0.074    0.075    0.077    0.079
                                  0.081    0.084    0.086    0.089    0.091    0.094
                                  0.096    0.098    0.100    0.100    0.110    0.110
                                  0.110    0.110    0.110    0.120    0.130    0.140
                                  0.150    0.160    0.170    0.180    0.190    0.230
                                  0.350    0.520    0.760    1.240    2.440    5.630
                                  8.560    9.810   11.000   12.100   13.000   13.600
                                 14.000   14.200   14.300   14.300   14.200   14.100
                                 14.000   13.900   13.700   13.500   13.400   13.200
                                 13.000   12.800   12.600   12.500   12.300   12.100
                                 11.900   11.700   11.600   11.400   11.200   11.000
                                 10.900   10.700   10.500   10.400   10.200   10.100
                                  9.910    9.750    9.590    9.430    9.280    9.120
                                  8.980    8.830    8.690    8.550    8.420    8.290
                                  8.150    8.000    7.850    7.710    7.560    7.410
```

7.270	7.120	6.980	6.850	6.710	6.580
6.450	6.330	6.210	6.090	5.970	5.860
5.750	5.640	5.540	5.440	5.340	5.240
5.150	5.050	4.960	4.880	4.790	4.710
4.620	4.540	4.470	4.390	4.310	4.240
4.170	4.100	4.030	3.960	3.900	3.830
3.770	3.710	3.650	3.590	3.530	3.470
3.420	3.360	3.310	3.260	3.210	3.160
3.110	3.060	3.010	2.970	2.920	2.880
2.830	2.790	2.750	2.710	2.660	2.620
2.590	2.550	2.510	2.470	2.440	2.400
2.370	2.330	2.300	2.260	2.230	2.200
2.170	2.140	2.110	2.080	2.050	2.020
1.990	1.960	1.930	1.910	1.880	1.860
1.830	1.800	1.780	1.750	1.730	1.710
1.680	1.660	1.640	1.620	1.600	1.570
1.550	1.530	1.510	1.490	1.470	1.450
1.430	1.410	1.400	1.380	1.360	1.340
1.320	1.310	1.290	1.270	1.260	1.240
1.230	1.210	1.190	1.180	1.170	1.150
1.140	1.120	1.110	1.090	1.080	1.070
1.050	1.040	1.030	1.020	1.000	0.990
0.980	0.970	0.960	0.940	0.930	0.920
0.910	0.900	0.890	0.880	0.870	0.860
0.850	0.840	0.830	0.820	0.810	0.800
0.790	0.780	0.770	0.760	0.760	0.750
0.740	0.730	0.720	0.710	0.710	0.700
0.690	0.680	0.680	0.670	0.660	0.650
0.650	0.640	0.630	0.630	0.620	0.610
0.610	0.600	0.590	0.590	0.580	0.580
0.570	0.560	0.560	0.550	0.550	0.540
0.540	0.530	0.530	0.520	0.510	0.510
0.500	0.500	0.490	0.490	0.490	0.480
0.480	0.470	0.470	0.460	0.460	0.450
0.450	0.450	0.440	0.440	0.430	0.430
0.430	0.420	0.420	0.410	0.410	0.410
0.400	0.400	0.400	0.390	0.390	0.390
0.380	0.380	0.380	0.370	0.370	0.370
0.360	0.360	0.360	0.360	0.350	0.350
0.350	0.340	0.340	0.340	0.340	0.330
0.330	0.330	0.330	0.320	0.320	0.320
0.320	0.310	0.310	0.310	0.310	0.310
0.300	0.300	0.300	0.300	0.300	0.290
0.290	0.290	0.290	0.290	0.280	0.280
0.280	0.280	0.280	0.270	0.270	0.270
0.270	0.270	0.270	0.260	0.260	0.260
0.260	0.260	0.260	0.260	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.230	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.220	0.220
0.220	0.220	0.220	0.220	0.220	0.220
0.220	0.220	0.220	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.210	0.210	0.210	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.180	0.180	0.180	0.180	0.180	0.180
0.180	0.180	0.180	0.180	0.180	0.180
0.180	0.180	0.180	0.180	0.180	0.180
0.180	0.180	0.180	0.180	0.180	0.180
0.170	0.170	0.170	0.170	0.170	0.170
0.170	0.170	0.170	0.170	0.170	0.170
0.170	0.170	0.170	0.170	0.170	0.170
0.170	0.170	0.170	0.170	0.170	0.170
0.170	0.170	0.170	0.170	0.170	0.170
0.170	0.170	0.170	0.170	0.170	0.170
0.160	0.160	0.160	0.160	0.160	0.160

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                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                          AND=BRONTE.WAT
STORE HYD           ID=2 HYD NO=1284DT= 0.2500 HRS  DA=   3.720 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0180
                         0.018    0.018    0.018    0.018    0.018    0.018
                         0.018    0.018    0.019    0.020    0.021    0.022
                         0.023    0.024    0.025    0.025    0.027    0.029
                         0.030    0.032    0.034    0.035    0.036    0.038
                         0.039    0.040    0.041    0.042    0.043    0.044
                         0.045    0.046    0.048    0.050    0.051    0.053
                         0.055    0.056    0.058    0.059    0.062    0.110
                         0.260    0.470    0.740    1.330    2.850    6.790
                         9.840   10.100   10.100    9.900    9.620    9.320
                         9.040    8.770    8.470    8.140    7.820    7.530
                         7.240    6.970    6.710    6.460    6.220    5.970
                         5.730    5.510    5.290    5.080    4.890    4.700
                         4.520    4.340    4.170    4.020    3.860    3.700
                         3.540    3.400    3.270    3.150    3.040    2.940
                         2.820    2.700    2.580    2.470    2.360    2.270
                         2.180    2.100    2.020    1.940    1.870    1.800
                         1.720    1.630    1.540    1.450    1.370    1.300
                         1.230    1.160    1.100    1.040    0.980    0.930
                         0.880    0.830    0.790    0.740    0.700    0.670
                         0.630    0.600    0.560    0.530    0.510    0.480
                         0.450    0.430    0.410    0.390    0.370    0.350
                         0.330    0.310    0.300    0.280    0.270    0.250
                         0.240    0.230    0.220    0.210    0.200    0.190
                         0.180    0.170    0.160    0.150    0.150    0.140
                         0.130    0.130    0.120    0.120    0.110    0.110
                         0.100    0.098    0.094    0.090    0.087    0.083
                         0.080    0.077    0.074    0.072    0.069    0.067
                         0.065    0.063    0.061    0.059    0.057    0.055
                         0.054    0.052    0.051    0.050    0.048    0.047
                         0.046    0.045    0.044    0.043    0.042    0.042
                         0.041    0.040    0.039    0.039    0.038    0.038
                         0.037    0.037    0.036    0.036    0.035    0.035
                         0.035    0.034    0.034    0.034    0.033    0.033
                         0.033    0.033    0.032    0.032    0.032    0.032
                         0.032    0.032    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
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                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                          AND=BRONTE.WAT
STORE HYD           ID=3 HYD NO=6284DT= 0.2500 HRS  DA=  17.780 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0850
                           0.085    0.085    0.085    0.085    0.085    0.085
                           0.085    0.085    0.085    0.086    0.088    0.089
                           0.090    0.092    0.093    0.095    0.098    0.100
                           0.100    0.110    0.110    0.110    0.120    0.120
                           0.120    0.130    0.130    0.140    0.140    0.140
                           0.150    0.150    0.150    0.160    0.160    0.160
                           0.170    0.180    0.180    0.190    0.210    0.260
                           0.420    0.630    0.920    1.570    3.170    7.220
                          10.100   11.100   13.300   15.200   16.900   18.200
                          19.300   20.300   20.900   21.300   21.500   21.500
                          21.400   21.200   20.900   20.600   20.200   19.900
                          19.500   19.100   18.700   18.300   18.000   17.600
                          17.200   16.900   16.500   16.200   15.800   15.500
                          15.200   14.900   14.600   14.300   14.000   13.700
                          13.400   13.100   12.900   12.600   12.300   12.100
                          11.800   11.600   11.400   11.100   10.900   10.700
                          10.500   10.200   10.000    9.800    9.580    9.360
                           9.140    8.930    8.720    8.510    8.310    8.110
                           7.920    7.740    7.560    7.380    7.210    7.050
                           6.890    6.740    6.590    6.440    6.310    6.170
                           6.040    5.910    5.790    5.670    5.550    5.440
                           5.330    5.230    5.120    5.020    4.930    4.830
                           4.740    4.650    4.560    4.480    4.400    4.320
                           4.240    4.160    4.090    4.010    3.940    3.870
                           3.810    3.740    3.680    3.620    3.550    3.490
                           3.440    3.380    3.320    3.270    3.220    3.160
                           3.110    3.060    3.010    2.970    2.920    2.870
                           2.830    2.790    2.740    2.700    2.660    2.620
```

2.580	2.540	2.500	2.470	2.430	2.390
2.360	2.320	2.290	2.260	2.220	2.190
2.160	2.130	2.100	2.070	2.040	2.010
1.980	1.960	1.930	1.900	1.880	1.850
1.820	1.800	1.780	1.750	1.730	1.700
1.680	1.660	1.640	1.620	1.590	1.570
1.550	1.530	1.510	1.490	1.470	1.450
1.430	1.420	1.400	1.380	1.360	1.350
1.330	1.310	1.300	1.280	1.260	1.250
1.230	1.220	1.200	1.190	1.170	1.160
1.140	1.130	1.120	1.100	1.090	1.080
1.060	1.050	1.040	1.030	1.010	1.000
0.990	0.980	0.970	0.960	0.950	0.930
0.920	0.910	0.900	0.890	0.880	0.870
0.860	0.850	0.840	0.830	0.830	0.820
0.810	0.800	0.790	0.780	0.770	0.760
0.760	0.750	0.740	0.730	0.720	0.720
0.710	0.700	0.700	0.690	0.680	0.670
0.670	0.660	0.650	0.650	0.640	0.630
0.630	0.620	0.620	0.610	0.600	0.600
0.590	0.590	0.580	0.570	0.570	0.560
0.560	0.550	0.550	0.540	0.540	0.530
0.530	0.520	0.520	0.510	0.510	0.500
0.500	0.500	0.490	0.490	0.480	0.480
0.470	0.470	0.470	0.460	0.460	0.450
0.450	0.450	0.440	0.440	0.440	0.430
0.430	0.430	0.420	0.420	0.420	0.410
0.410	0.410	0.400	0.400	0.400	0.390
0.390	0.390	0.380	0.380	0.380	0.380
0.370	0.370	0.370	0.370	0.360	0.360
0.360	0.360	0.350	0.350	0.350	0.350
0.340	0.340	0.340	0.340	0.340	0.330
0.330	0.330	0.330	0.320	0.320	0.320
0.320	0.320	0.320	0.310	0.310	0.310
0.310	0.310	0.300	0.300	0.300	0.300
0.300	0.300	0.290	0.290	0.290	0.290
0.290	0.290	0.290	0.280	0.280	0.280
0.280	0.280	0.280	0.280	0.270	0.270
0.270	0.270	0.270	0.270	0.270	0.270
0.260	0.260	0.260	0.260	0.260	0.260
0.260	0.260	0.260	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.230	0.220
0.220	0.220	0.220	0.220	0.220	0.220
0.220	0.220	0.220	0.220	0.220	0.220
0.220	0.220	0.220	0.220	0.220	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190

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*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                         AND=BRONTE.WAT
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STORE HYD ID=2 HYD NO=1285DT= 0.2500 HRS DA= 6.230 SQ KM

HYDROGRAPH ORDINATES (CMS) INITIAL FLOW= 0.0300

0.030	0.030	0.030	0.030	0.030	0.030
0.030	0.030	0.031	0.032	0.033	0.034
0.035	0.036	0.037	0.038	0.039	0.041
0.043	0.045	0.047	0.049	0.051	0.053
0.054	0.056	0.057	0.059	0.060	0.062
0.063	0.064	0.066	0.069	0.071	0.073
0.075	0.078	0.080	0.082	0.085	0.140
0.300	0.540	0.840	1.490	3.180	7.350
10.600	11.100	11.300	11.400	11.300	11.200
11.000	10.900	10.800	10.500	10.300	10.100
9.950	9.760	9.570	9.390	9.190	8.990
8.790	8.600	8.410	8.220	8.040	7.860
7.690	7.510	7.340	7.170	7.000	6.820
6.650	6.490	6.330	6.190	6.050	5.920
5.770	5.610	5.460	5.310	5.170	5.040
4.910	4.780	4.660	4.550	4.440	4.330
4.200	4.060	3.930	3.800	3.670	3.550
3.430	3.320	3.210	3.100	3.000	2.900
2.800	2.710	2.620	2.530	2.450	2.370
2.290	2.220	2.140	2.070	2.000	1.940
1.880	1.810	1.750	1.700	1.640	1.590
1.540	1.490	1.440	1.390	1.350	1.300
1.260	1.220	1.180	1.140	1.100	1.070
1.030	1.000	0.970	0.940	0.910	0.880
0.850	0.820	0.800	0.770	0.750	0.720
0.700	0.680	0.660	0.640	0.620	0.600
0.580	0.560	0.550	0.530	0.510	0.500
0.480	0.470	0.450	0.440	0.430	0.410
0.400	0.390	0.380	0.370	0.360	0.350
0.340	0.330	0.320	0.310	0.300	0.290
0.280	0.270	0.270	0.260	0.250	0.250
0.240	0.230	0.230	0.220	0.210	0.210
0.200	0.200	0.190	0.190	0.180	0.180
0.180	0.170	0.170	0.160	0.160	0.160
0.150	0.150	0.150	0.140	0.140	0.140
0.130	0.130	0.130	0.130	0.120	0.120
0.120	0.120	0.110	0.110	0.110	0.110
0.110	0.100	0.100	0.100	0.099	0.097
0.095	0.094	0.092	0.091	0.090	0.088
0.087	0.086	0.085	0.084	0.083	0.082
0.081	0.080	0.079	0.078	0.077	0.076
0.075	0.075	0.074	0.073	0.072	0.072
0.071	0.070	0.070	0.069	0.069	0.068
0.068	0.067	0.067	0.066	0.066	0.065
0.065	0.064	0.064	0.063	0.063	0.063
0.062	0.062	0.062	0.061	0.061	0.061
0.060	0.060	0.060	0.060	0.059	0.059
0.059	0.059	0.058	0.058	0.058	0.058
0.057	0.057	0.057	0.057	0.057	0.057
0.056	0.056	0.056	0.056	0.056	0.056
0.055	0.055	0.055	0.055	0.055	0.055
0.055	0.055	0.054	0.054	0.054	0.054
0.054	0.054	0.054	0.054	0.054	0.054
0.054	0.053	0.053	0.053	0.053	0.053
0.053	0.053	0.053	0.053	0.053	0.053
0.053	0.053	0.053	0.053	0.052	0.052
0.052	0.052	0.052	0.052	0.052	0.052
0.052	0.052	0.052	0.052	0.052	0.052
0.052	0.052	0.052	0.052	0.052	0.052
0.052	0.052	0.052	0.052	0.052	0.051
0.051	0.051	0.051	0.051	0.051	0.051
0.051	0.051	0.051	0.051	0.051	0.051
0.051	0.051	0.051	0.051	0.051	0.051
0.051	0.051	0.051	0.051	0.051	0.051
0.051	0.051	0.051	0.051	0.051	0.051
0.051	0.051	0.051	0.051	0.051	0.051
0.051	0.051	0.051	0.051	0.051	0.051
0.051	0.051	0.051	0.051	0.051	0.051
0.050	0.050	0.050	0.050	0.050	0.050

```
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.050    0.050    0.050    0.050
                         0.050    0.050    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.049
                         0.049    0.049    0.049    0.049    0.049    0.047
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                          AND=BRONTE.WAT
STORE HYD           ID=3 HYD NO=6285DT= 0.2500 HRS  DA=  24.010 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.1100
                         0.110    0.110    0.110    0.110    0.110    0.110
                         0.110    0.110    0.120    0.120    0.120    0.120
                         0.120    0.120    0.120    0.130    0.130    0.130
                         0.140    0.140    0.140    0.150    0.150    0.160
                         0.160    0.170    0.170    0.180    0.180    0.190
                         0.190    0.200    0.200    0.210    0.220    0.220
                         0.230    0.230    0.240    0.240    0.250    0.310
                         0.480    0.710    1.050    1.790    3.580    7.880
                        11.100   13.000   15.900   18.000   20.000   22.000
                        23.900   25.600   27.000   28.300   29.200   30.000
                        30.500   30.700   30.800   30.700   30.500   30.100
                        29.700   29.200   28.700   28.200   27.600   27.100
                        26.500   25.900   25.400   24.900   24.300   23.800
                        23.300   22.800   22.300   21.800   21.300   20.900
                        20.400   20.000   19.500   19.100   18.700   18.200
                        17.800   17.500   17.100   16.700   16.300   16.000
                        15.600   15.300   14.900   14.500   14.200   13.800
                        13.500   13.200   12.800   12.500   12.200   11.900
                        11.600   11.300   11.000   10.700   10.400   10.200
                         9.900    9.650    9.400    9.170    8.940    8.720
                         8.500    8.300    8.100    7.900    7.720    7.530
                         7.360    7.190    7.020    6.860    6.710    6.560
                         6.410    6.270    6.130    6.000    5.870    5.740
                         5.620    5.500    5.390    5.280    5.170    5.060
                         4.960    4.860    4.760    4.670    4.570    4.480
                         4.400    4.310    4.230    4.150    4.070    3.990
                         3.920    3.850    3.780    3.710    3.640    3.570
                         3.510    3.450    3.390    3.330    3.270    3.210
                         3.160    3.100    3.050    3.000    2.950    2.900
                         2.850    2.800    2.760    2.710    2.670    2.620
                         2.580    2.540    2.500    2.460    2.420    2.380
                         2.350    2.310    2.270    2.240    2.210    2.170
                         2.140    2.110    2.080    2.050    2.020    1.990
                         1.960    1.930    1.900    1.870    1.850    1.820
                         1.790    1.770    1.740    1.720    1.700    1.670
                         1.650    1.630    1.610    1.580    1.560    1.540
                         1.520    1.500    1.480    1.460    1.440    1.420
                         1.410    1.390    1.370    1.350    1.330    1.320
                         1.300    1.280    1.270    1.250    1.240    1.220
```

