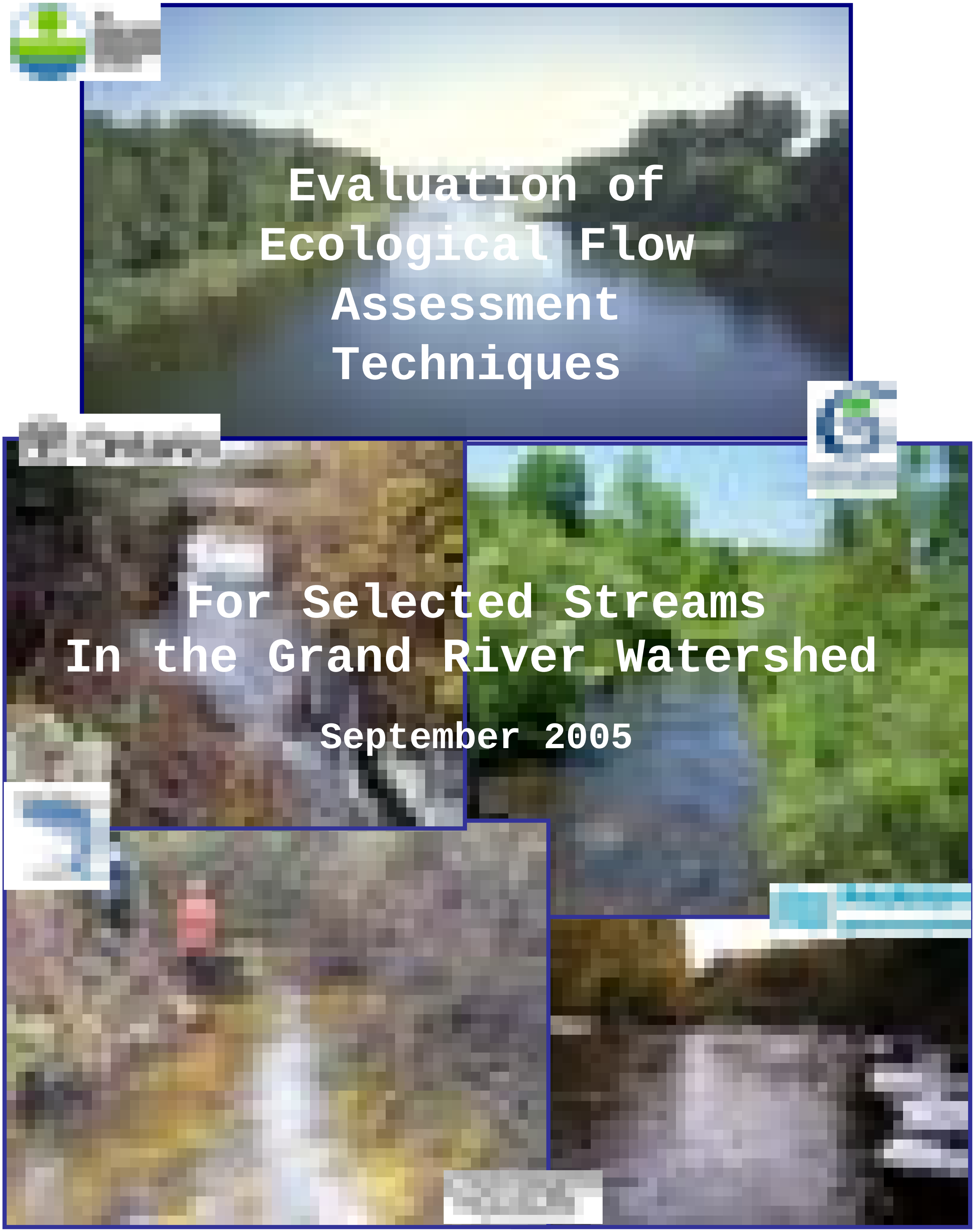

Evaluation of Ecological Flow Assessment Techniques

For Selected Streams In the Grand River Watershed

September 2005

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Ecological Flow Assessment Techniques
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Prepared by:

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Executive Summary

Ecological flow requirements, or instream flow needs, refer to the flows that need to be maintained to ensure that a river continues to sustain its full natural range of aquatic organisms and habitat. With the growing competition for water takings for human uses there is a need for a better understanding of the natural environment's water needs. Through the request of the Ontario Ministry of the Environment and Conservation Ontario, three conservation authorities including the Grand River Conservation Authority were contracted to complete pilot studies. The intent of the pilot studies was to further investigate means of quantifying ecological flow requirements in an Ontario context.