1.210	1.190	1.180	1.160	1.150	1.140
1.120	1.110	1.100	1.080	1.070	1.060
1.050	1.030	1.020	1.010	1.000	0.990
0.980	0.970	0.960	0.940	0.930	0.920
0.910	0.900	0.890	0.880	0.880	0.870
0.860	0.850	0.840	0.830	0.820	0.810
0.810	0.800	0.790	0.780	0.770	0.770
0.760	0.750	0.740	0.740	0.730	0.720
0.710	0.710	0.700	0.690	0.690	0.680
0.670	0.670	0.660	0.660	0.650	0.640
0.640	0.630	0.630	0.620	0.620	0.610
0.600	0.600	0.590	0.590	0.580	0.580
0.570	0.570	0.560	0.560	0.550	0.550
0.550	0.540	0.540	0.530	0.530	0.520
0.520	0.520	0.510	0.510	0.500	0.500
0.500	0.490	0.490	0.490	0.480	0.480
0.480	0.470	0.470	0.470	0.460	0.460
0.460	0.450	0.450	0.450	0.440	0.440
0.440	0.430	0.430	0.430	0.430	0.420
0.420	0.420	0.420	0.410	0.410	0.410
0.410	0.400	0.400	0.400	0.400	0.390
0.390	0.390	0.390	0.380	0.380	0.380
0.380	0.380	0.370	0.370	0.370	0.370
0.370	0.360	0.360	0.360	0.360	0.360
0.360	0.350	0.350	0.350	0.350	0.350
0.350	0.340	0.340	0.340	0.340	0.340
0.340	0.340	0.330	0.330	0.330	0.330
0.330	0.330	0.330	0.320	0.320	0.320
0.320	0.320	0.320	0.320	0.320	0.310
0.310	0.310	0.310	0.310	0.310	0.310
0.310	0.310	0.300	0.300	0.300	0.300
0.300	0.300	0.300	0.300	0.300	0.300
0.290	0.290	0.290	0.290	0.290	0.290
0.290	0.290	0.290	0.290	0.290	0.290
0.290	0.280	0.280	0.280	0.280	0.280
0.280	0.280	0.280	0.280	0.280	0.280
0.280	0.280	0.280	0.270	0.270	0.270
0.270	0.270	0.270	0.270	0.270	0.270
0.270	0.270	0.270	0.270	0.270	0.270
0.270	0.270	0.270	0.260	0.260	0.260
0.260	0.260	0.260	0.260	0.260	0.260
0.260	0.260	0.260	0.260	0.260	0.260
0.260	0.260	0.260	0.260	0.260	0.260
0.260	0.260	0.260	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240

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*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                            AND=BRONTE.WAT
STORE HYD            ID=1 HYD NO=1291DT= 0.2500 HRS  DA=   2.430 SQ KM
                      HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0120
```

0.012	0.012	0.012	0.012	0.012	0.012
0.012	0.012	0.012	0.012	0.012	0.012
0.012	0.013	0.013	0.013	0.014	0.014
0.014	0.015	0.015	0.016	0.016	0.017
0.017	0.018	0.018	0.019	0.019	0.020
0.020	0.020	0.021	0.021	0.022	0.023
0.023	0.024	0.025	0.025	0.026	0.030
0.047	0.086	0.150	0.240	0.450	0.950
1.770	2.480	2.780	2.870	2.910	2.930

2.940	2.940	2.940	2.930	2.910	2.890
2.870	2.840	2.820	2.800	2.770	2.740
2.720	2.690	2.660	2.630	2.600	2.570
2.540	2.500	2.470	2.440	2.410	2.380
2.350	2.310	2.280	2.250	2.220	2.190
2.160	2.130	2.100	2.060	2.030	2.000
1.970	1.940	1.910	1.880	1.850	1.820
1.790	1.760	1.720	1.690	1.660	1.620
1.590	1.560	1.520	1.490	1.460	1.430
1.400	1.380	1.350	1.320	1.290	1.270
1.240	1.220	1.190	1.170	1.140	1.120
1.100	1.080	1.060	1.030	1.010	0.990
0.970	0.950	0.930	0.910	0.900	0.880
0.860	0.840	0.830	0.810	0.790	0.780
0.760	0.750	0.730	0.720	0.700	0.690
0.680	0.660	0.650	0.640	0.620	0.610
0.600	0.590	0.570	0.560	0.550	0.540
0.530	0.520	0.510	0.500	0.490	0.480
0.470	0.460	0.450	0.440	0.430	0.430
0.420	0.410	0.400	0.390	0.390	0.380
0.370	0.360	0.360	0.350	0.340	0.340
0.330	0.320	0.320	0.310	0.310	0.300
0.290	0.290	0.280	0.280	0.270	0.270
0.260	0.260	0.250	0.250	0.240	0.240
0.230	0.230	0.220	0.220	0.220	0.210
0.210	0.200	0.200	0.200	0.190	0.190
0.190	0.180	0.180	0.180	0.170	0.170
0.170	0.160	0.160	0.160	0.160	0.150
0.150	0.150	0.140	0.140	0.140	0.140
0.130	0.130	0.130	0.130	0.130	0.120
0.120	0.120	0.120	0.120	0.110	0.110
0.110	0.110	0.110	0.100	0.100	0.100
0.099	0.097	0.096	0.094	0.093	0.091
0.090	0.089	0.087	0.086	0.084	0.083
0.082	0.081	0.079	0.078	0.077	0.076
0.075	0.074	0.072	0.071	0.070	0.069
0.068	0.067	0.066	0.065	0.064	0.064
0.063	0.062	0.061	0.060	0.059	0.058
0.058	0.057	0.056	0.055	0.055	0.054
0.053	0.053	0.052	0.051	0.051	0.050
0.049	0.049	0.048	0.048	0.047	0.046
0.046	0.045	0.045	0.044	0.044	0.043
0.043	0.042	0.042	0.042	0.041	0.041
0.040	0.040	0.039	0.039	0.039	0.038
0.038	0.037	0.037	0.037	0.036	0.036
0.036	0.035	0.035	0.035	0.034	0.034
0.034	0.034	0.033	0.033	0.033	0.032
0.032	0.032	0.032	0.031	0.031	0.031
0.031	0.030	0.030	0.030	0.030	0.030
0.029	0.029	0.029	0.029	0.029	0.028
0.028	0.028	0.028	0.028	0.028	0.027
0.027	0.027	0.027	0.027	0.027	0.026
0.026	0.026	0.026	0.026	0.026	0.026
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.023	0.023	0.023	0.023	0.023
0.023	0.023	0.023	0.023	0.023	0.023
0.023	0.023	0.022	0.022	0.022	0.022
0.022	0.022	0.022	0.022	0.022	0.022
0.022	0.022	0.022	0.022	0.022	0.022
0.022	0.021	0.021	0.021	0.021	0.021
0.021	0.021	0.021	0.021	0.021	0.021
0.021	0.021	0.021	0.021	0.021	0.021
0.021	0.021	0.021	0.021	0.021	0.021
0.021	0.021	0.020	0.020	0.020	0.020
0.020	0.020	0.020	0.020	0.020	0.020
0.020	0.020	0.020	0.020	0.020	0.020
0.020	0.020	0.020	0.020	0.020	0.020
0.020	0.020	0.020	0.020	0.020	0.020
0.020	0.020	0.020	0.020	0.020	0.020

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                         0.020    0.020    0.020    0.020    0.020    0.020
                         0.020    0.020    0.020    0.020    0.020    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.019
                         0.019    0.019    0.019    0.019    0.019    0.018
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                          AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=1292DT= 0.2500 HRS  DA=   1.420 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0068
                         0.007    0.007    0.007    0.007    0.007    0.007
                         0.007    0.007    0.007    0.007    0.008    0.008
                         0.008    0.008    0.009    0.009    0.009    0.010
                         0.010    0.011    0.011    0.012    0.012    0.013
                         0.013    0.014    0.014    0.014    0.015    0.015
                         0.015    0.016    0.016    0.017    0.017    0.018
                         0.019    0.019    0.020    0.020    0.021    0.034
                         0.078    0.140    0.220    0.390    0.820    1.940
                         2.820    2.940    2.970    2.960    2.910    2.860
                         2.810    2.770    2.710    2.640    2.570    2.500
                         2.440    2.380    2.320    2.260    2.200    2.140
                         2.080    2.020    1.960    1.910    1.860    1.810
                         1.750    1.700    1.660    1.610    1.560    1.520
                         1.470    1.420    1.380    1.350    1.310    1.270
                         1.240    1.200    1.160    1.120    1.080    1.050
                         1.020    0.990    0.960    0.930    0.900    0.880
                         0.850    0.810    0.780    0.750    0.720    0.690
                         0.660    0.630    0.610    0.580    0.560    0.540
                         0.520    0.500    0.480    0.460    0.440    0.420
                         0.410    0.390    0.370    0.360    0.350    0.330
                         0.320    0.310    0.290    0.280    0.270    0.260
                         0.250    0.240    0.230    0.220    0.210    0.210
                         0.200    0.190    0.180    0.180    0.170    0.160
                         0.160    0.150    0.140    0.140    0.130    0.130
                         0.120    0.120    0.120    0.110    0.110    0.100
                         0.099    0.095    0.092    0.089    0.085    0.082
                         0.079    0.077    0.074    0.071    0.069    0.067
                         0.064    0.062    0.060    0.058    0.056    0.054
                         0.052    0.051    0.049    0.048    0.046    0.045
                         0.043    0.042    0.041    0.039    0.038    0.037
                         0.036    0.035    0.034    0.033    0.032    0.031
                         0.031    0.030    0.029    0.028    0.028    0.027
                         0.026    0.026    0.025    0.024    0.024    0.023
                         0.023    0.022    0.022    0.022    0.021    0.021
                         0.020    0.020    0.020    0.019    0.019    0.019
                         0.018    0.018    0.018    0.018    0.017    0.017
                         0.017    0.017    0.016    0.016    0.016    0.016
                         0.016    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.014    0.014    0.014    0.014
                         0.014    0.014    0.014    0.014    0.014    0.014
                         0.014    0.013    0.013    0.013    0.013    0.013
                         0.013    0.013    0.013    0.013    0.013    0.013
                         0.013    0.013    0.013    0.013    0.013    0.013
                         0.013    0.013    0.013    0.013    0.013    0.012
                         0.012    0.012    0.012    0.012    0.012    0.012
                         0.012    0.012    0.012    0.012    0.012    0.012
                         0.012    0.012    0.012    0.012    0.012    0.012
                         0.012    0.012    0.012    0.012    0.012    0.012
                         0.012    0.012    0.012    0.012    0.012    0.012
                         0.012    0.012    0.012    0.012    0.012    0.012
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                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.012    0.012    0.012    0.012
                                 0.012    0.012    0.011    0.011    0.011    0.011
                                 0.011    0.011    0.011    0.011    0.011    0.011
                                 0.011    0.011    0.011    0.011    0.011    0.011
                                 0.011    0.011    0.011    0.011    0.011    0.011
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                         AND=BRONTE.WAT
STORE HYD            ID=4 HYD NO=6292DT= 0.2500 HRS  DA=   3.850 SQ KM
                      HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0180
                                 0.018    0.018    0.018    0.018    0.018    0.018
                                 0.018    0.018    0.018    0.019    0.019    0.020
                                 0.020    0.021    0.021    0.022    0.022    0.023
                                 0.024    0.025    0.026    0.027    0.028    0.029
                                 0.030    0.030    0.031    0.032    0.033    0.034
                                 0.034    0.035    0.036    0.037    0.038    0.039
                                 0.040    0.042    0.043    0.044    0.045    0.059
                                 0.100    0.170    0.260    0.460    0.940    2.120
                                 3.230    3.930    4.710    5.250    5.510    5.630
                                 5.670    5.670    5.630    5.570    5.500    5.430
                                 5.350    5.270    5.190    5.110    5.020    4.940
                                 4.860    4.770    4.690    4.600    4.520    4.440
                                 4.360    4.280    4.200    4.120    4.040    3.970
                                 3.890    3.810    3.740    3.670    3.600    3.530
                                 3.460    3.390    3.330    3.260    3.190    3.120
                                 3.050    2.990    2.930    2.870    2.810    2.760
                                 2.700    2.640    2.580    2.510    2.450    2.390
                                 2.320    2.260    2.210    2.150    2.090    2.040
                                 1.990    1.940    1.890    1.840    1.800    1.750
                                 1.710    1.660    1.620    1.580    1.540    1.510
```

1.470	1.430	1.400	1.360	1.330	1.300
1.270	1.240	1.210	1.180	1.150	1.130
1.100	1.070	1.050	1.020	1.000	0.980
0.950	0.930	0.910	0.890	0.870	0.850
0.830	0.810	0.790	0.780	0.760	0.740
0.720	0.710	0.690	0.680	0.660	0.650
0.630	0.620	0.610	0.590	0.580	0.570
0.560	0.540	0.530	0.520	0.510	0.500
0.490	0.480	0.470	0.460	0.450	0.440
0.430	0.420	0.410	0.410	0.400	0.390
0.380	0.370	0.370	0.360	0.350	0.340
0.340	0.330	0.320	0.320	0.310	0.310
0.300	0.290	0.290	0.280	0.280	0.270
0.270	0.260	0.260	0.250	0.250	0.240
0.240	0.230	0.230	0.220	0.220	0.220
0.210	0.210	0.210	0.200	0.200	0.190
0.190	0.190	0.180	0.180	0.180	0.170
0.170	0.170	0.170	0.160	0.160	0.160
0.150	0.150	0.150	0.150	0.140	0.140
0.140	0.140	0.140	0.130	0.130	0.130
0.130	0.130	0.120	0.120	0.120	0.120
0.120	0.110	0.110	0.110	0.110	0.110
0.110	0.100	0.100	0.100	0.100	0.099
0.097	0.096	0.095	0.093	0.092	0.091
0.090	0.089	0.087	0.086	0.085	0.084
0.083	0.082	0.081	0.080	0.079	0.078
0.077	0.076	0.075	0.074	0.073	0.072
0.072	0.071	0.070	0.069	0.068	0.068
0.067	0.066	0.066	0.065	0.064	0.063
0.063	0.062	0.062	0.061	0.060	0.060
0.059	0.059	0.058	0.057	0.057	0.056
0.056	0.055	0.055	0.054	0.054	0.053
0.053	0.053	0.052	0.052	0.051	0.051
0.050	0.050	0.050	0.049	0.049	0.049
0.048	0.048	0.048	0.047	0.047	0.047
0.046	0.046	0.046	0.045	0.045	0.045
0.044	0.044	0.044	0.044	0.043	0.043
0.043	0.043	0.042	0.042	0.042	0.042
0.042	0.041	0.041	0.041	0.041	0.041
0.040	0.040	0.040	0.040	0.040	0.039
0.039	0.039	0.039	0.039	0.039	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.037	0.037	0.037	0.037	0.037	0.037
0.037	0.037	0.036	0.036	0.036	0.036
0.036	0.036	0.036	0.036	0.036	0.036
0.035	0.035	0.035	0.035	0.035	0.035
0.035	0.035	0.035	0.035	0.035	0.035
0.034	0.034	0.034	0.034	0.034	0.034
0.034	0.034	0.034	0.034	0.034	0.034
0.034	0.034	0.034	0.033	0.033	0.033
0.033	0.033	0.033	0.033	0.033	0.033
0.033	0.033	0.033	0.033	0.033	0.033
0.033	0.033	0.033	0.033	0.033	0.033
0.032	0.032	0.032	0.032	0.032	0.032
0.032	0.032	0.032	0.032	0.032	0.032
0.032	0.032	0.032	0.032	0.032	0.032
0.032	0.032	0.032	0.032	0.032	0.032
0.032	0.032	0.032	0.032	0.032	0.032
0.032	0.032	0.032	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.031	0.030	0.030	0.030	0.030	0.030
0.030	0.030	0.030	0.030	0.030	0.030

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                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                           AND=BRONTE.WAT
STORE HYD           ID=2 HYD NO=1293DT= 0.2500 HRS  DA=   0.940 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0045
                         0.004    0.004    0.004    0.004    0.004    0.004
                         0.004    0.004    0.005    0.005    0.005    0.005
                         0.005    0.006    0.006    0.006    0.006    0.007
                         0.007    0.007    0.008    0.008    0.008    0.009
                         0.009    0.009    0.009    0.010    0.010    0.010
                         0.010    0.011    0.011    0.011    0.012    0.012
                         0.013    0.013    0.013    0.014    0.014    0.025
                         0.059    0.110    0.170    0.300    0.640    1.470
                         2.100    2.180    2.200    2.190    2.150    2.110
                         2.070    2.030    1.980    1.930    1.880    1.820
                         1.770    1.720    1.680    1.630    1.590    1.540
                         1.490    1.450    1.410    1.360    1.320    1.280
                         1.250    1.210    1.170    1.140    1.100    1.070
                         1.030    1.000    0.970    0.940    0.910    0.890
                         0.860    0.830    0.800    0.770    0.740    0.720
                         0.700    0.680    0.650    0.630    0.610    0.600
                         0.570    0.550    0.530    0.500    0.480    0.460
                         0.440    0.420    0.400    0.390    0.370    0.350
                         0.340    0.320    0.310    0.300    0.280    0.270
                         0.260    0.250    0.240    0.230    0.220    0.210
                         0.200    0.190    0.180    0.180    0.170    0.160
                         0.150    0.150    0.140    0.140    0.130    0.130
                         0.120    0.120    0.110    0.110    0.100    0.097
                         0.093    0.090    0.086    0.083    0.079    0.076
                         0.073    0.070    0.067    0.065    0.062    0.060
                         0.057    0.055    0.053    0.051    0.049    0.047
                         0.046    0.044    0.042    0.041    0.039    0.038
                         0.036    0.035    0.034    0.033    0.032    0.031
                         0.030    0.029    0.028    0.027    0.026    0.025
                         0.024    0.024    0.023    0.022    0.021    0.021
                         0.020    0.020    0.019    0.019    0.018    0.018
                         0.017    0.017    0.016    0.016    0.016    0.015
                         0.015    0.015    0.014    0.014    0.014    0.013
                         0.013    0.013    0.013    0.012    0.012    0.012
                         0.012    0.012    0.011    0.011    0.011    0.011
                         0.011    0.011    0.011    0.010    0.010    0.010
                         0.010    0.010    0.010    0.010    0.010    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.008    0.008
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                                   0.008    0.008    0.008    0.008    0.008    0.008
                                   0.008    0.008    0.008    0.008    0.008    0.008
                                   0.008    0.008    0.008    0.008    0.008    0.008
                                   0.008    0.008    0.008    0.008    0.008    0.008
                                   0.008    0.008    0.008    0.008    0.008    0.008
                                   0.008    0.008    0.008    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
                                   0.007    0.007    0.007    0.007    0.007    0.007
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                         AND=BRONTE.WAT
STORE HYD           ID=4 HYD NO=6293DT= 0.2500 HRS  DA=   4.790 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0230
                                   0.023    0.023    0.023    0.023    0.023    0.023
                                   0.023    0.023    0.023    0.023    0.024    0.024
                                   0.025    0.025    0.026    0.027    0.028    0.029
                                   0.030    0.031    0.032    0.033    0.035    0.036
                                   0.037    0.038    0.039    0.041    0.042    0.043
                                   0.044    0.045    0.046    0.047    0.048    0.050
                                   0.051    0.053    0.054    0.056    0.058    0.069
                                   0.110    0.190    0.300    0.510    1.000    2.170
                                   3.710    4.850    5.680    6.470    7.070    7.420
                                   7.590    7.650    7.640    7.570    7.470    7.360
                                   7.240    7.120    6.990    6.860    6.740    6.610
                                   6.480    6.350    6.220    6.100    5.970    5.850
                                   5.730    5.610    5.490    5.380    5.270    5.150
                                   5.040    4.930    4.820    4.720    4.620    4.520
                                   4.430    4.330    4.230    4.130    4.040    3.950
                                   3.850    3.770    3.680    3.600    3.520    3.440
                                   3.360    3.280    3.200    3.110    3.030    2.940
                                   2.860    2.780    2.700    2.620    2.550    2.480
                                   2.410    2.340    2.280    2.210    2.150    2.090
                                   2.040    1.980    1.930    1.870    1.820    1.780
                                   1.730    1.680    1.640    1.590    1.550    1.510
                                   1.470    1.430    1.400    1.360    1.330    1.290
                                   1.260    1.230    1.200    1.170    1.140    1.110
                                   1.080    1.060    1.030    1.010    0.980    0.960
                                   0.930    0.910    0.890    0.870    0.850    0.830
                                   0.810    0.790    0.770    0.750    0.740    0.720
                                   0.700    0.690    0.670    0.660    0.640    0.630
                                   0.610    0.600    0.590    0.570    0.560    0.550
                                   0.540    0.520    0.510    0.500    0.490    0.480
                                   0.470    0.460    0.450    0.440    0.430    0.420
                                   0.410    0.410    0.400    0.390    0.380    0.370
```

0.370	0.360	0.350	0.340	0.340	0.330
0.320	0.320	0.310	0.310	0.300	0.290
0.290	0.280	0.280	0.270	0.270	0.260
0.260	0.250	0.250	0.240	0.240	0.230
0.230	0.230	0.220	0.220	0.210	0.210
0.210	0.200	0.200	0.200	0.190	0.190
0.190	0.180	0.180	0.180	0.170	0.170
0.170	0.170	0.160	0.160	0.160	0.150
0.150	0.150	0.150	0.150	0.140	0.140
0.140	0.140	0.130	0.130	0.130	0.130
0.130	0.130	0.120	0.120	0.120	0.120
0.120	0.120	0.110	0.110	0.110	0.110
0.110	0.110	0.100	0.100	0.100	0.100
0.100	0.098	0.097	0.096	0.095	0.094
0.093	0.092	0.090	0.089	0.088	0.087
0.086	0.085	0.084	0.084	0.083	0.082
0.081	0.080	0.079	0.078	0.078	0.077
0.076	0.075	0.074	0.074	0.073	0.072
0.072	0.071	0.070	0.070	0.069	0.068
0.068	0.067	0.067	0.066	0.066	0.065
0.064	0.064	0.063	0.063	0.062	0.062
0.061	0.061	0.061	0.060	0.060	0.059
0.059	0.058	0.058	0.058	0.057	0.057
0.056	0.056	0.056	0.055	0.055	0.055
0.054	0.054	0.054	0.053	0.053	0.053
0.053	0.052	0.052	0.052	0.052	0.051
0.051	0.051	0.051	0.050	0.050	0.050
0.050	0.049	0.049	0.049	0.049	0.049
0.048	0.048	0.048	0.048	0.048	0.047
0.047	0.047	0.047	0.047	0.047	0.046
0.046	0.046	0.046	0.046	0.046	0.045
0.045	0.045	0.045	0.045	0.045	0.045
0.045	0.044	0.044	0.044	0.044	0.044
0.044	0.044	0.044	0.043	0.043	0.043
0.043	0.043	0.043	0.043	0.043	0.043
0.043	0.043	0.042	0.042	0.042	0.042
0.042	0.042	0.042	0.042	0.042	0.042
0.042	0.042	0.042	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.039	0.039	0.039	0.039
0.039	0.039	0.039	0.039	0.039	0.039
0.039	0.039	0.039	0.039	0.039	0.039
0.039	0.039	0.039	0.039	0.039	0.039
0.039	0.039	0.039	0.039	0.039	0.039
0.039	0.039	0.039	0.039	0.039	0.039
0.039	0.039	0.039	0.039	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.038	0.038	0.038	0.038	0.038	0.038
0.037	0.037	0.037	0.037	0.037	0.037
0.037	0.037	0.037	0.037	0.037	0.037
0.037	0.037	0.037	0.037	0.037	0.037

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*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                        AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=6294DT= 0.2500 HRS  DA=  28.800 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.1400
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0.140	0.140	0.140	0.140	0.140	0.140

0.140	0.140	0.140	0.140	0.140	0.140
0.150	0.150	0.150	0.150	0.160	0.160
0.170	0.170	0.180	0.180	0.190	0.190
0.200	0.210	0.210	0.220	0.230	0.230
0.240	0.240	0.250	0.260	0.260	0.270
0.280	0.290	0.290	0.300	0.310	0.380
0.590	0.900	1.350	2.300	4.580	10.000
14.800	17.800	21.600	24.500	27.100	29.400
31.500	33.200	34.700	35.800	36.700	37.300
37.700	37.900	37.800	37.600	37.200	36.700
36.200	35.600	34.900	34.300	33.600	32.900
32.200	31.500	30.900	30.200	29.600	28.900
28.300	27.700	27.100	26.500	25.900	25.400
24.800	24.300	23.800	23.200	22.700	22.200
21.700	21.200	20.800	20.300	19.900	19.400
19.000	18.500	18.100	17.700	17.200	16.800
16.400	16.000	15.500	15.100	14.700	14.400
14.000	13.600	13.300	12.900	12.600	12.200
11.900	11.600	11.300	11.000	10.800	10.500
10.200	9.980	9.740	9.500	9.270	9.050
8.830	8.620	8.420	8.220	8.030	7.850
7.670	7.500	7.330	7.170	7.010	6.850
6.700	6.560	6.420	6.280	6.150	6.020
5.890	5.770	5.650	5.530	5.420	5.310
5.200	5.100	5.000	4.900	4.810	4.710
4.620	4.530	4.450	4.360	4.280	4.200
4.120	4.040	3.970	3.900	3.830	3.760
3.690	3.620	3.560	3.500	3.440	3.380
3.320	3.260	3.210	3.150	3.100	3.050
2.990	2.940	2.900	2.850	2.800	2.760
2.710	2.670	2.630	2.580	2.540	2.500
2.460	2.430	2.390	2.350	2.310	2.280
2.240	2.210	2.180	2.150	2.110	2.080
2.050	2.020	1.990	1.960	1.930	1.910
1.880	1.850	1.830	1.800	1.780	1.750
1.730	1.700	1.680	1.660	1.630	1.610
1.590	1.570	1.550	1.530	1.510	1.490
1.470	1.450	1.430	1.410	1.390	1.380
1.360	1.340	1.330	1.310	1.290	1.280
1.260	1.250	1.230	1.220	1.200	1.190
1.170	1.160	1.150	1.130	1.120	1.110
1.090	1.080	1.070	1.060	1.050	1.030
1.020	1.010	1.000	0.990	0.980	0.970
0.960	0.950	0.940	0.930	0.920	0.910
0.900	0.890	0.880	0.870	0.860	0.850
0.840	0.840	0.830	0.820	0.810	0.800
0.790	0.790	0.780	0.770	0.760	0.760
0.750	0.740	0.740	0.730	0.720	0.720
0.710	0.700	0.700	0.690	0.680	0.680
0.670	0.670	0.660	0.650	0.650	0.640
0.640	0.630	0.630	0.620	0.620	0.610
0.610	0.600	0.600	0.590	0.590	0.580
0.580	0.570	0.570	0.570	0.560	0.560
0.550	0.550	0.550	0.540	0.540	0.530
0.530	0.530	0.520	0.520	0.520	0.510
0.510	0.500	0.500	0.500	0.490	0.490
0.490	0.490	0.480	0.480	0.480	0.470
0.470	0.470	0.460	0.460	0.460	0.460
0.450	0.450	0.450	0.450	0.440	0.440
0.440	0.440	0.430	0.430	0.430	0.430
0.420	0.420	0.420	0.420	0.420	0.410
0.410	0.410	0.410	0.410	0.400	0.400
0.400	0.400	0.400	0.390	0.390	0.390
0.390	0.390	0.390	0.380	0.380	0.380
0.380	0.380	0.380	0.380	0.370	0.370
0.370	0.370	0.370	0.370	0.370	0.360
0.360	0.360	0.360	0.360	0.360	0.360
0.350	0.350	0.350	0.350	0.350	0.350
0.350	0.350	0.350	0.340	0.340	0.340
0.340	0.340	0.340	0.340	0.340	0.340
0.340	0.330	0.330	0.330	0.330	0.330

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                         0.330    0.330    0.330    0.330    0.330    0.330
                         0.330    0.320    0.320    0.320    0.320    0.320
                         0.320    0.320    0.320    0.320    0.320    0.320
                         0.320    0.320    0.310    0.310    0.310    0.310
                         0.310    0.310    0.310    0.310    0.310    0.310
                         0.310    0.310    0.310    0.310    0.310    0.310
                         0.310    0.300    0.300    0.300    0.300    0.300
                         0.300    0.300    0.300    0.300    0.300    0.300
                         0.300    0.300    0.300    0.300    0.300    0.300
                         0.300    0.300    0.300    0.300    0.300    0.290
                         0.290    0.290    0.290    0.290    0.290    0.290
                         0.290    0.290    0.290    0.290    0.290    0.290
                         0.290    0.290    0.290    0.290    0.290    0.290
                         0.290    0.290    0.290    0.290    0.290    0.290
                         0.290    0.290    0.290    0.290    0.290    0.280
                         0.280    0.280    0.280    0.280    0.280    0.280
                         0.280    0.280    0.280    0.280    0.280    0.280
                         0.280    0.280    0.280    0.280    0.280    0.280
                         0.280    0.280    0.280    0.280    0.280    0.280
                         0.280    0.280    0.280    0.280    0.280    0.280
                         0.280    0.280    0.280    0.280    0.280    0.280
                         0.280    0.280    0.280    0.280    0.280    0.280
                         0.280    0.280    0.280    0.280    0.280    0.270
                         0.270    0.270    0.270    0.270    0.270    0.270
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                           AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=1301DT= 0.2500 HRS  DA=   4.930 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0240
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.024    0.024    0.025    0.026    0.027
                         0.028    0.029    0.030    0.031    0.032    0.034
                         0.036    0.038    0.039    0.041    0.043    0.044
                         0.046    0.047    0.048    0.049    0.051    0.052
                         0.053    0.054    0.056    0.059    0.063    0.067
                         0.070    0.074    0.077    0.080    0.085    0.140
                         0.290    0.510    0.790    1.390    2.960    6.830
                         9.850   10.300   10.400   10.300   10.200   10.100
                         9.900    9.750    9.550    9.320    9.090    8.870
                         8.660    8.450    8.240    8.050    7.840    7.630
                         7.430    7.230    7.040    6.850    6.670    6.490
                         6.320    6.140    5.980    5.820    5.650    5.480
                         5.320    5.170    5.020    4.890    4.760    4.640
                         4.500    4.360    4.220    4.090    3.960    3.840
                         3.730    3.620    3.510    3.410    3.320    3.220
                         3.110    2.990    2.880    2.760    2.660    2.550
                         2.450    2.360    2.270    2.180    2.090    2.010
                         1.930    1.860    1.790    1.720    1.650    1.590
                         1.530    1.470    1.410    1.360    1.300    1.250
                         1.210    1.160    1.110    1.070    1.030    0.990
                         0.950    0.920    0.880    0.850    0.820    0.790
                         0.760    0.730    0.700    0.670    0.650    0.630
                         0.600    0.580    0.560    0.540    0.520    0.500
                         0.480    0.460    0.450    0.430    0.410    0.400
                         0.380    0.370    0.360    0.350    0.330    0.320
                         0.310    0.300    0.290    0.280    0.270    0.260
                         0.250    0.240    0.230    0.230    0.220    0.210
                         0.210    0.200    0.190    0.190    0.180    0.170
                         0.170    0.160    0.160    0.150    0.150    0.150
                         0.140    0.140    0.130    0.130    0.130    0.120
                         0.120    0.120    0.110    0.110    0.110    0.100
                         0.100    0.099    0.097    0.094    0.092    0.090
                         0.088    0.086    0.084    0.083    0.081    0.079
                         0.078    0.076    0.075    0.073    0.072    0.071
                         0.069    0.068    0.067    0.066    0.065    0.064
                         0.063    0.062    0.061    0.060    0.060    0.059
                         0.058    0.057    0.057    0.056    0.055    0.055
                         0.054    0.054    0.053    0.053    0.052    0.052
                         0.051    0.051    0.050    0.050    0.050    0.049
                         0.049    0.049    0.048    0.048    0.048    0.047
                         0.047    0.047    0.047    0.046    0.046    0.046
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                          0.046    0.046    0.045    0.045    0.045    0.045
                          0.045    0.045    0.045    0.044    0.044    0.044
                          0.044    0.044    0.044    0.044    0.044    0.043
                          0.043    0.043    0.043    0.043    0.043    0.043
                          0.043    0.043    0.043    0.043    0.042    0.042
                          0.042    0.042    0.042    0.042    0.042    0.042
                          0.042    0.042    0.042    0.042    0.042    0.042
                          0.042    0.042    0.042    0.042    0.042    0.041
                          0.041    0.041    0.041    0.041    0.041    0.041
                          0.041    0.041    0.041    0.041    0.041    0.041
                          0.041    0.041    0.041    0.041    0.041    0.041
                          0.041    0.041    0.041    0.041    0.041    0.041
                          0.041    0.041    0.041    0.041    0.041    0.041
                          0.041    0.041    0.041    0.041    0.041    0.041
                          0.041    0.041    0.041    0.041    0.041    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.040    0.040    0.040    0.040    0.040    0.040
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.039    0.039    0.039    0.039    0.039
                          0.039    0.038    0.038    0.038    0.038    0.038
                          0.038    0.038    0.038    0.038    0.038    0.038
                          0.038    0.038    0.038    0.038    0.038    0.037
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                          AND=BRONTE.WAT
STORE HYD           ID=3 HYD NO=6301DT= 0.2500 HRS  DA=  33.730 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.1600
                          0.160    0.160    0.160    0.160    0.160    0.160
                          0.160    0.160    0.160    0.160    0.160    0.160
                          0.170    0.170    0.170    0.170    0.180    0.180
                          0.180    0.190    0.190    0.200    0.200    0.210
                          0.220    0.220    0.230    0.240    0.240    0.250
                          0.260    0.270    0.270    0.280    0.290    0.300
                          0.310    0.320    0.330    0.340    0.350    0.420
                          0.580    0.760    1.040    1.710    3.380    7.340
                          9.850   10.900   13.700   16.700   20.100   23.600
                         26.900   30.000   32.800   35.300   37.500   39.400
                         41.000   42.400   43.400   44.200   44.700   45.000
                         45.000   44.800   44.500   44.000   43.400   42.700
```

42.000	41.200	40.400	39.600	38.700	37.900
37.100	36.300	35.500	34.700	33.900	33.200
32.400	31.700	30.900	30.200	29.500	28.900
28.200	27.500	26.900	26.300	25.700	25.100
24.500	23.900	23.300	22.800	22.200	21.700
21.100	20.600	20.100	19.500	19.000	18.500
18.000	17.500	17.100	16.600	16.100	15.700
15.300	14.800	14.400	14.000	13.700	13.300
12.900	12.600	12.300	11.900	11.600	11.300
11.000	10.700	10.500	10.200	9.940	9.690
9.450	9.220	8.990	8.770	8.560	8.360
8.160	7.970	7.780	7.600	7.420	7.250
7.090	6.930	6.770	6.620	6.480	6.330
6.200	6.060	5.930	5.800	5.680	5.560
5.450	5.330	5.220	5.120	5.010	4.910
4.810	4.720	4.620	4.530	4.450	4.360
4.280	4.190	4.110	4.040	3.960	3.890
3.820	3.750	3.680	3.610	3.550	3.480
3.420	3.360	3.300	3.240	3.190	3.130
3.080	3.030	2.980	2.930	2.880	2.830
2.780	2.740	2.690	2.650	2.610	2.570
2.530	2.490	2.450	2.410	2.370	2.340
2.300	2.260	2.230	2.200	2.160	2.130
2.100	2.070	2.040	2.010	1.980	1.950
1.920	1.900	1.870	1.840	1.820	1.790
1.770	1.740	1.720	1.700	1.680	1.650
1.630	1.610	1.590	1.570	1.550	1.530
1.510	1.490	1.470	1.450	1.430	1.410
1.400	1.380	1.360	1.350	1.330	1.310
1.300	1.280	1.270	1.250	1.240	1.220
1.210	1.200	1.180	1.170	1.160	1.140
1.130	1.120	1.110	1.090	1.080	1.070
1.060	1.050	1.040	1.020	1.010	1.000
0.990	0.980	0.970	0.960	0.950	0.940
0.930	0.920	0.920	0.910	0.900	0.890
0.880	0.870	0.860	0.860	0.850	0.840
0.830	0.820	0.820	0.810	0.800	0.790
0.790	0.780	0.770	0.770	0.760	0.750
0.750	0.740	0.730	0.730	0.720	0.720
0.710	0.700	0.700	0.690	0.690	0.680
0.680	0.670	0.670	0.660	0.650	0.650
0.650	0.640	0.640	0.630	0.630	0.620
0.620	0.610	0.610	0.600	0.600	0.600
0.590	0.590	0.580	0.580	0.580	0.570
0.570	0.560	0.560	0.560	0.550	0.550
0.550	0.540	0.540	0.540	0.530	0.530
0.530	0.520	0.520	0.520	0.510	0.510
0.510	0.510	0.500	0.500	0.500	0.490
0.490	0.490	0.490	0.480	0.480	0.480
0.480	0.470	0.470	0.470	0.470	0.470
0.460	0.460	0.460	0.460	0.450	0.450
0.450	0.450	0.450	0.440	0.440	0.440
0.440	0.440	0.440	0.430	0.430	0.430
0.430	0.430	0.430	0.420	0.420	0.420
0.420	0.420	0.420	0.410	0.410	0.410
0.410	0.410	0.410	0.410	0.400	0.400
0.400	0.400	0.400	0.400	0.400	0.390
0.390	0.390	0.390	0.390	0.390	0.390
0.390	0.390	0.380	0.380	0.380	0.380
0.380	0.380	0.380	0.380	0.380	0.380
0.370	0.370	0.370	0.370	0.370	0.370
0.370	0.370	0.370	0.370	0.370	0.360
0.360	0.360	0.360	0.360	0.360	0.360
0.360	0.360	0.360	0.360	0.360	0.360
0.360	0.350	0.350	0.350	0.350	0.350
0.350	0.350	0.350	0.350	0.350	0.350
0.350	0.350	0.350	0.350	0.350	0.340
0.340	0.340	0.340	0.340	0.340	0.340
0.340	0.340	0.340	0.340	0.340	0.340
0.340	0.340	0.340	0.340	0.340	0.340
0.340	0.340	0.330	0.330	0.330	0.330