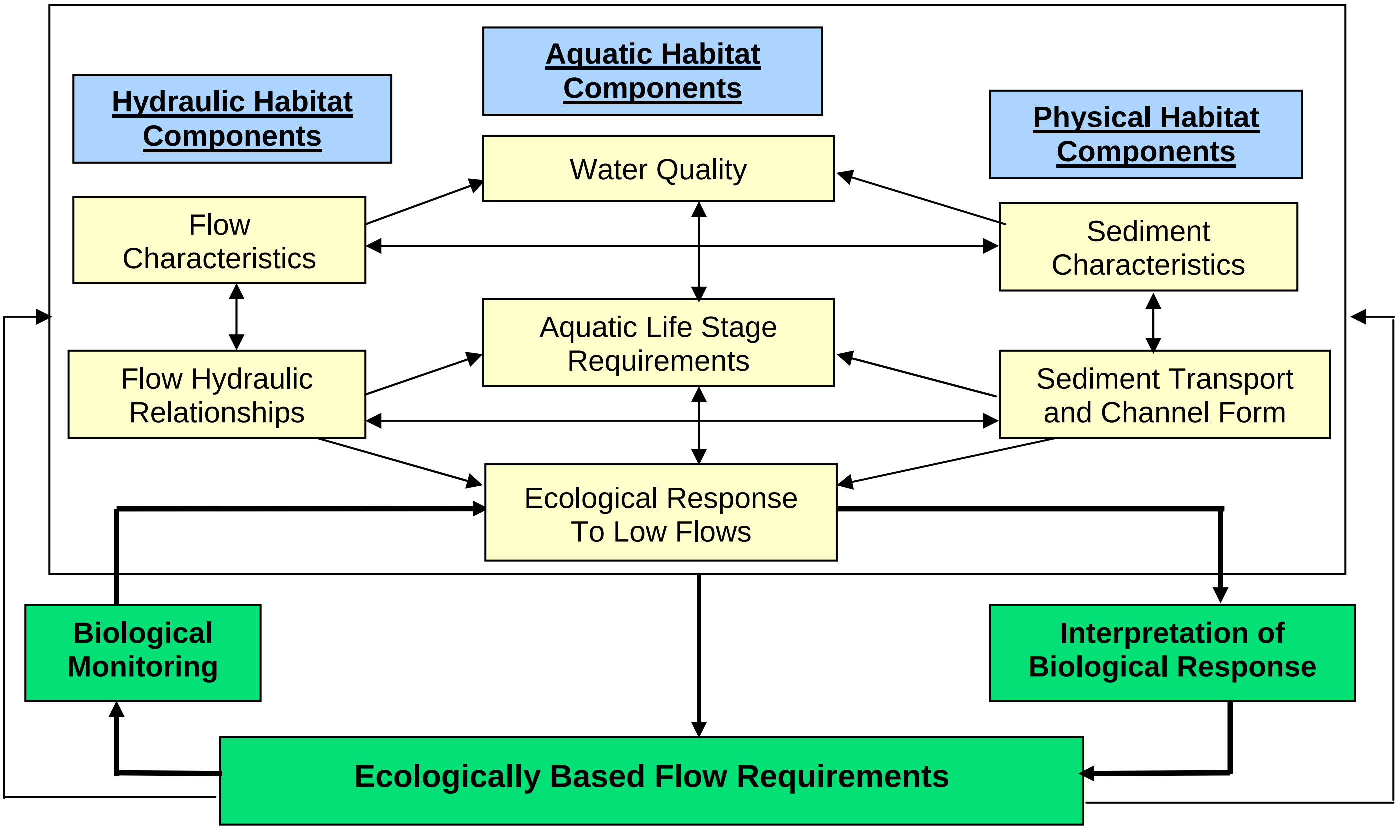
The goal of this project was to provide a process or framework to estimate ecological flow requirements for pilot reaches and investigate options for transferring requirements established for pilot reaches to other areas in the watershed. The study also had an important objective to investigate options for monitoring biological response. It is important to monitor biological response to confirm the effectiveness of management strategies or prescribed flows. To accomplish these objectives, the Grand River Conservation Authority, selected 8 pilot reaches to test and compare a variety of established methods for determining ecological flow requirements. Each pilot study reach had unique circumstances regarding physical characteristics, water use, and aquatic ecology. Eight reaches were selected to provide a wide range of conditions for assessment of the tools and approaches. An effort was made to outline these characteristics in this report using a case study approach. For each pilot reach, site characterization and water takings based on the Permit to Take Water database are provided in Chapters 5 and 6, respectively.