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                           0.330    0.330    0.330    0.330    0.330    0.330
                           0.330    0.330    0.330    0.330    0.330    0.330
                           0.330    0.330    0.330    0.330    0.330    0.330
                           0.330    0.330    0.330    0.330    0.330    0.330
                           0.320    0.320    0.320    0.320    0.320    0.320
                           0.320    0.320    0.320    0.320    0.320    0.320
                           0.320    0.320    0.320    0.320    0.320    0.320
                           0.320    0.320    0.320    0.320    0.320    0.320
                           0.320    0.320    0.320    0.320    0.320    0.320
                           0.320    0.320    0.320    0.320    0.320    0.320
                           0.320    0.320    0.320    0.320    0.320    0.320
                           0.320    0.310    0.310    0.310    0.310    0.310
                           0.310    0.310    0.310    0.310    0.310    0.310
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                              AND=BRONTE.WAT
STORE HYD            ID=2 HYD NO=1302DT= 0.2500 HRS  DA=   3.590 SQ KM
                        HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0170
                           0.017    0.017    0.017    0.017    0.017    0.017
                           0.017    0.017    0.018    0.018    0.019    0.020
                           0.020    0.021    0.022    0.022    0.023    0.024
                           0.026    0.027    0.028    0.029    0.030    0.031
                           0.032    0.033    0.034    0.035    0.036    0.037
                           0.037    0.038    0.040    0.046    0.056    0.066
                           0.076    0.085    0.094    0.100    0.120    0.160
                           0.260    0.390    0.560    0.920    1.860    4.340
                           6.330    6.610    6.690    6.680    6.610    6.520
                           6.420    6.340    6.220    6.080    5.950    5.820
                           5.690    5.560    5.440    5.320    5.200    5.070
                           4.940    4.820    4.710    4.590    4.480    4.370
                           4.260    4.150    4.050    3.950    3.840    3.740
                           3.630    3.540    3.450    3.360    3.280    3.200
                           3.110    3.020    2.930    2.850    2.770    2.690
                           2.610    2.540    2.470    2.410    2.340    2.280
                           2.210    2.130    2.060    1.980    1.910    1.840
                           1.780    1.710    1.650    1.590    1.540    1.480
                           1.430    1.380    1.330    1.280    1.240    1.190
                           1.150    1.110    1.070    1.030    1.000    0.960
                           0.930    0.890    0.860    0.830    0.800    0.770
                           0.750    0.720    0.700    0.670    0.650    0.630
                           0.600    0.580    0.560    0.540    0.520    0.510
                           0.490    0.470    0.460    0.440    0.430    0.410
                           0.400    0.380    0.370    0.360    0.350    0.330
                           0.320    0.310    0.300    0.290    0.280    0.270
                           0.260    0.260    0.250    0.240    0.230    0.220
                           0.220    0.210    0.200    0.200    0.190    0.180
                           0.180    0.170    0.170    0.160    0.160    0.150
                           0.150    0.140    0.140    0.140    0.130    0.130
                           0.120    0.120    0.120    0.110    0.110    0.110
                           0.110    0.100    0.100    0.097    0.095    0.092
                           0.090    0.088    0.085    0.083    0.081    0.079
                           0.077    0.076    0.074    0.072    0.071    0.069
                           0.068    0.066    0.065    0.063    0.062    0.061
                           0.060    0.059    0.058    0.056    0.055    0.054
                           0.054    0.053    0.052    0.051    0.050    0.049
                           0.049    0.048    0.047    0.046    0.046    0.045
                           0.045    0.044    0.043    0.043    0.042    0.042
                           0.041    0.041    0.041    0.040    0.040    0.039
                           0.039    0.039    0.038    0.038    0.038    0.037
                           0.037    0.037    0.036    0.036    0.036    0.036
                           0.035    0.035    0.035    0.035    0.035    0.034
                           0.034    0.034    0.034    0.034    0.034    0.033
                           0.033    0.033    0.033    0.033    0.033    0.033
                           0.032    0.032    0.032    0.032    0.032    0.032
                           0.032    0.032    0.032    0.032    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.031    0.031    0.031    0.031
                           0.031    0.031    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
                           0.030    0.030    0.030    0.030    0.030    0.030
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                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.028
*
* HYDROGRAPH GENERATED BY FILE=SCS100.DAT
*                          AND=BRONTE.WAT
STORE HYD           ID=3 HYD NO=6302DT= 0.2500 HRS  DA=  37.320 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.1800
                         0.180    0.180    0.180    0.180    0.180    0.180
                         0.180    0.180    0.180    0.180    0.180    0.180
                         0.180    0.180    0.190    0.190    0.190    0.190
                         0.200    0.200    0.210    0.210    0.220    0.220
                         0.230    0.230    0.240    0.250    0.260    0.260
                         0.270    0.280    0.290    0.300    0.320    0.340
                         0.360    0.370    0.390    0.410    0.430    0.490
                         0.590    0.740    0.990    1.480    2.580    5.350
                         8.000   10.500   13.200   15.100   17.200   19.600
                        22.400   25.500   28.700   31.900   34.800   37.500
                        40.000   42.200   44.000   45.600   46.900   48.000
                        48.700   49.200   49.400   49.400   49.200   48.800
                        48.300   47.700   46.900   46.100   45.300   44.400
                        43.500   42.500   41.600   40.700   39.800   38.900
                        38.100   37.200   36.300   35.500   34.700   33.900
                        33.100   32.300   31.600   30.800   30.100   29.400
                        28.700   28.000   27.300   26.700   26.000   25.400
                        24.700   24.100   23.500   22.900   22.300   21.700
                        21.100   20.600   20.000   19.500   18.900   18.400
                        17.900   17.400   16.900   16.400   16.000   15.500
                        15.100   14.700   14.300   13.900   13.500   13.100
                        12.800   12.500   12.100   11.800   11.500   11.200
                        10.900   10.600   10.300   10.100    9.830    9.580
```

9.340	9.110	8.890	8.670	8.460	8.260
8.060	7.870	7.680	7.500	7.330	7.160
7.000	6.840	6.690	6.540	6.390	6.250
6.110	5.980	5.850	5.730	5.600	5.490
5.370	5.260	5.150	5.040	4.940	4.840
4.740	4.650	4.560	4.470	4.380	4.300
4.210	4.130	4.050	3.980	3.900	3.830
3.760	3.690	3.620	3.560	3.490	3.430
3.370	3.310	3.250	3.200	3.140	3.090
3.030	2.980	2.930	2.880	2.840	2.790
2.740	2.700	2.660	2.610	2.570	2.530
2.490	2.450	2.410	2.380	2.340	2.300
2.270	2.230	2.200	2.170	2.140	2.100
2.070	2.040	2.010	1.990	1.960	1.930
1.900	1.880	1.850	1.820	1.800	1.770
1.750	1.730	1.700	1.680	1.660	1.640
1.620	1.600	1.570	1.550	1.530	1.520
1.500	1.480	1.460	1.440	1.420	1.410
1.390	1.370	1.360	1.340	1.320	1.310
1.290	1.280	1.260	1.250	1.240	1.220
1.210	1.190	1.180	1.170	1.160	1.140
1.130	1.120	1.110	1.100	1.080	1.070
1.060	1.050	1.040	1.030	1.020	1.010
1.000	0.990	0.980	0.970	0.960	0.950
0.940	0.930	0.920	0.910	0.910	0.900
0.890	0.880	0.870	0.870	0.860	0.850
0.840	0.830	0.830	0.820	0.810	0.810
0.800	0.790	0.790	0.780	0.770	0.770
0.760	0.750	0.750	0.740	0.740	0.730
0.720	0.720	0.710	0.710	0.700	0.700
0.690	0.690	0.680	0.680	0.670	0.670
0.660	0.660	0.650	0.650	0.640	0.640
0.630	0.630	0.630	0.620	0.620	0.610
0.610	0.610	0.600	0.600	0.590	0.590
0.590	0.580	0.580	0.580	0.570	0.570
0.570	0.560	0.560	0.560	0.550	0.550
0.550	0.540	0.540	0.540	0.540	0.530
0.530	0.530	0.520	0.520	0.520	0.520
0.510	0.510	0.510	0.510	0.500	0.500
0.500	0.500	0.500	0.490	0.490	0.490
0.490	0.480	0.480	0.480	0.480	0.480
0.470	0.470	0.470	0.470	0.470	0.470
0.460	0.460	0.460	0.460	0.460	0.450
0.450	0.450	0.450	0.450	0.450	0.450
0.440	0.440	0.440	0.440	0.440	0.440
0.440	0.430	0.430	0.430	0.430	0.430
0.430	0.430	0.420	0.420	0.420	0.420
0.420	0.420	0.420	0.420	0.420	0.410
0.410	0.410	0.410	0.410	0.410	0.410
0.410	0.410	0.400	0.400	0.400	0.400
0.400	0.400	0.400	0.400	0.400	0.400
0.400	0.400	0.390	0.390	0.390	0.390
0.390	0.390	0.390	0.390	0.390	0.390
0.390	0.390	0.390	0.380	0.380	0.380
0.380	0.380	0.380	0.380	0.380	0.380
0.380	0.380	0.380	0.380	0.380	0.380
0.380	0.370	0.370	0.370	0.370	0.370
0.370	0.370	0.370	0.370	0.370	0.370
0.370	0.370	0.370	0.370	0.370	0.370
0.370	0.370	0.370	0.360	0.360	0.360
0.360	0.360	0.360	0.360	0.360	0.360
0.360	0.360	0.360	0.360	0.360	0.360
0.360	0.360	0.360	0.360	0.360	0.360
0.360	0.360	0.360	0.360	0.360	0.360
0.360	0.350	0.350	0.350	0.350	0.350
0.350	0.350	0.350	0.350	0.350	0.350
0.350	0.350	0.350	0.350	0.350	0.350
0.350	0.350	0.350	0.350	0.350	0.350
0.350	0.350	0.350	0.350	0.350	0.350
0.350	0.350	0.350	0.350	0.350	0.350
0.350	0.350	0.350	0.350	0.350	0.340

0.340	0.340	0.340	0.340	0.340	0.340
0.340	0.340	0.340	0.340	0.340	0.340

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*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                         AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=1281DT= 0.2500 HRS  DA=   6.910 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0330
                        0.033    0.033    0.033    0.033    0.033    0.034
                        0.036    0.096    0.280    0.500    0.670    0.790
                        0.830    0.840    0.830    0.830    0.820    0.810
                        0.800    0.790    0.780    0.770    0.760    0.750
                        0.740    0.730    0.720    0.710    0.700    0.690
                        0.690    0.680    0.670    0.660    0.650    0.640
                        0.640    0.630    0.620    0.610    0.610    0.600
                        0.590    0.580    0.580    0.570    0.560    0.560
                        0.550    0.540    0.540    0.530    0.520    0.520
                        0.510    0.500    0.500    0.490    0.490    0.480
                        0.470    0.470    0.460    0.460    0.450    0.450
                        0.440    0.440    0.430    0.430    0.420    0.420
                        0.410    0.410    0.400    0.400    0.390    0.390
                        0.380    0.380    0.370    0.370    0.360    0.360
                        0.360    0.350    0.350    0.340    0.340    0.340
                        0.330    0.330    0.320    0.320    0.320    0.310
                        0.310    0.310    0.300    0.300    0.300    0.290
                        0.290    0.290    0.280    0.280    0.280    0.270
                        0.270    0.270    0.270    0.260    0.260    0.260
                        0.250    0.250    0.250    0.250    0.240    0.240
                        0.240    0.240    0.230    0.230    0.230    0.230
                        0.220    0.220    0.220    0.220    0.210    0.210
                        0.210    0.210    0.210    0.200    0.200    0.200
                        0.200    0.200    0.190    0.190    0.190    0.190
                        0.190    0.180    0.180    0.180    0.180    0.180
                        0.170    0.170    0.170    0.170    0.170    0.170
                        0.160    0.160    0.160    0.160    0.160    0.160
                        0.160    0.150    0.150    0.150    0.150    0.150
                        0.150    0.150    0.140    0.140    0.140    0.140
                        0.140    0.140    0.140    0.140    0.130    0.130
                        0.130    0.130    0.130    0.130    0.130    0.130
                        0.130    0.120    0.120    0.120    0.120    0.120
                        0.120    0.120    0.120    0.120    0.120    0.110
                        0.110    0.110    0.110    0.110    0.110    0.110
                        0.110    0.110    0.110    0.110    0.110    0.100
                        0.100    0.100    0.100    0.100    0.100    0.100
                        0.100    0.099    0.098    0.098    0.097    0.096
                        0.095    0.095    0.094    0.094    0.093    0.092
                        0.092    0.091    0.091    0.090    0.089    0.089
                        0.088    0.088    0.087    0.087    0.086    0.086
                        0.085    0.084    0.084    0.083    0.083    0.082
                        0.082    0.082    0.081    0.081    0.080    0.080
                        0.079    0.079    0.078    0.078    0.078    0.077
                        0.077    0.076    0.076    0.075    0.075    0.075
                        0.074    0.074    0.074    0.073    0.073    0.073
                        0.072    0.072    0.071    0.071    0.071    0.070
                        0.070    0.070    0.070    0.069    0.069    0.069
                        0.068    0.068    0.068    0.067    0.067    0.067
                        0.067    0.066    0.066    0.066    0.065    0.065
                        0.065    0.065    0.064    0.064    0.064    0.064
                        0.063    0.063    0.063    0.063    0.063    0.062
                        0.062    0.062    0.062    0.061    0.061    0.061
                        0.061    0.061    0.060    0.060    0.060    0.060
                        0.060    0.059    0.059    0.059    0.059    0.059
                        0.059    0.058    0.058    0.058    0.058    0.058
                        0.058    0.057    0.057    0.057    0.057    0.057
                        0.057    0.056    0.056    0.056    0.056    0.056
                        0.056    0.056    0.055    0.055    0.055    0.055
                        0.055    0.055    0.055    0.055    0.054    0.054
                        0.054    0.054    0.054    0.054    0.054    0.054
                        0.053    0.053    0.053    0.053    0.053    0.053
                        0.053    0.053    0.053    0.052    0.052    0.052
                        0.052    0.052    0.052    0.052    0.052    0.052
                        0.052    0.052    0.051    0.051    0.051    0.051
                        0.051    0.051    0.051    0.051    0.051    0.051
                        0.051    0.051    0.050    0.050    0.050    0.050
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                              0.050    0.050    0.050    0.050    0.050    0.050
                              0.050    0.050    0.050    0.049    0.049    0.049
                              0.049    0.049    0.049    0.049    0.049    0.049
                              0.049    0.049    0.049    0.049    0.049    0.049
                              0.049    0.048    0.048    0.048    0.048    0.048
                              0.048    0.048    0.048    0.048    0.048    0.048
                              0.048    0.048    0.048    0.048    0.048    0.048
                              0.048    0.048    0.047    0.047    0.047    0.047
                              0.047    0.047    0.047    0.047    0.047    0.047
                              0.047    0.047    0.047    0.047    0.047    0.047
                              0.047    0.047    0.047    0.047    0.047    0.047
                              0.047    0.046    0.046    0.046    0.046    0.046
                              0.046    0.046    0.046    0.046    0.046    0.046
                              0.046    0.046    0.046    0.046    0.046    0.046
                              0.046    0.046    0.046    0.046    0.046    0.046
                              0.046    0.046    0.046    0.046    0.046    0.045
                              0.045    0.045    0.045    0.045    0.045    0.045
                              0.045    0.045    0.045    0.045    0.045    0.045
                              0.045    0.045    0.045    0.045    0.045    0.045
                              0.045    0.045    0.045    0.045    0.045    0.045
                              0.045    0.045    0.045    0.045    0.045    0.045
                              0.045    0.045    0.045    0.045    0.045    0.044
                              0.044    0.044    0.044    0.044    0.044    0.044
                              0.044    0.044    0.044    0.044    0.044    0.044
                              0.044    0.044    0.044    0.044    0.044    0.044
                              0.044    0.044    0.044    0.044    0.044    0.044
                              0.044    0.044    0.044    0.044    0.044    0.044
                              0.044    0.044    0.044    0.044    0.044    0.044
                              0.044    0.044    0.044    0.044    0.044    0.044
                              0.044    0.044    0.043    0.043    0.043    0.043
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                            AND=BRONTE.WAT
STORE HYD            ID=1 HYD NO=1282DT= 0.2500 HRS  DA=   3.730 SQ KM
                      HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0180
                              0.018    0.018    0.018    0.018    0.020    0.024
                              0.033    0.580    1.160    1.220    1.220    1.190
                              1.150    1.100    1.060    1.020    0.980    0.940
                              0.900    0.870    0.830    0.800    0.760    0.730
                              0.700    0.670    0.650    0.620    0.590    0.570
                              0.550    0.530    0.500    0.480    0.460    0.450
                              0.430    0.410    0.390    0.380    0.360    0.350
                              0.340    0.320    0.310    0.300    0.290    0.270
                              0.260    0.250    0.240    0.230    0.230    0.220
                              0.210    0.200    0.190    0.190    0.180    0.170
                              0.170    0.160    0.150    0.150    0.140    0.140
                              0.130    0.130    0.120    0.120    0.120    0.110
                              0.110    0.100    0.100    0.097    0.094    0.091
                              0.088    0.085    0.083    0.080    0.078    0.075
                              0.073    0.071    0.069    0.067    0.065    0.063
                              0.062    0.060    0.058    0.057    0.055    0.054
                              0.053    0.051    0.050    0.049    0.048    0.047
                              0.046    0.045    0.044    0.043    0.042    0.041
                              0.040    0.040    0.039    0.038    0.038    0.037
                              0.036    0.036    0.035    0.035    0.034    0.034
                              0.033    0.033    0.032    0.032    0.032    0.031
                              0.031    0.031    0.030    0.030    0.030    0.029
                              0.029    0.029    0.029    0.028    0.028    0.028
                              0.028    0.028    0.027    0.027    0.027    0.027
                              0.027    0.027    0.027    0.026    0.026    0.026
                              0.026    0.026    0.026    0.026    0.026    0.026
                              0.026    0.025    0.025    0.025    0.025    0.025
                              0.025    0.025    0.025    0.025    0.025    0.025
                              0.025    0.025    0.025    0.025    0.025    0.025
                              0.025    0.025    0.025    0.025    0.025    0.025
                              0.025    0.024    0.024    0.024    0.024    0.024
                              0.024    0.024    0.024    0.024    0.024    0.024
                              0.024    0.024    0.024    0.024    0.024    0.024
                              0.024    0.024    0.024    0.024    0.024    0.024
                              0.024    0.024    0.024    0.024    0.024    0.024
                              0.024    0.024    0.024    0.024    0.024    0.024
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                  0.024    0.024    0.024    0.024    0.024    0.024
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                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.025    0.025    0.025    0.025
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                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.025    0.025    0.025    0.025    0.025    0.025
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.024    0.024    0.024    0.024
                  0.024    0.024    0.023    0.023    0.023    0.023
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                      AND=BRONTE.WAT
STORE HYD          ID=3 HYD NO=6282DT= 0.2500 HRS  DA=  10.640 SQ KM
                    HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0510
                  0.051    0.051    0.051    0.051    0.052    0.056
                  0.066    0.590    1.170    1.310    1.480    1.650
                  1.770    1.840    1.860    1.840    1.810    1.760
                  1.720    1.670    1.630    1.590    1.540    1.500
                  1.460    1.430    1.390    1.350    1.320    1.290
                  1.250    1.220    1.190    1.160    1.140    1.110
```

1.080	1.060	1.030	1.010	0.990	0.960
0.940	0.920	0.900	0.880	0.860	0.850
0.830	0.810	0.790	0.780	0.760	0.750
0.730	0.720	0.710	0.690	0.680	0.670
0.650	0.640	0.630	0.620	0.610	0.600
0.590	0.580	0.570	0.560	0.550	0.540
0.530	0.520	0.510	0.500	0.500	0.490
0.480	0.470	0.470	0.460	0.450	0.450
0.440	0.430	0.430	0.420	0.410	0.410
0.400	0.400	0.390	0.390	0.380	0.380
0.370	0.370	0.360	0.360	0.350	0.350
0.340	0.340	0.340	0.330	0.330	0.320
0.320	0.320	0.310	0.310	0.300	0.300
0.300	0.290	0.290	0.290	0.280	0.280
0.280	0.270	0.270	0.270	0.270	0.260
0.260	0.260	0.250	0.250	0.250	0.250
0.240	0.240	0.240	0.240	0.230	0.230
0.230	0.230	0.230	0.220	0.220	0.220
0.220	0.210	0.210	0.210	0.210	0.210
0.200	0.200	0.200	0.200	0.200	0.200
0.190	0.190	0.190	0.190	0.190	0.190
0.180	0.180	0.180	0.180	0.180	0.180
0.180	0.170	0.170	0.170	0.170	0.170
0.170	0.170	0.160	0.160	0.160	0.160
0.160	0.160	0.160	0.160	0.150	0.150
0.150	0.150	0.150	0.150	0.150	0.150
0.150	0.150	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.140	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.100	0.100	0.100	0.100	0.100	0.100
0.100	0.100	0.100	0.100	0.100	0.100
0.100	0.099	0.099	0.099	0.098	0.098
0.098	0.097	0.097	0.097	0.096	0.096
0.096	0.095	0.095	0.095	0.094	0.094
0.094	0.093	0.093	0.093	0.092	0.092
0.092	0.092	0.091	0.091	0.091	0.091
0.090	0.090	0.090	0.089	0.089	0.089
0.089	0.089	0.088	0.088	0.088	0.088
0.087	0.087	0.087	0.087	0.086	0.086
0.086	0.086	0.086	0.085	0.085	0.085
0.085	0.085	0.084	0.084	0.084	0.084
0.084	0.084	0.083	0.083	0.083	0.083
0.083	0.082	0.082	0.082	0.082	0.082
0.082	0.082	0.081	0.081	0.081	0.081
0.081	0.081	0.080	0.080	0.080	0.080
0.080	0.080	0.080	0.079	0.079	0.079
0.079	0.079	0.079	0.079	0.079	0.078
0.078	0.078	0.078	0.078	0.078	0.078
0.078	0.078	0.077	0.077	0.077	0.077
0.077	0.077	0.077	0.077	0.077	0.077
0.076	0.076	0.076	0.076	0.076	0.076
0.076	0.076	0.076	0.076	0.075	0.075
0.075	0.075	0.075	0.075	0.075	0.075
0.075	0.075	0.075	0.075	0.074	0.074
0.074	0.074	0.074	0.074	0.074	0.074
0.074	0.074	0.074	0.074	0.074	0.074
0.073	0.073	0.073	0.073	0.073	0.073
0.073	0.073	0.073	0.073	0.073	0.073
0.073	0.073	0.073	0.072	0.072	0.072
0.072	0.072	0.072	0.072	0.072	0.072
0.072	0.072	0.072	0.072	0.072	0.072
0.072	0.072	0.072	0.072	0.071	0.071
0.071	0.071	0.071	0.071	0.071	0.071
0.071	0.071	0.071	0.071	0.071	0.071

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                         0.071    0.071    0.071    0.071    0.071    0.071
                         0.071    0.070    0.070    0.070    0.070    0.070
                         0.070    0.070    0.070    0.070    0.070    0.070
                         0.070    0.070    0.070    0.070    0.070    0.070
                         0.070    0.070    0.070    0.070    0.070    0.070
                         0.070    0.069    0.069    0.069    0.069    0.069
                         0.069    0.069    0.069    0.069    0.069    0.069
                         0.069    0.069    0.069    0.069    0.069    0.069
                         0.069    0.069    0.069    0.069    0.069    0.069
                         0.069    0.069    0.069    0.069    0.069    0.069
                         0.068    0.068    0.068    0.068    0.068    0.068
                         0.068    0.068    0.068    0.068    0.068    0.068
                         0.068    0.068    0.068    0.068    0.068    0.068
                         0.068    0.068    0.068    0.068    0.068    0.068
                         0.068    0.068    0.068    0.068    0.068    0.068
                         0.068    0.068    0.068    0.067    0.067    0.067
                         0.067    0.067    0.067    0.067    0.067    0.067
                         0.067    0.067    0.067    0.067    0.067    0.067
                         0.067    0.067    0.067    0.067    0.067    0.067
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                    AND=BRONTE.WAT
STORE HYD            ID=1 HYD NO=1283DT= 0.2500 HRS  DA=   3.420 SQ KM
                      HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0160
                         0.016    0.016    0.016    0.016    0.016    0.017
                         0.018    0.059    0.180    0.330    0.420    0.460
                         0.470    0.470    0.460    0.460    0.450    0.440
                         0.440    0.430    0.420    0.410    0.410    0.400
                         0.390    0.390    0.380    0.370    0.370    0.360
                         0.350    0.350    0.340    0.340    0.330    0.330
                         0.320    0.310    0.310    0.300    0.300    0.290
                         0.290    0.280    0.280    0.270    0.270    0.270
                         0.260    0.260    0.250    0.250    0.240    0.240
                         0.240    0.230    0.230    0.230    0.220    0.220
                         0.210    0.210    0.210    0.200    0.200    0.200
                         0.190    0.190    0.190    0.190    0.180    0.180
                         0.180    0.170    0.170    0.170    0.170    0.160
                         0.160    0.160    0.160    0.150    0.150    0.150
                         0.150    0.140    0.140    0.140    0.140    0.140
                         0.130    0.130    0.130    0.130    0.130    0.120
                         0.120    0.120    0.120    0.120    0.120    0.110
                         0.110    0.110    0.110    0.110    0.110    0.100
                         0.100    0.100    0.100    0.099    0.097    0.096
                         0.095    0.093    0.092    0.091    0.090    0.088
                         0.087    0.086    0.085    0.084    0.083    0.082
                         0.081    0.080    0.079    0.078    0.077    0.076
                         0.075    0.074    0.073    0.072    0.071    0.070
                         0.070    0.069    0.068    0.067    0.066    0.066
                         0.065    0.064    0.063    0.063    0.062    0.061
                         0.061    0.060    0.059    0.059    0.058    0.057
                         0.057    0.056    0.056    0.055    0.054    0.054
                         0.053    0.053    0.052    0.052    0.051    0.051
                         0.050    0.050    0.049    0.049    0.049    0.048
                         0.048    0.047    0.047    0.046    0.046    0.046
                         0.045    0.045    0.045    0.044    0.044    0.043
                         0.043    0.043    0.042    0.042    0.042    0.041
                         0.041    0.041    0.041    0.040    0.040    0.040
                         0.039    0.039    0.039    0.039    0.038    0.038
                         0.038    0.038    0.037    0.037    0.037    0.037
                         0.037    0.036    0.036    0.036    0.036    0.035
                         0.035    0.035    0.035    0.035    0.035    0.034
                         0.034    0.034    0.034    0.034    0.034    0.033
                         0.033    0.033    0.033    0.033    0.033    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.028    0.028    0.028    0.028
                         0.028    0.028    0.028    0.028    0.028    0.028
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                              0.028   0.028   0.028   0.028   0.028   0.028
                              0.028   0.027   0.027   0.027   0.027   0.027
                              0.027   0.027   0.027   0.027   0.027   0.027
                              0.027   0.027   0.027   0.027   0.027   0.027
                              0.027   0.027   0.027   0.027   0.027   0.027
                              0.026   0.026   0.026   0.026   0.026   0.026
                              0.026   0.026   0.026   0.026   0.026   0.026
                              0.026   0.026   0.026   0.026   0.026   0.026
                              0.026   0.026   0.026   0.026   0.026   0.026
                              0.026   0.026   0.026   0.026   0.026   0.026
                              0.026   0.026   0.026   0.025   0.025   0.025
                              0.025   0.025   0.025   0.025   0.025   0.025
                              0.025   0.025   0.025   0.025   0.025   0.025
                              0.025   0.025   0.025   0.025   0.025   0.025
                              0.025   0.025   0.025   0.025   0.025   0.025
                              0.025   0.025   0.025   0.025   0.025   0.025
                              0.025   0.025   0.025   0.025   0.025   0.025
                              0.025   0.025   0.025   0.025   0.025   0.025
                              0.025   0.025   0.025   0.025   0.025   0.025
                              0.025   0.025   0.025   0.025   0.025   0.025
                              0.025   0.025   0.025   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.024   0.024   0.024   0.024   0.024
                              0.024   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
                              0.023   0.023   0.023   0.023   0.023   0.023
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                          AND=BRONTE.WAT
STORE HYD           ID=2 HYD NO=6283DT= 0.2500 HRS  DA=  14.060 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0670
                              0.067   0.067   0.067   0.067   0.069   0.073
                              0.084   0.650   1.350   1.630   1.900   2.110
                              2.240   2.310   2.320   2.300   2.260   2.210
                              2.160   2.100   2.050   2.000   1.950   1.900
                              1.860   1.810   1.770   1.730   1.690   1.650
                              1.610   1.570   1.540   1.500   1.470   1.430
                              1.400   1.370   1.340   1.310   1.290   1.260
                              1.230   1.210   1.180   1.160   1.130   1.110
                              1.090   1.070   1.050   1.030   1.010   0.990
                              0.970   0.950   0.930   0.920   0.900   0.880
                              0.870   0.850   0.840   0.820   0.810   0.790
                              0.780   0.770   0.760   0.740   0.730   0.720
                              0.710   0.700   0.680   0.670   0.660   0.650
                              0.640   0.630   0.620   0.610   0.600   0.590
                              0.590   0.580   0.570   0.560   0.550   0.540
                              0.540   0.530   0.520   0.510   0.510   0.500
                              0.490   0.490   0.480   0.470   0.470   0.460
```

0.460	0.450	0.440	0.440	0.430	0.430
0.420	0.420	0.410	0.410	0.400	0.400
0.390	0.390	0.380	0.380	0.370	0.370
0.360	0.360	0.360	0.350	0.350	0.340
0.340	0.340	0.330	0.330	0.330	0.320
0.320	0.320	0.310	0.310	0.310	0.300
0.300	0.300	0.290	0.290	0.290	0.280
0.280	0.280	0.280	0.270	0.270	0.270
0.270	0.260	0.260	0.260	0.260	0.250
0.250	0.250	0.250	0.240	0.240	0.240
0.240	0.240	0.230	0.230	0.230	0.230
0.230	0.220	0.220	0.220	0.220	0.220
0.210	0.210	0.210	0.210	0.210	0.210
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.180	0.180	0.180	0.180
0.180	0.180	0.180	0.180	0.180	0.170
0.170	0.170	0.170	0.170	0.170	0.170
0.170	0.170	0.160	0.160	0.160	0.160
0.160	0.160	0.160	0.160	0.160	0.160
0.160	0.150	0.150	0.150	0.150	0.150
0.150	0.150	0.150	0.150	0.150	0.150
0.150	0.150	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.140	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.100	0.100	0.100
0.100	0.100	0.100	0.100	0.100	0.100
0.100	0.100	0.100	0.100	0.100	0.100
0.100	0.100	0.100	0.100	0.100	0.100
0.100	0.100	0.100	0.100	0.100	0.100
0.100	0.100	0.100	0.100	0.100	0.100
0.100	0.100	0.100	0.100	0.100	0.100
0.100	0.100	0.100	0.100	0.100	0.099
0.099	0.099	0.099	0.099	0.099	0.099
0.099	0.099	0.099	0.099	0.099	0.098
0.098	0.098	0.098	0.098	0.098	0.098
0.098	0.098	0.098	0.098	0.098	0.097
0.097	0.097	0.097	0.097	0.097	0.097
0.097	0.097	0.097	0.097	0.097	0.097
0.097	0.096	0.096	0.096	0.096	0.096
0.096	0.096	0.096	0.096	0.096	0.096
0.096	0.096	0.096	0.096	0.095	0.095
0.095	0.095	0.095	0.095	0.095	0.095
0.095	0.095	0.095	0.095	0.095	0.095
0.095	0.095	0.095	0.095	0.094	0.094
0.094	0.094	0.094	0.094	0.094	0.094
0.094	0.094	0.094	0.094	0.094	0.094
0.094	0.094	0.094	0.094	0.094	0.094
0.093	0.093	0.093	0.093	0.093	0.093
0.093	0.093	0.093	0.093	0.093	0.093
0.093	0.093	0.093	0.093	0.093	0.093
0.093	0.093	0.093	0.092	0.092	0.092
0.092	0.092	0.092	0.092	0.092	0.092
0.092	0.092	0.092	0.092	0.092	0.092
0.092	0.092	0.092	0.092	0.092	0.092

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                         0.092    0.092    0.092    0.092    0.091    0.091
                         0.091    0.091    0.091    0.091    0.091    0.091
                         0.091    0.091    0.091    0.091    0.091    0.091
                         0.091    0.091    0.091    0.091    0.091    0.091
                         0.091    0.091    0.091    0.091    0.091    0.091
                         0.091    0.090    0.090    0.090    0.090    0.090
                         0.090    0.090    0.090    0.090    0.090    0.090
                         0.090    0.090    0.090    0.090    0.090    0.089
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                           AND=BRONTE.WAT
STORE HYD           ID=2 HYD NO=1284DT= 0.2500 HRS  DA=   3.720 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0180
                         0.018    0.018    0.018    0.018    0.020    0.026
                         0.039    0.830    1.670    1.730    1.700    1.640
                         1.550    1.470    1.390    1.320    1.250    1.180
                         1.110    1.050    1.000    0.940    0.890    0.840
                         0.800    0.750    0.710    0.670    0.640    0.600
                         0.570    0.540    0.510    0.480    0.460    0.430
                         0.410    0.390    0.370    0.350    0.330    0.310
                         0.300    0.280    0.270    0.250    0.240    0.230
                         0.220    0.200    0.190    0.180    0.180    0.170
                         0.160    0.150    0.140    0.140    0.130    0.120
                         0.120    0.110    0.110    0.100    0.098    0.094
                         0.090    0.086    0.082    0.079    0.076    0.073
                         0.070    0.067    0.064    0.062    0.060    0.058
                         0.056    0.054    0.052    0.050    0.048    0.047
                         0.045    0.044    0.043    0.042    0.040    0.039
                         0.038    0.037    0.037    0.036    0.035    0.034
                         0.033    0.033    0.032    0.032    0.031    0.031
                         0.030    0.030    0.029    0.029    0.028    0.028
                         0.028    0.027    0.027    0.027    0.026    0.026
                         0.026    0.026    0.026    0.025    0.025    0.025
                         0.025    0.025    0.025    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
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                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.024    0.024    0.024    0.024
                          0.024    0.024    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.023
                          0.023    0.023    0.023    0.023    0.023    0.022
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                           AND=BRONTE.WAT
STORE HYD           ID=3 HYD NO=6284DT= 0.2500 HRS  DA=  17.780 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0850
                          0.085    0.085    0.085    0.085    0.087    0.093
                          0.110    0.920    1.680    1.730    1.870    2.110
                          2.390    2.660    2.900    3.100    3.240    3.310
                          3.330    3.300    3.250    3.180    3.090    3.000
                          2.910    2.820    2.730    2.640    2.560    2.480
                          2.400    2.320    2.250    2.180    2.120    2.060
                          2.000    1.940    1.880    1.830    1.780    1.730
                          1.680    1.640    1.590    1.550    1.510    1.470
                          1.430    1.400    1.360    1.330    1.300    1.270
                          1.240    1.210    1.180    1.150    1.130    1.100
                          1.080    1.050    1.030    1.010    0.990    0.970
                          0.950    0.930    0.910    0.890    0.880    0.860
                          0.840    0.830    0.810    0.800    0.780    0.770
                          0.760    0.740    0.730    0.720    0.700    0.690
                          0.680    0.670    0.660    0.650    0.640    0.630
                          0.620    0.610    0.600    0.590    0.580    0.570
                          0.570    0.560    0.550    0.540    0.530    0.530
                          0.520    0.510    0.510    0.500    0.490    0.490
                          0.480    0.470    0.470    0.460    0.460    0.450
                          0.440    0.440    0.430    0.430    0.420    0.420
                          0.410    0.410    0.400    0.400    0.390    0.390
                          0.390    0.380    0.380    0.370    0.370    0.370
                          0.360    0.360    0.350    0.350    0.350    0.340
                          0.340    0.340    0.330    0.330    0.330    0.320
                          0.320    0.320    0.310    0.310    0.310    0.310
                          0.300    0.300    0.300    0.290    0.290    0.290
                          0.290    0.280    0.280    0.280    0.280    0.270
                          0.270    0.270    0.270    0.270    0.260    0.260
```

0.260	0.260	0.260	0.250	0.250	0.250
0.250	0.250	0.240	0.240	0.240	0.240
0.240	0.240	0.230	0.230	0.230	0.230
0.230	0.230	0.220	0.220	0.220	0.220
0.220	0.220	0.220	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.180
0.180	0.180	0.180	0.180	0.180	0.180
0.180	0.180	0.180	0.180	0.180	0.170
0.170	0.170	0.170	0.170	0.170	0.170
0.170	0.170	0.170	0.170	0.170	0.170
0.170	0.160	0.160	0.160	0.160	0.160
0.160	0.160	0.160	0.160	0.160	0.160
0.160	0.160	0.160	0.160	0.160	0.160
0.160	0.150	0.150	0.150	0.150	0.150
0.150	0.150	0.150	0.150	0.150	0.150
0.150	0.150	0.150	0.150	0.150	0.150
0.150	0.150	0.150	0.150	0.150	0.150
0.150	0.140	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.140	0.140	0.140	0.140	0.140	0.140
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.130	0.130	0.130	0.130	0.130	0.130
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.120	0.120	0.120
0.120	0.120	0.120	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110
0.110	0.110	0.110	0.110	0.110	0.110

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*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                           AND=BRONTE.WAT
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STORE HYD   ID=2 HYD NO=1285DT= 0.2500 HRS DA=   6.230 SQ KM

HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=   0.0300

0.030	0.030	0.030	0.030	0.032	0.038
0.051	0.910	1.840	1.950	1.960	1.930
1.870	1.810	1.750	1.700	1.640	1.590
1.530	1.480	1.440	1.390	1.340	1.300
1.260	1.220	1.180	1.140	1.100	1.060
1.030	1.000	0.960	0.930	0.900	0.870
0.840	0.820	0.790	0.770	0.740	0.720
0.690	0.670	0.650	0.630	0.610	0.590
0.570	0.550	0.540	0.520	0.500	0.490
0.470	0.460	0.440	0.430	0.420	0.400
0.390	0.380	0.370	0.360	0.350	0.340
0.330	0.320	0.310	0.300	0.290	0.280
0.270	0.260	0.260	0.250	0.240	0.230
0.230	0.220	0.220	0.210	0.200	0.200
0.190	0.190	0.180	0.180	0.170	0.170
0.160	0.160	0.160	0.150	0.150	0.140
0.140	0.140	0.130	0.130	0.130	0.120
0.120	0.120	0.120	0.110	0.110	0.110
0.110	0.100	0.100	0.099	0.097	0.095
0.093	0.091	0.090	0.088	0.086	0.085
0.083	0.081	0.080	0.079	0.077	0.076
0.075	0.074	0.072	0.071	0.070	0.069
0.068	0.067	0.066	0.065	0.064	0.063
0.063	0.062	0.061	0.060	0.060	0.059
0.058	0.058	0.057	0.056	0.056	0.055
0.055	0.054	0.054	0.053	0.053	0.052
0.052	0.051	0.051	0.051	0.050	0.050
0.050	0.049	0.049	0.049	0.048	0.048
0.048	0.047	0.047	0.047	0.047	0.046
0.046	0.046	0.046	0.046	0.045	0.045
0.045	0.045	0.045	0.045	0.044	0.044
0.044	0.044	0.044	0.044	0.044	0.043
0.043	0.043	0.043	0.043	0.043	0.043
0.043	0.043	0.043	0.043	0.042	0.042
0.042	0.042	0.042	0.042	0.042	0.042
0.042	0.042	0.042	0.042	0.042	0.042
0.042	0.042	0.042	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.041	0.041	0.041	0.041	0.041	0.041
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040
0.040	0.040	0.040	0.040	0.040	0.040

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                        0.040    0.040    0.040    0.040    0.040    0.040
                        0.040    0.040    0.040    0.040    0.040    0.040
                        0.040    0.040    0.040    0.040    0.040    0.040
                        0.040    0.040    0.040    0.040    0.040    0.040
                        0.040    0.040    0.040    0.040    0.040    0.040
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.039    0.039
                        0.039    0.039    0.039    0.039    0.038    0.038
                        0.038    0.038    0.038    0.038    0.038    0.038
                        0.038    0.038    0.038    0.038    0.038    0.038
                        0.038    0.038    0.038    0.038    0.038    0.038
                        0.038    0.038    0.038    0.038    0.038    0.038
                        0.038    0.038    0.038    0.038    0.038    0.038
                        0.038    0.038    0.038    0.038    0.038    0.038
                        0.038    0.038    0.038    0.038    0.038    0.038
                        0.038    0.038    0.038    0.038    0.038    0.037
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                         AND=BRONTE.WAT
STORE HYD           ID=3 HYD NO=6285DT= 0.2500 HRS  DA=  24.010 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.1100
                        0.110    0.110    0.110    0.110    0.120    0.120
                        0.140    1.020    1.840    1.950    2.260    2.610
                        2.850    3.050    3.230    3.430    3.640    3.860
                        4.080    4.270    4.420    4.520    4.560    4.560
                        4.520    4.450    4.360    4.250    4.130    4.010
                        3.890    3.770    3.650    3.540    3.430    3.320
                        3.210    3.110    3.020    2.920    2.840    2.750
                        2.670    2.590    2.510    2.440    2.370    2.300
                        2.230    2.170    2.110    2.050    2.000    1.940
                        1.890    1.840    1.790    1.750    1.700    1.660
                        1.620    1.580    1.540    1.500    1.460    1.430
                        1.390    1.360    1.330    1.300    1.270    1.240
                        1.210    1.190    1.160    1.140    1.110    1.090
                        1.060    1.040    1.020    1.000    0.980    0.960
                        0.940    0.920    0.910    0.890    0.870    0.860
                        0.840    0.830    0.810    0.800    0.780    0.770
                        0.760    0.740    0.730    0.720    0.710    0.690
                        0.680    0.670    0.660    0.650    0.640    0.630
                        0.620    0.610    0.600    0.600    0.590    0.580
                        0.570    0.560    0.550    0.550    0.540    0.530
                        0.530    0.520    0.510    0.510    0.500    0.490
                        0.490    0.480    0.470    0.470    0.460    0.460
                        0.450    0.450    0.440    0.440    0.430    0.430
                        0.420    0.420    0.410    0.410    0.410    0.400
                        0.400    0.390    0.390    0.380    0.380    0.380
                        0.370    0.370    0.370    0.360    0.360    0.360
                        0.350    0.350    0.350    0.340    0.340    0.340
                        0.340    0.330    0.330    0.330    0.320    0.320
                        0.320    0.320    0.310    0.310    0.310    0.310
                        0.300    0.300    0.300    0.300    0.300    0.290
                        0.290    0.290    0.290    0.290    0.280    0.280
                        0.280    0.280    0.280    0.270    0.270    0.270
                        0.270    0.270    0.270    0.260    0.260    0.260
                        0.260    0.260    0.260    0.260    0.250    0.250
                        0.250    0.250    0.250    0.250    0.250    0.250
                        0.240    0.240    0.240    0.240    0.240    0.240
                        0.240    0.240    0.230    0.230    0.230    0.230
                        0.230    0.230    0.230    0.230    0.230    0.230
                        0.220    0.220    0.220    0.220    0.220    0.220
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                         0.220    0.220    0.220    0.220    0.220    0.220
                         0.210    0.210    0.210    0.210    0.210    0.210
                         0.210    0.210    0.210    0.210    0.210    0.210
                         0.210    0.210    0.200    0.200    0.200    0.200
                         0.200    0.200    0.200    0.200    0.200    0.200
                         0.200    0.200    0.200    0.200    0.200    0.200
                         0.200    0.200    0.190    0.190    0.190    0.190
                         0.190    0.190    0.190    0.190    0.190    0.190
                         0.190    0.190    0.190    0.190    0.190    0.190
                         0.190    0.190    0.190    0.190    0.190    0.190
                         0.190    0.190    0.180    0.180    0.180    0.180
                         0.180    0.180    0.180    0.180    0.180    0.180
                         0.180    0.180    0.180    0.180    0.180    0.180
                         0.180    0.180    0.180    0.180    0.180    0.180
                         0.180    0.180    0.180    0.180    0.180    0.180
                         0.180    0.180    0.180    0.180    0.180    0.180
                         0.180    0.170    0.170    0.170    0.170    0.170
                         0.170    0.170    0.170    0.170    0.170    0.170
                         0.170    0.170    0.170    0.170    0.170    0.170
                         0.170    0.170    0.170    0.170    0.170    0.170
                         0.170    0.170    0.170    0.170    0.170    0.170
                         0.170    0.170    0.170    0.170    0.170    0.170
                         0.170    0.170    0.170    0.170    0.170    0.170
                         0.170    0.170    0.170    0.170    0.170    0.170
                         0.170    0.170    0.170    0.170    0.170    0.170
                         0.170    0.170    0.170    0.170    0.170    0.170
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.160    0.160    0.160    0.160    0.160
                         0.160    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
                         0.150    0.150    0.150    0.150    0.150    0.150
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                          AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=1291DT= 0.2500 HRS  DA=   2.430 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0120
                         0.012    0.012    0.012    0.012    0.012    0.012
                         0.014    0.069    0.230    0.410    0.490    0.500
                         0.500    0.490    0.480    0.480    0.470    0.460
                         0.450    0.440    0.430    0.420    0.410    0.400
                         0.400    0.390    0.380    0.370    0.370    0.360
                         0.350    0.340    0.340    0.330    0.320    0.320
                         0.310    0.310    0.300    0.290    0.290    0.280
                         0.280    0.270    0.270    0.260    0.260    0.250
                         0.250    0.240    0.240    0.230    0.230    0.220
```

0.220	0.220	0.210	0.210	0.200	0.200
0.200	0.190	0.190	0.180	0.180	0.180
0.170	0.170	0.170	0.160	0.160	0.160
0.160	0.150	0.150	0.150	0.140	0.140
0.140	0.140	0.130	0.130	0.130	0.130
0.120	0.120	0.120	0.120	0.120	0.110
0.110	0.110	0.110	0.110	0.100	0.100
0.100	0.099	0.097	0.095	0.094	0.092
0.090	0.089	0.087	0.086	0.084	0.083
0.082	0.080	0.079	0.078	0.076	0.075
0.074	0.073	0.071	0.070	0.069	0.068
0.067	0.066	0.065	0.064	0.063	0.062
0.061	0.060	0.059	0.058	0.057	0.056
0.056	0.055	0.054	0.053	0.052	0.052
0.051	0.050	0.050	0.049	0.048	0.047
0.047	0.046	0.046	0.045	0.044	0.044
0.043	0.043	0.042	0.042	0.041	0.040
0.040	0.039	0.039	0.039	0.038	0.038
0.037	0.037	0.036	0.036	0.035	0.035
0.035	0.034	0.034	0.034	0.033	0.033
0.032	0.032	0.032	0.031	0.031	0.031
0.030	0.030	0.030	0.030	0.029	0.029
0.029	0.029	0.028	0.028	0.028	0.028
0.027	0.027	0.027	0.027	0.026	0.026
0.026	0.026	0.026	0.025	0.025	0.025
0.025	0.025	0.024	0.024	0.024	0.024
0.024	0.024	0.023	0.023	0.023	0.023
0.023	0.023	0.023	0.022	0.022	0.022
0.022	0.022	0.022	0.022	0.022	0.021
0.021	0.021	0.021	0.021	0.021	0.021
0.021	0.021	0.020	0.020	0.020	0.020
0.020	0.020	0.020	0.020	0.020	0.020
0.020	0.020	0.019	0.019	0.019	0.019
0.019	0.019	0.019	0.019	0.019	0.019
0.019	0.019	0.019	0.019	0.019	0.019
0.018	0.018	0.018	0.018	0.018	0.018
0.018	0.018	0.018	0.018	0.018	0.018
0.018	0.018	0.018	0.018	0.018	0.018
0.018	0.018	0.018	0.018	0.018	0.018
0.017	0.017	0.017	0.017	0.017	0.017
0.017	0.017	0.017	0.017	0.017	0.017
0.017	0.017	0.017	0.017	0.017	0.017
0.017	0.017	0.017	0.017	0.017	0.017
0.017	0.017	0.017	0.017	0.017	0.017
0.017	0.017	0.017	0.017	0.017	0.017
0.017	0.017	0.017	0.017	0.017	0.017
0.017	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.016	0.016	0.016
0.016	0.016	0.016	0.015	0.015	0.015
0.015	0.015	0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015	0.015	0.015
0.015	0.015	0.015	0.015	0.015	0.015

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                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.015
                         0.015    0.015    0.015    0.015    0.015    0.014
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                           AND=BRONTE.WAT
STORE HYD            ID=1 HYD NO=1292DT= 0.2500 HRS  DA=   1.420 SQ KM
                      HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0068
                         0.007    0.007    0.007    0.007    0.007    0.009
                         0.013    0.240    0.480    0.500    0.500    0.490
                         0.470    0.450    0.440    0.420    0.400    0.390
                         0.370    0.360    0.340    0.330    0.320    0.300
                         0.290    0.280    0.270    0.260    0.250    0.240
                         0.230    0.220    0.210    0.200    0.200    0.190
                         0.180    0.170    0.170    0.160    0.150    0.150
                         0.140    0.140    0.130    0.130    0.120    0.120
                         0.110    0.110    0.100    0.100    0.097    0.093
                         0.090    0.086    0.083    0.080    0.077    0.074
                         0.072    0.069    0.066    0.064    0.062    0.060
                         0.058    0.056    0.054    0.052    0.050    0.048
                         0.047    0.045    0.044    0.042    0.041    0.039
                         0.038    0.037    0.036    0.035    0.034    0.033
                         0.032    0.031    0.030    0.029    0.028    0.027
                         0.026    0.026    0.025    0.024    0.024    0.023
                         0.022    0.022    0.021    0.021    0.020    0.020
                         0.019    0.019    0.018    0.018    0.018    0.017
                         0.017    0.017    0.016    0.016    0.016    0.015
                         0.015    0.015    0.015    0.014    0.014    0.014
                         0.014    0.013    0.013    0.013    0.013    0.013
                         0.013    0.012    0.012    0.012    0.012    0.012
                         0.012    0.012    0.011    0.011    0.011    0.011
                         0.011    0.011    0.011    0.011    0.011    0.011
                         0.011    0.010    0.010    0.010    0.010    0.010
                         0.010    0.010    0.010    0.010    0.010    0.010
                         0.010    0.010    0.010    0.010    0.010    0.010
                         0.010    0.010    0.010    0.010    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
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                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
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                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
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                              0.009     0.009     0.009     0.009     0.009     0.009
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                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.009
                              0.009     0.009     0.009     0.009     0.009     0.008
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                           AND=BRONTE.WAT
STORE HYD           ID=4 HYD NO=6292DT= 0.2500 HRS  DA=   3.850 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0180
                              0.018     0.018     0.018     0.018     0.019     0.021
                              0.025     0.250     0.550     0.720     0.880     0.960
                              0.970     0.950     0.930     0.910     0.880     0.860
                              0.830     0.810     0.780     0.760     0.740     0.720
                              0.700     0.680     0.660     0.640     0.620     0.610
                              0.590     0.570     0.560     0.540     0.530     0.510
                              0.500     0.490     0.470     0.460     0.450     0.440
                              0.430     0.420     0.400     0.390     0.380     0.370
                              0.360     0.360     0.350     0.340     0.330     0.320
                              0.310     0.310     0.300     0.290     0.280     0.280
                              0.270     0.260     0.260     0.250     0.250     0.240
                              0.240     0.230     0.220     0.220     0.210     0.210
                              0.210     0.200     0.200     0.190     0.190     0.180
                              0.180     0.180     0.170     0.170     0.170     0.160
                              0.160     0.160     0.150     0.150     0.150     0.140
                              0.140     0.140     0.130     0.130     0.130     0.130
                              0.120     0.120     0.120     0.120     0.120     0.110
                              0.110     0.110     0.110     0.110     0.100     0.100
                              0.100     0.098     0.097     0.095     0.093     0.092
                              0.090     0.089     0.087     0.086     0.085     0.083
```

0.082	0.081	0.079	0.078	0.077	0.076
0.075	0.073	0.072	0.071	0.070	0.069
0.068	0.067	0.066	0.065	0.065	0.064
0.063	0.062	0.061	0.060	0.060	0.059
0.058	0.057	0.057	0.056	0.055	0.055
0.054	0.053	0.053	0.052	0.052	0.051
0.050	0.050	0.049	0.049	0.048	0.048
0.047	0.047	0.046	0.046	0.045	0.045
0.045	0.044	0.044	0.043	0.043	0.043
0.042	0.042	0.041	0.041	0.041	0.040
0.040	0.040	0.039	0.039	0.039	0.039
0.038	0.038	0.038	0.037	0.037	0.037
0.037	0.036	0.036	0.036	0.036	0.036
0.035	0.035	0.035	0.035	0.035	0.034
0.034	0.034	0.034	0.034	0.033	0.033
0.033	0.033	0.033	0.033	0.032	0.032
0.032	0.032	0.032	0.032	0.031	0.031
0.031	0.031	0.031	0.031	0.031	0.031
0.030	0.030	0.030	0.030	0.030	0.030
0.030	0.030	0.030	0.030	0.029	0.029
0.029	0.029	0.029	0.029	0.029	0.029
0.029	0.029	0.029	0.029	0.029	0.028
0.028	0.028	0.028	0.028	0.028	0.028
0.028	0.028	0.028	0.028	0.028	0.028
0.028	0.028	0.028	0.028	0.027	0.027
0.027	0.027	0.027	0.027	0.027	0.027
0.027	0.027	0.027	0.027	0.027	0.027
0.027	0.027	0.027	0.027	0.027	0.027
0.027	0.027	0.027	0.027	0.027	0.027
0.026	0.026	0.026	0.026	0.026	0.026
0.026	0.026	0.026	0.026	0.026	0.026
0.026	0.026	0.026	0.026	0.026	0.026
0.026	0.026	0.026	0.026	0.026	0.026
0.026	0.026	0.026	0.026	0.026	0.026
0.026	0.026	0.026	0.026	0.026	0.026
0.026	0.026	0.026	0.026	0.026	0.026
0.026	0.026	0.026	0.026	0.026	0.026
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.025	0.025	0.025	0.025	0.025	0.025
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
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0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
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0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
0.024	0.024	0.024	0.024	0.024	0.024
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                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.024    0.024
                         0.024    0.024    0.024    0.024    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
                         0.023    0.023    0.023    0.023    0.023    0.023
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                           AND=BRONTE.WAT
STORE HYD           ID=2 HYD NO=1293DT= 0.2500 HRS  DA=   0.940 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0045
                         0.004    0.004    0.004    0.004    0.005    0.006
                         0.009    0.180    0.370    0.390    0.390    0.380
                         0.360    0.350    0.330    0.320    0.310    0.290
                         0.280    0.270    0.260    0.250    0.230    0.220
                         0.220    0.210    0.200    0.190    0.180    0.170
                         0.170    0.160    0.150    0.150    0.140    0.130
                         0.130    0.120    0.120    0.110    0.110    0.100
                         0.099    0.095    0.091    0.087    0.084    0.080
                         0.077    0.074    0.071    0.068    0.065    0.063
                         0.060    0.058    0.055    0.053    0.051    0.049
                         0.047    0.045    0.044    0.042    0.040    0.039
                         0.037    0.036    0.035    0.033    0.032    0.031
                         0.030    0.029    0.028    0.027    0.026    0.025
                         0.024    0.023    0.022    0.022    0.021    0.020
                         0.020    0.019    0.018    0.018    0.017    0.017
                         0.016    0.016    0.015    0.015    0.015    0.014
                         0.014    0.013    0.013    0.013    0.012    0.012
                         0.012    0.012    0.011    0.011    0.011    0.011
                         0.010    0.010    0.010    0.010    0.010    0.009
                         0.009    0.009    0.009    0.009    0.009    0.009
                         0.008    0.008    0.008    0.008    0.008    0.008
                         0.008    0.008    0.008    0.008    0.007    0.007
                         0.007    0.007    0.007    0.007    0.007    0.007
                         0.007    0.007    0.007    0.007    0.007    0.007
                         0.007    0.007    0.007    0.007    0.007    0.007
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
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                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
                         0.006    0.006    0.006    0.006    0.006    0.006
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                            AND=BRONTE.WAT
STORE HYD           ID=4 HYD NO=6293DT= 0.2500 HRS  DA=   4.790 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0230
                         0.023    0.023    0.023    0.023    0.023    0.025
                         0.030    0.240    0.630    0.910    1.090    1.230
                         1.300    1.310    1.280    1.250    1.210    1.170
                         1.140    1.100    1.060    1.030    1.000    0.970
                         0.930    0.910    0.880    0.850    0.820    0.800
                         0.770    0.750    0.730    0.700    0.680    0.660
                         0.640    0.620    0.600    0.590    0.570    0.550
                         0.540    0.520    0.510    0.490    0.480    0.460
                         0.450    0.440    0.430    0.420    0.400    0.390
                         0.380    0.370    0.360    0.350    0.340    0.330
                         0.330    0.320    0.310    0.300    0.290    0.290
                         0.280    0.270    0.270    0.260    0.250    0.250
                         0.240    0.230    0.230    0.220    0.220    0.210
                         0.210    0.200    0.200    0.190    0.190    0.190
                         0.180    0.180    0.170    0.170    0.170    0.160
                         0.160    0.160    0.150    0.150    0.150    0.140
                         0.140    0.140    0.140    0.130    0.130    0.130
                         0.130    0.120    0.120    0.120    0.120    0.110
                         0.110    0.110    0.110    0.110    0.100    0.100
                         0.100    0.100    0.098    0.096    0.095    0.093
                         0.092    0.090    0.089    0.088    0.086    0.085
                         0.084    0.082    0.081    0.080    0.079    0.078
                         0.077    0.076    0.075    0.074    0.073    0.072
                         0.071    0.070    0.069    0.068    0.067    0.066
                         0.066    0.065    0.064    0.063    0.063    0.062
                         0.061    0.061    0.060    0.059    0.059    0.058
                         0.057    0.057    0.056    0.056    0.055    0.055
                         0.054    0.054    0.053    0.053    0.052    0.052
                         0.051    0.051    0.050    0.050    0.050    0.049
                         0.049    0.048    0.048    0.048    0.047    0.047
                         0.047    0.046    0.046    0.046    0.045    0.045
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                         0.045    0.044    0.044    0.044    0.044    0.043
                         0.043    0.043    0.043    0.042    0.042    0.042
                         0.042    0.041    0.041    0.041    0.041    0.041
                         0.040    0.040    0.040    0.040    0.040    0.039
                         0.039    0.039    0.039    0.039    0.039    0.038
                         0.038    0.038    0.038    0.038    0.038    0.038
                         0.037    0.037    0.037    0.037    0.037    0.037
                         0.037    0.037    0.036    0.036    0.036    0.036
                         0.036    0.036    0.036    0.036    0.036    0.036
                         0.036    0.035    0.035    0.035    0.035    0.035
                         0.035    0.035    0.035    0.035    0.035    0.035
                         0.035    0.035    0.034    0.034    0.034    0.034
                         0.034    0.034    0.034    0.034    0.034    0.034
                         0.034    0.034    0.034    0.034    0.034    0.034
                         0.034    0.034    0.033    0.033    0.033    0.033
                         0.033    0.033    0.033    0.033    0.033    0.033
                         0.033    0.033    0.033    0.033    0.033    0.033
                         0.033    0.033    0.033    0.033    0.033    0.033
                         0.033    0.033    0.033    0.033    0.033    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
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                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
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                         0.030    0.030    0.030    0.030    0.030    0.030
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                         0.030    0.030    0.030    0.030    0.030    0.030
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                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
                         0.029    0.029    0.029    0.029    0.029    0.029
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                          AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=6294DT= 0.2500 HRS  DA=  28.800 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.1400
                         0.140    0.140    0.140    0.140    0.140    0.150
```

0.170	1.270	2.470	2.860	3.350	3.850
4.160	4.350	4.510	4.680	4.850	5.030
5.210	5.370	5.480	5.550	5.560	5.530
5.450	5.350	5.230	5.100	4.960	4.810
4.670	4.520	4.380	4.240	4.110	3.980
3.860	3.740	3.620	3.510	3.410	3.300
3.200	3.110	3.020	2.930	2.850	2.770
2.690	2.610	2.540	2.470	2.400	2.340
2.270	2.210	2.150	2.100	2.040	1.990
1.940	1.890	1.850	1.800	1.760	1.710
1.670	1.630	1.590	1.560	1.520	1.490
1.450	1.420	1.390	1.360	1.330	1.300
1.270	1.250	1.220	1.200	1.170	1.150
1.120	1.100	1.080	1.060	1.040	1.020
1.000	0.980	0.960	0.950	0.930	0.910
0.900	0.880	0.870	0.850	0.840	0.820
0.810	0.800	0.780	0.770	0.760	0.750
0.730	0.720	0.710	0.700	0.690	0.680
0.670	0.660	0.650	0.640	0.630	0.630
0.620	0.610	0.600	0.590	0.580	0.580
0.570	0.560	0.560	0.550	0.540	0.540
0.530	0.520	0.520	0.510	0.500	0.500
0.490	0.490	0.480	0.480	0.470	0.470
0.460	0.460	0.450	0.450	0.440	0.440
0.440	0.430	0.430	0.420	0.420	0.410
0.410	0.410	0.400	0.400	0.400	0.390
0.390	0.390	0.380	0.380	0.380	0.370
0.370	0.370	0.360	0.360	0.360	0.360
0.350	0.350	0.350	0.350	0.340	0.340
0.340	0.340	0.330	0.330	0.330	0.330
0.330	0.320	0.320	0.320	0.320	0.310
0.310	0.310	0.310	0.310	0.310	0.300
0.300	0.300	0.300	0.300	0.300	0.290
0.290	0.290	0.290	0.290	0.290	0.280
0.280	0.280	0.280	0.280	0.280	0.280
0.280	0.270	0.270	0.270	0.270	0.270
0.270	0.270	0.270	0.260	0.260	0.260
0.260	0.260	0.260	0.260	0.260	0.260
0.260	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.220	0.220	0.220
0.220	0.220	0.220	0.220	0.220	0.220
0.220	0.220	0.220	0.220	0.220	0.220
0.220	0.220	0.220	0.220	0.220	0.220
0.220	0.220	0.220	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.210	0.210	0.210	0.210	0.210	0.210
0.210	0.210	0.210	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.200	0.200	0.200	0.200
0.200	0.200	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190
0.190	0.190	0.190	0.190	0.190	0.190

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                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.190
                          0.190    0.190    0.190    0.190    0.190    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
                          0.180    0.180    0.180    0.180    0.180    0.180
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                            AND=BRONTE.WAT
STORE HYD           ID=1 HYD NO=1301DT= 0.2500 HRS  DA=   4.930 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0240
                          0.023    0.023    0.023    0.024    0.026    0.031
                          0.044    0.850    1.710    1.800    1.800    1.760
                          1.700    1.640    1.580    1.520    1.460    1.400
                          1.350    1.300    1.250    1.200    1.150    1.110
                          1.060    1.020    0.980    0.950    0.910    0.880
                          0.840    0.810    0.780    0.750    0.720    0.690
                          0.670    0.640    0.620    0.590    0.570    0.550
                          0.530    0.510    0.490    0.470    0.450    0.440
                          0.420    0.410    0.390    0.380    0.360    0.350
                          0.340    0.320    0.310    0.300    0.290    0.280
                          0.270    0.260    0.250    0.240    0.230    0.230
                          0.220    0.210    0.200    0.200    0.190    0.180
                          0.180    0.170    0.170    0.160    0.160    0.150
                          0.150    0.140    0.140    0.130    0.130    0.120
                          0.120    0.120    0.110    0.110    0.110    0.100
                          0.100    0.098    0.095    0.093    0.090    0.088
                          0.085    0.083    0.081    0.079    0.077    0.075
                          0.073    0.072    0.070    0.068    0.067    0.065
                          0.064    0.063    0.061    0.060    0.059    0.058
                          0.057    0.056    0.055    0.054    0.053    0.052
                          0.051    0.050    0.049    0.049    0.048    0.047
                          0.046    0.046    0.045    0.045    0.044    0.044
                          0.043    0.043    0.042    0.042    0.041    0.041
                          0.040    0.040    0.040    0.039    0.039    0.039
                          0.038    0.038    0.038    0.037    0.037    0.037
                          0.037    0.036    0.036    0.036    0.036    0.036
                          0.035    0.035    0.035    0.035    0.035    0.035
                          0.035    0.034    0.034    0.034    0.034    0.034
                          0.034    0.034    0.034    0.034    0.033    0.033
                          0.033    0.033    0.033    0.033    0.033    0.033
                          0.033    0.033    0.033    0.033    0.033    0.033
                          0.033    0.033    0.033    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
                          0.032    0.032    0.032    0.032    0.032    0.032
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                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.032    0.032    0.032    0.032
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                         0.032    0.032    0.032    0.032    0.032    0.032
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                         0.032    0.032    0.032    0.032    0.032    0.032
                         0.032    0.032    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
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                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.031    0.031    0.031
                         0.031    0.031    0.031    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
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                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.030
                         0.030    0.030    0.030    0.030    0.030    0.029
*
* HYDROGRAPH GENERATED BY FILE=SCS25mm.dat
*                            AND=BRONTE.WAT
STORE HYD           ID=3 HYD NO=6301DT= 0.2500 HRS  DA=  33.730 SQ KM
                     HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.1600
                         0.160    0.160    0.160    0.160    0.160    0.170
                         0.180    0.990    1.890    2.630    3.620    4.240
                         4.730    5.170    5.500    5.710    5.860    5.980
                         6.090    6.220    6.350    6.470    6.550    6.600
                         6.600    6.550    6.470    6.350    6.210    6.050
                         5.880    5.710    5.530    5.360    5.190    5.020
                         4.860    4.700    4.550    4.410    4.270    4.130
                         4.000    3.880    3.760    3.640    3.530    3.420
                         3.320    3.220    3.130    3.030    2.950    2.860
                         2.780    2.700    2.630    2.550    2.480    2.410
                         2.350    2.290    2.220    2.170    2.110    2.050
                         2.000    1.950    1.900    1.850    1.810    1.760
```

1.720	1.680	1.640	1.600	1.560	1.530
1.490	1.460	1.430	1.400	1.360	1.330
1.310	1.280	1.250	1.230	1.200	1.180
1.150	1.130	1.110	1.090	1.070	1.040
1.030	1.010	0.990	0.970	0.950	0.940
0.920	0.900	0.890	0.870	0.860	0.840
0.830	0.820	0.800	0.790	0.780	0.770
0.750	0.740	0.730	0.720	0.710	0.700
0.690	0.680	0.670	0.660	0.650	0.640
0.640	0.630	0.620	0.610	0.600	0.600
0.590	0.580	0.580	0.570	0.560	0.560
0.550	0.540	0.540	0.530	0.530	0.520
0.510	0.510	0.500	0.500	0.490	0.490
0.480	0.480	0.470	0.470	0.470	0.460
0.460	0.450	0.450	0.440	0.440	0.440
0.430	0.430	0.430	0.420	0.420	0.420
0.410	0.410	0.410	0.400	0.400	0.400
0.390	0.390	0.390	0.390	0.380	0.380
0.380	0.380	0.370	0.370	0.370	0.370
0.360	0.360	0.360	0.360	0.350	0.350
0.350	0.350	0.350	0.340	0.340	0.340
0.340	0.340	0.340	0.330	0.330	0.330
0.330	0.330	0.330	0.320	0.320	0.320
0.320	0.320	0.320	0.310	0.310	0.310
0.310	0.310	0.310	0.310	0.310	0.300
0.300	0.300	0.300	0.300	0.300	0.300
0.300	0.300	0.290	0.290	0.290	0.290
0.290	0.290	0.290	0.290	0.290	0.290
0.280	0.280	0.280	0.280	0.280	0.280
0.280	0.280	0.280	0.280	0.280	0.280
0.270	0.270	0.270	0.270	0.270	0.270
0.270	0.270	0.270	0.270	0.270	0.270
0.270	0.270	0.270	0.260	0.260	0.260
0.260	0.260	0.260	0.260	0.260	0.260
0.260	0.260	0.260	0.260	0.260	0.260
0.260	0.260	0.260	0.260	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250
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0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.240	0.240	0.240	0.240
0.240	0.240	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.230	0.230
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0.230	0.230	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.230	0.220
0.220	0.220	0.220	0.220	0.220	0.220
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                         0.220    0.220    0.220    0.220    0.220    0.220
                         0.220    0.220    0.220    0.220    0.220    0.220
                         0.220    0.220    0.220    0.210    0.210    0.210
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*                          AND=BRONTE.WAT
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                      HYDROGRAPH ORDINATES (CMS) INITIAL FLOW=    0.0170
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                         0.031    0.520    1.050    1.110    1.110    1.090
                         1.060    1.030    1.000    0.970    0.940    0.900
                         0.870    0.840    0.810    0.780    0.750    0.730
                         0.700    0.680    0.650    0.630    0.610    0.590
                         0.570    0.550    0.530    0.510    0.490    0.470
                         0.460    0.440    0.430    0.410    0.400    0.380
                         0.370    0.360    0.350    0.330    0.320    0.310
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                         0.080    0.078    0.076    0.074    0.072    0.070
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                                  0.022    0.022    0.022    0.022    0.022    0.022
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*                           AND=BRONTE.WAT
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                                  0.190    0.680    1.210    1.320    2.140    3.010
                                  3.730    4.670    5.260    5.710    6.120    6.410
                                  6.590    6.700    6.790    6.880    6.980    7.080
                                  7.170    7.230    7.250    7.230    7.160    7.050
                                  6.910    6.750    6.570    6.380    6.190    6.000
                                  5.810    5.620    5.440    5.260    5.090    4.930
                                  4.770    4.620    4.470    4.330    4.190    4.060
                                  3.940    3.820    3.700    3.590    3.480    3.380
                                  3.280    3.180    3.090    3.000    2.910    2.830
                                  2.750    2.670    2.600    2.530    2.460    2.390
                                  2.330    2.270    2.210    2.150    2.090    2.040
                                  1.990    1.940    1.890    1.840    1.800    1.750
                                  1.710    1.670    1.630    1.590    1.560    1.520
                                  1.490    1.460    1.420    1.390    1.360    1.330
                                  1.300    1.280    1.250    1.230    1.200    1.180
                                  1.150    1.130    1.110    1.090    1.070    1.050
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                                  0.650    0.640    0.630    0.620    0.610    0.610
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0.230	0.230	0.230	0.230	0.230	0.230
0.230	0.230	0.230	0.230	0.230	0.230

APPENDIX D

STREAMFLOW DATA RATIONALIZATION

PEIL

PLANNERS
CONSULTING
ENGINEERS &
LANDSCAPE
ARCHITECTS

APPENDIX D

ADDITIONAL VALIDATION OF MODEL FOR INDIAN CREEK

For additional validation of the hydrologic model, especially for the Indian Creek portion, two temporary water level recording gauges were installed within the Indian Creek watershed. One of them was located on the West Branch of Indian Creek at Britannia Road (Node 6284 in the model) and the other was located on the East Branch at the CNR railway embankment culvert (Node 6292 in the model). These two pressure transducer gauges were installed on April 19, 2001, and were ultimately removed around November 9, 2001. Moreover, a temporary tipping-bucket rain gauge was located within the Indian Creek watershed, and although it was installed at the same time as the two aforementioned water level recorders, no measurable rainfall was recorded at that gauge until July 23, 2001. **Table D 1** summarizes the rainfall amounts recorded by the temporary rainfall for the 2001 field season. Supplementary recording rainfall data were obtained from Conservation Halton for their Kelso Park gauge for the period April 1, 1999 to July 20, 2001. The daily rainfall amounts for this gauge are summarized on three separate pages at the end of this memo. Additional streamflow data were supposed to be available from the Gartner-Lee gauge located at the outlet of Subcatchment 1291 on the East Branch of Indian Creek, and the re-established Zimmerman Gauge (at node 6240 in the model), but these were never made available to our Study Team.

After reviewing the available streamflow data for the Britannia Road and CNR Culvert gauges, only two events created a sufficiently ‘noticeable’ response that was at least worth making an attempt at simulating them. These two 6-day duration runs were May 20-25, 2001 and October 4-9, 2001.The measured and modelled hydrographs for these two events are displayed in **Figures D 1** and **D 2**, respectively. Without going into a lot of discussion about the differences between the observed and simulated results, a few general comments noted below should be kept in mind when viewing the hydrograph comparison plots in **Figures D 1** and **D 2**.

1. Rainfall data for the May 2001 event was taken from the Kelso gauge records, and the site specific gauge was not function. The October 2001 simulation utilized the site specific raingauge.

2. Rainfall amounts for the May to November 2001 period were extremely below normal for much of southern Ontario. According the Kelso gauge records, the May 2001 totals were about 20 mm below normal, whereas the June totals were about 40 mm below normal. In some locations of southern Ontario, rainfall amounts for July and early August were almost nil. With such a severe drought, it difficult to secure sufficient streamflow responses from runoff events to validate any hydrologic model, especially when one of the objectives of the modelling exercise is to generate flood (high) flow estimates. The *Ontario Flood Plain Management Guidelines* (OMNR, 1986) suggest that events generating at least 25 mm of runoff should be used to adequately calibrate and verify any hydrologic model for high flow estimates. In this regard, the streamflow data collected during the 2001 field season turned out to be rather ‘poor’ for model validation purposes.

3. Generally speaking, during drought periods any rainfall events that do occur are usually of a highly convective (e.g. thunderstorm) nature. When most of the rainfall activity is generated almost entirely from thunderstorm activity, the spatial distribution of rainfall depths becomes extremely variable, even over very small distances (e.g. much less than 0.5 km). In such cases, as were exhibited in the summer of 2001, it is very difficult to secure represent rainfall amounts for model input. Clearly, from a close examination of **Figures D 1** and **D 2**, the rainfall amounts on the two watersheds upstream of the respective gauges were not representative at all. The results shown in **Figure D 1** were produced by applying the Kelso gauge totals to the Britannia Road gauged area with no adjustment, but in order to get the response shown for the CNR Culvert gauge, half the rainfall amount was applied to the area upstream of the gauge (that is Subcatchments 1291 and 1292). Even with this adjustment, the rainfall amounts between hours 36 and 60 were overestimated. In **Figure D 2**, the modelled response for the Britannia Road gauge was obtained by doubling the measured rainfall total, and making no adjustments to area upstream of the CNR Culvert gauge. In either case, these rainfall adjustments were still not representative of the responses observed by the two streamgauges.

4. Moreover, it is well-known that the Niagara Escarpment exerts a great influence on the rainfall amounts for watersheds above and below it's ridges. From my examination of the data, it would appear that the East Branch of Indian Creek experienced much less rainfall that the West Branch for the entire summer of 2001. Notice that the CNR Culvert gauge response in **Figure D 2** is almost flat compared to the one shown at the Britannia Road gauge. Granted, the drainage area for the Britannia Road gauge is almost 5 times bigger than the CNR Culvert gauge, and so it is collecting rainfall from a much wider area, and we would expect more 'responses' in that gauge.

5. In addition to the general lack of rainfall that occurs during a drought period, excessive weed growth at streamgauge locations will greatly influence the rating curves. If a gauge located at culvert or bridge is subject to some 'silting-up', then the weed growth can enter the culvert or bridge opening, greatly influencing the hydraulic control. Securing a good 'stable' rating curve for the two gauges was very difficult for the period under consideration. Moreover, because both gauges used a pressure transducer device, estimates of the background (or ambient) atmospheric air pressure were required to get the 'correct' water depth in the culvert barrel or bridge opening. Uncertainties in estimating the background atmospheric air pressure could change the water level readings by 10 to 15 cm. Consequently, there are considerable uncertainties in the gauge rating curves, and the actual water levels recorded. In this regard, estimation error in the measured flows could easily be on the order of ±50 to 100%.

In summary then, there were difficulties in securing good quality rainfall and streamflow data for the 2001 field season. It was possible to apply the Indian Creek portion of the model to two observed events, and make some comparison between measured and modelled results at two gauged locations. In this regard, all measured streamflow data are valuable in checking the timing of flow responses. From examination of the hydrograph comparison plots shown here, and knowing the complications in the measured data noted above, there are no obvious discrepancies between the observed and simulated results that would require major adjustments in any of the model inputs variables or parameters. If anything, the results shown here demonstrate that the overland, channel and baseflow routing procedures in the model are reasonable representations of the actual response of Indian Creek. The response unit drainage variables and parameters have already been validated from hydrograph comparisons at more than 120 good quality streamgauge locations over the past 15 years throughout southern Ontario, five of which are located within the drainage areas of Conservation Halton.

Table D 1 – Summary of Rainfall Amounts for 2001 Field Season
(Only Shown for days with measurable rainfall)

Date	Amount	Month to Date	Date	Amount	Month to Date
April 19 to July 22, 2001	Nil	Nil	September 26	1.8	17.8
July 23	0.2	0.2	September 27	0.2	18.0
July 25	0.2	0.4	September 28	0.2	18.2
August 10	0.4	0.4	October 4	1.4	1.4
August 16	2.6	3.0	October 5	11.6	13.0
August 17	0.2	3.2	October 6	2.6	15.6
August 19	4.0	7.2	October 11	0.8	16.4
August 20	1.8	9.0	October 12	1.8	18.2
August 23	0.2	9.2	October 14	0.2	18.4
August 26	0.6	9.8	October 16	1.0	19.4
August 28	0.8	10.6	October 17	1.0	20.4
			October 23	0.6	21.0
September 3	1.0	1.0	October 25	1.8	22.8
September 19	5.6	6.6	October 26	0.2	23.0
September 21	3.6	10.2			
September 22	0.2	10.4	November 1	0.2	0.2
September 24	1.6	12.0	November 2	0.2	0.4
September 25	4.0	16.0	November 4	0.4	0.8

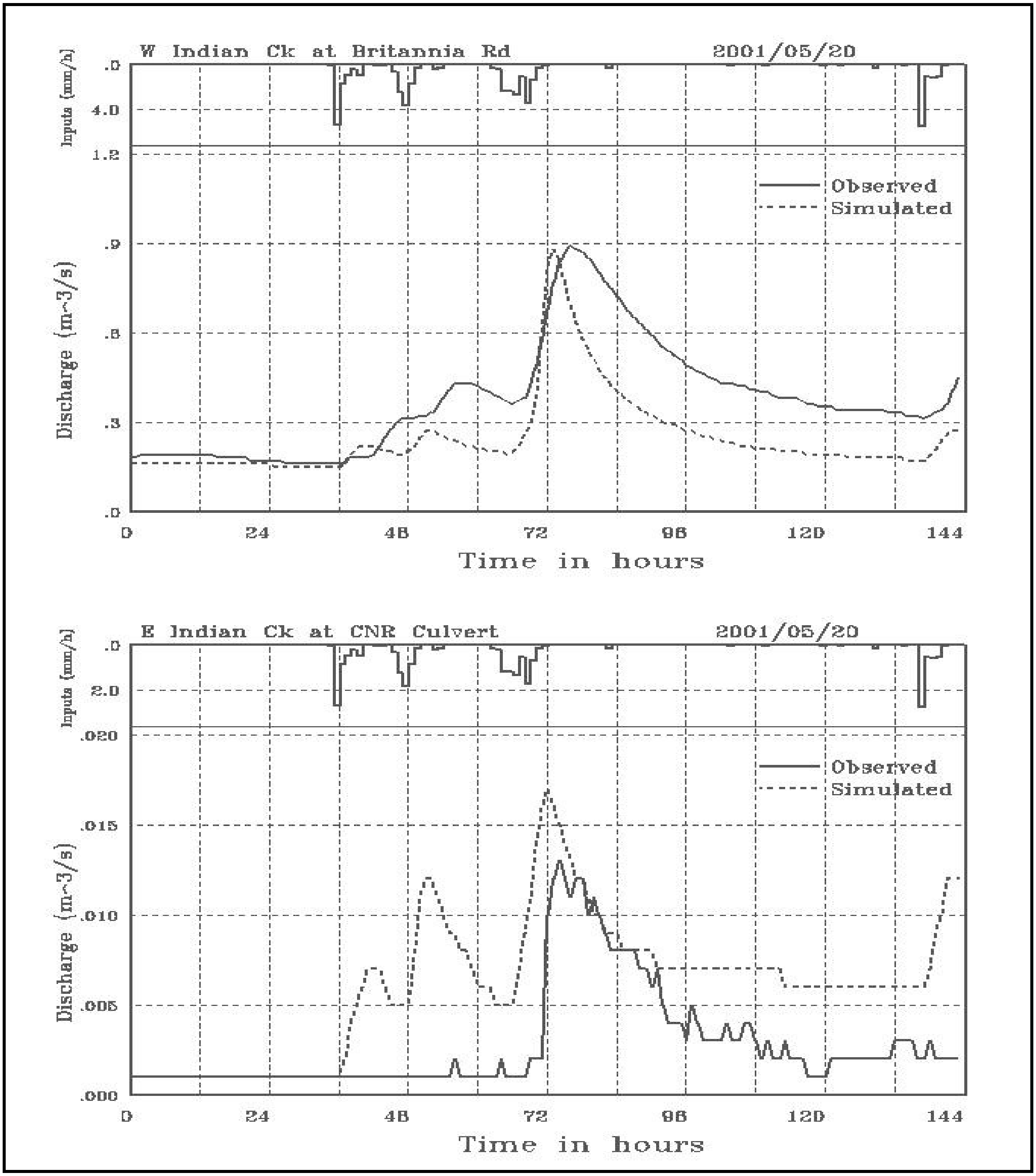

Figure D 1 – Observed and simulated hydrographs for May 20-25, 2001 event at the Britannia Road and CNR Culvert gauges

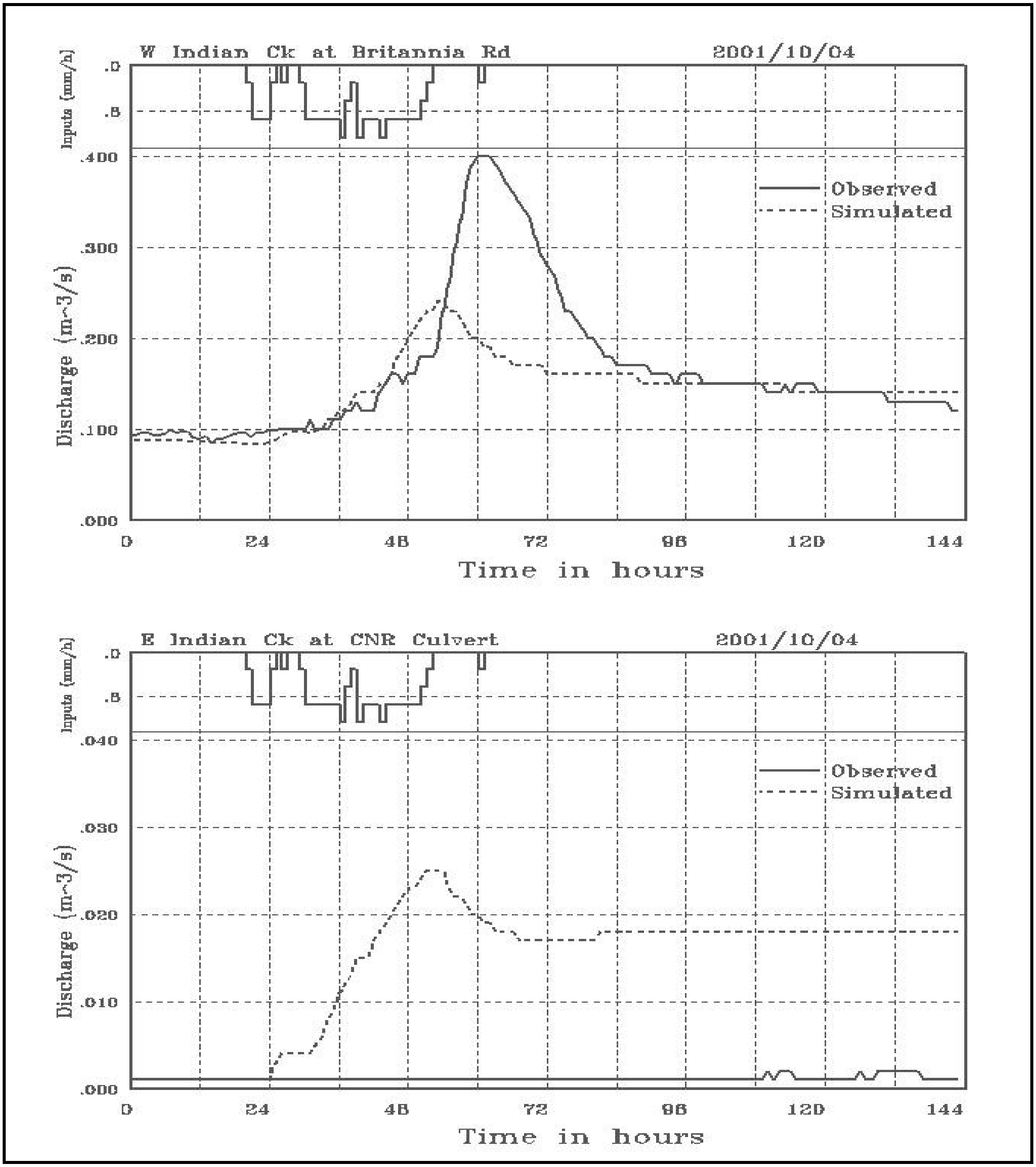

Figure D 2 – Observed and simulated hydrographs for October 4-9, 2001 event

MILTON KELSO 6155187

Daily Total Rainfall Depths (mm) for 1999

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	---	---	---	6.8#									1
2	---	---	---								52.6		2
3	---	---	---					2.4				0.2	3
4	---	---	---					10.6				2.4	4
5	---	---	---									32.4	5
6	---	---	---	75.2				1.6		0.2		3.6	6
7	---	---	---	33.4		55.6		1.6					7
8	---	---	---	32.6				6.2		6.0			8
9	---	---	---									0.4	9
10	---	---	---					1.8		0.4	3.0	2.2	10
11	---	---	---					0.2			0.2		11
12	---	---	---	0.2						0.6	0.6		12
13	---	---	---	2.0			0.2			84.2			13
14	---	---	---			6.2				1.6		2.0	14
15	---	---	---								0.4	19.6	15
16	---	---	---	4.6			0.6					3.2#	16
17	---	---	---	0.4		1.2	10.8					---	17
18	---	---	---	0.4		0.4					0.2	---	18
19	---	---	---	0.2			2.8					---	19
20	---	---	---							0.2	4.4	---	20
21	---	---	---	1.0							0.4	---	21
22	---	---	---	18.2						5.4		---	22
23	---	---	---	4.6						0.4		---	23
24	---	---	---				11.0				5.0	---	24
25	---	---	---				0.2	0.8				---	25
26	---	---	---					2.8			12.8	---	26
27	---	---	---				0.2					---	27
28	---	---	---				6.8			0.2		---	28
29	---		---									---	29
30	---		---				0.2					---	30
31	---		---				94.6			0.2		---	31
TOTAL	---	---	---	180#		63.4	127	28.0		99.4	79.6	66.0#	TOTAL
MAXDAY	---	---	---	75.2#		55.6	94.6	10.6		84.2	52.6	32.4#	MAX
72 hr	---	---	---	141		55.6	101	94.8		86.4	52.8	38.6	141.2
48 hr	---	---	---	141		55.6	94.8	94.8		86.4	52.6	36.0	141.2
36	---	---	---	131		55.6	94.8	94.6		86.4	52.6	35.8	130.6
24	---	---	---	78.6		55.6	94.6	94.6		84.4	52.6	35.2	94.6
12	---	---	---	75.4		55.6	94.4	93.2		84.0	45.2	31.4	94.4
6	---	---	---	73.6		55.6	93.0	10.2		74.8	26.6	30.0	93.0
4	---	---	---	67.4		55.6	92.6	10.2		58.8	20.6	29.0	92.6
3	---	---	---	63.0		55.6	90.2	10.2		54.6	17.0	29.0	90.2
2	---	---	---	49.4		55.6	65.2	10.0		49.8	12.2	27.0	65.2
1 hr	---	---	---	31.0		39.4	38.0	10.0		44.4	7.4	18.2	44.4

NOTE: # incomplete total

TOTAL AMOUNT FOR YEAR, 643

MILTON KELSO 6155187

Daily Total Rainfall Depths (mm) for 2000

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	---	0.2			5.2	0.4		65.2	1.4	0.2	---	---	1
2	---			0.6	0.2	3.4		0.8	21.2	0.4	---	---	2
3	---	0.4		1.0				0.4	0.8	0.4	---	---	3
4	---			3.6		0.2		0.2	1.4	5.8	---	---	4
5	---					2.0		0.4	0.6	3.2	---	---	5
6	---					3.0		1.4	0.2	2.4	---	---	6
7	---				1.2			0.2	2.2	5.8	---	---	7
8	---				0.4	0.4		5.2	2.0	2.4	---	---	8
9	---		1.2	0.2	21.8	12.8		40.0	3.4	1.4	---	---	9
10	---				9.6			7.8	17.4	2.0	---	---	10
11	---			0.2	2.2	9.8	0.4		1.0	1.0	---	---	11
12	---			2.8	116	0.6	0.6	0.4	2.2	0.2	---	---	12
13	---				14.4	41.6		0.4	0.2	0.2	---	---	13
14	---						21.4	0.4	14.2	0.4	---	---	14
15	---	0.4					4.0	7.6	0.8	0.6	---	---	15
16	---						6.4	0.8	0.6	2.4	---	---	16
17	---			1.8	0.8		14.6	0.2	0.4	1.2	---	---	17
18	---			0.2	33.2		0.2	0.4	3.6	0.8	---	---	18
19	---				1.8		0.8	0.4	0.2	0.8	---	---	19
20	---		0.2	63.4			1.0	0.4	4.2	0.6	---	---	20
21	---		1.6	3.6	0.2		0.4	0.4	0.8	0.6	---	---	21
22	---		1.0	2.0				1.0	6.2	3.8	---	---	22
23	---		0.2		8.4		0.4	13.6	26.6	1.8	---	---	23
24	---				15.0		0.4	0.2	0.6	1.6	---	---	24
25	---		2.4				0.4			2.0	---	---	25
26	---				0.2		0.4			0.8#	---	---	26
27	#		6.4				0.4			---	---	---	27
28			0.4	0.6			20.4			---	---	---	28
29							0.4	0.6	0.4	---	---	---	29
30					0.2		18.2	0.4	0.4	---	---	---	30
31			0.2		9.8		12.4	0.6		---		---	31
TOTAL	#	1.0	13.6	80.0	241	74.2	103	149	113	42.8#	---	---	TOTAL
MAXDAY	#	0.4	6.4	63.4	116	41.6	21.4	65.2	26.6	5.8#	---	---	MAX
72 hr		0.6	8.8	69.0	140	52.0	44.6	96.0	37.6	13.6	---	---	139.6
48 hr		0.4	6.8	68.8	133	50.2	30.6	94.6	32.8	10.4	---	---	133.0
36		0.4	6.8	66.6	133	42.2	30.6	72.0	32.8	8.2	---	---	133.0
24		0.4	6.4	64.8	130	41.6	24.6	71.8	30.4	6.6	---	---	130.4
12		0.4	6.4	54.8	91.4	41.6	23.2	65.2	24.2	5.8	---	---	91.4
6		0.4	6.4	41.8	91.4	36.2	18.0	65.2	20.6	5.2	---	---	91.4
4		0.4	5.4	36.8	89.2	26.6	17.6	65.2	20.6	5.2	---	---	89.2
3		0.4	5.0	35.4	74.8	23.4	17.4	65.0	20.4	4.8	---	---	74.8
2		0.4	4.6	29.0	50.2	19.4	17.2	64.4	17.8	4.0	---	---	64.4
1 hr		0.4	3.0	21.4	36.6	10.8	13.8	45.8	13.8	2.8	---	---	45.8

NOTE: # incomplete total TOTAL AMOUNT FOR YEAR, 818

MILTON KELSO 6155187

Daily Total Rainfall Depths (mm) for 2001

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	---	---	---	---		8.2	0.4	---	---	---	---	---	1
2	---	---	---	---		0.6	0.4	---	---	---	---	---	2
3	---	---	---	---	0.2	10.2	0.6	---	---	---	---	---	3
4	---	---	---	---	0.2	0.6	3.2	---	---	---	---	---	4
5	---	---	---	---		0.4	0.2	---	---	---	---	---	5
6	---	---	---	---		0.4	0.2	---	---	---	---	---	6
7	---	---	---	---		0.4	2.4	---	---	---	---	---	7
8	---	---	---	---	0.2	0.4	0.2	---	---	---	---	---	8
9	---	---	---	6.6#		0.2	0.4	---	---	---	---	---	9
10	---	---	---	0.8		0.4	0.6	---	---	---	---	---	10
11	---	---	---	0.4		2.4	0.4	---	---	---	---	---	11
12	---	---	---	6.8		1.2	0.4	---	---	---	---	---	12
13	---	---	---	0.6		0.6	0.4	---	---	---	---	---	13
14	---	---	---	0.6		0.8	0.2	---	---	---	---	---	14
15	---	---	---	0.6		0.4	0.2	---	---	---	---	---	15
16	---	---	---	6.2		0.6	0.6	---	---	---	---	---	16
17	---	---	---	0.6	0.2	0.6	2.8	---	---	---	---	---	17
18	---	---	---	0.6		0.4	0.4	---	---	---	---	---	18
19	---	---	---	0.4		0.4	0.4	---	---	---	---	---	19
20	---	---	---	0.2		0.4	0.4#	---	---	---	---	---	20
21	---	---	---	3.2	16.6	0.6	---	---	---	---	---	---	21
22	---	---	---	0.2	26.6	0.4	---	---	---	---	---	---	22
23	---	---	---	0.4	0.6	0.4	---	---	---	---	---	---	23
24	---	---	---	0.6	0.4	0.2	---	---	---	---	---	---	24
25	---	---	---	0.4	12.6	0.6	---	---	---	---	---	---	25
26	---	---	---	0.8	0.8	1.0	---	---	---	---	---	---	26
27	---	---	---		9.0	1.0	---	---	---	---	---	---	27
28	---	---	---		1.0	0.4	---	---	---	---	---	---	28
29	---		---		0.4	0.4	---	---	---	---	---	---	29
30	---		---	0.2	0.4	1.2	---	---	---	---	---	---	30
31	---		---		0.4		---	---		---		---	31
TOTAL	---	---	---	30.2#	69.6	35.8	14.8#	---	---	---	---	---	TOTAL
MAXDAY	---	---	---	6.8#	26.6	10.2	3.2#	---	---	---	---	---	MAX
72 hr	---	---	---	13.4	44.0	19.4	4.8	---	---	---	---	---	44.0
48 hr	---	---	---	7.4	43.6	16.6	3.8	---	---	---	---	---	43.6
36	---	---	---	7.4	43.0	10.8	3.8	---	---	---	---	---	43.0
24	---	---	---	6.8	29.4	10.2	3.2	---	---	---	---	---	29.4
12	---	---	---	6.6	18.6	8.0	3.2	---	---	---	---	---	18.6
6	---	---	---	6.6	17.0	6.2	2.6	---	---	---	---	---	17.0
4	---	---	---	6.2	12.2	5.0	2.6	---	---	---	---	---	12.2
3	---	---	---	6.0	10.2	4.2	2.4	---	---	---	---	---	10.2
2	---	---	---	5.4	9.0	3.6	2.4	---	---	---	---	---	9.0
1 hr	---	---	---	3.2	7.0	3.0	2.4	---	---	---	---	---	7.0

NOTE: # incomplete total TOTAL AMOUNT FOR YEAR, 150