The components of the instream flow study and interactions between the components are visualized in Flow Diagram A. Each yellow box in the diagram is a component of the GRCA study, with the interactions among them symbolized with arrows. The components can be categorized under hydraulic, aquatic and physical habitats, shown by the blue boxes. The components all lead to the establishment of a framework or process to estimate ecological flow requirements (the bottom green box). The feedback loops indicate that there must be continual monitoring of biological response to adapt ecologically based flow requirements and confirm their effectiveness. Biological monitoring is a component outside of the components box since it is in preliminary stages in this report, but is something that will need to be further investigated. The science around monitoring biological response is evolving; additional research is needed in this area to advance the science and approaches to effectively monitoring biological response. Diagram A does not show the how the data components are processed and manipulated to obtain the ecologically based flow requirements. Please refer to the process diagram (Flow Diagram B) for information on generating information for ecological flow requirements.

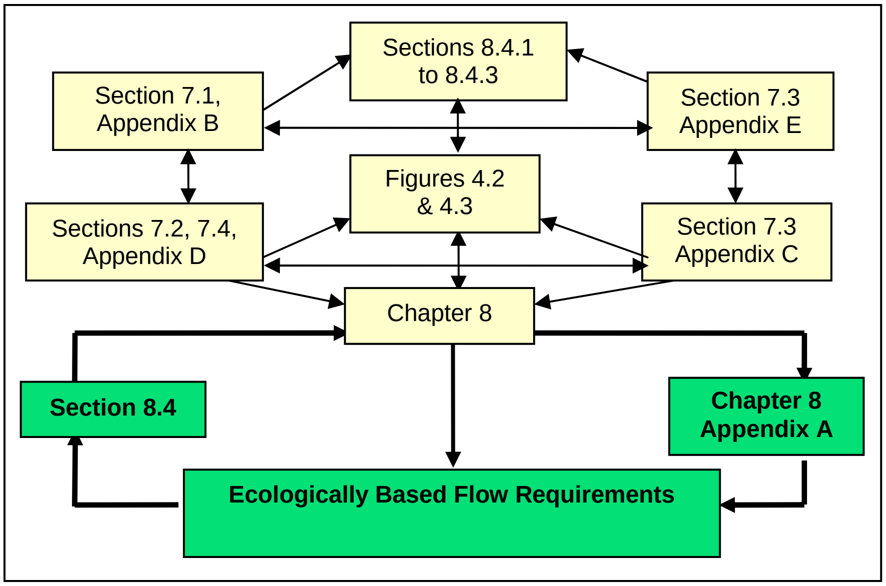
Flow Diagram B depicts the process that the GRCA study pursued to evaluate instream flow techniques. The white boxes on the left side give a general idea of what is involved in each step of the process, and the coloured boxes show in more detail what is comprised in each step. This diagram shows a process that could be taken to ultimately set PTTW conditions, for a high water use area or in an area where there is a large discrete taking. The whole intensive process, however, is not required to assess the conditions of all PTTW permits. Permits of low volumes or applications in low-intensity water taking regions may

not have to go through the entire process of this flow diagram. Select sections of the diagram may be all that is required for low-intensity permits.

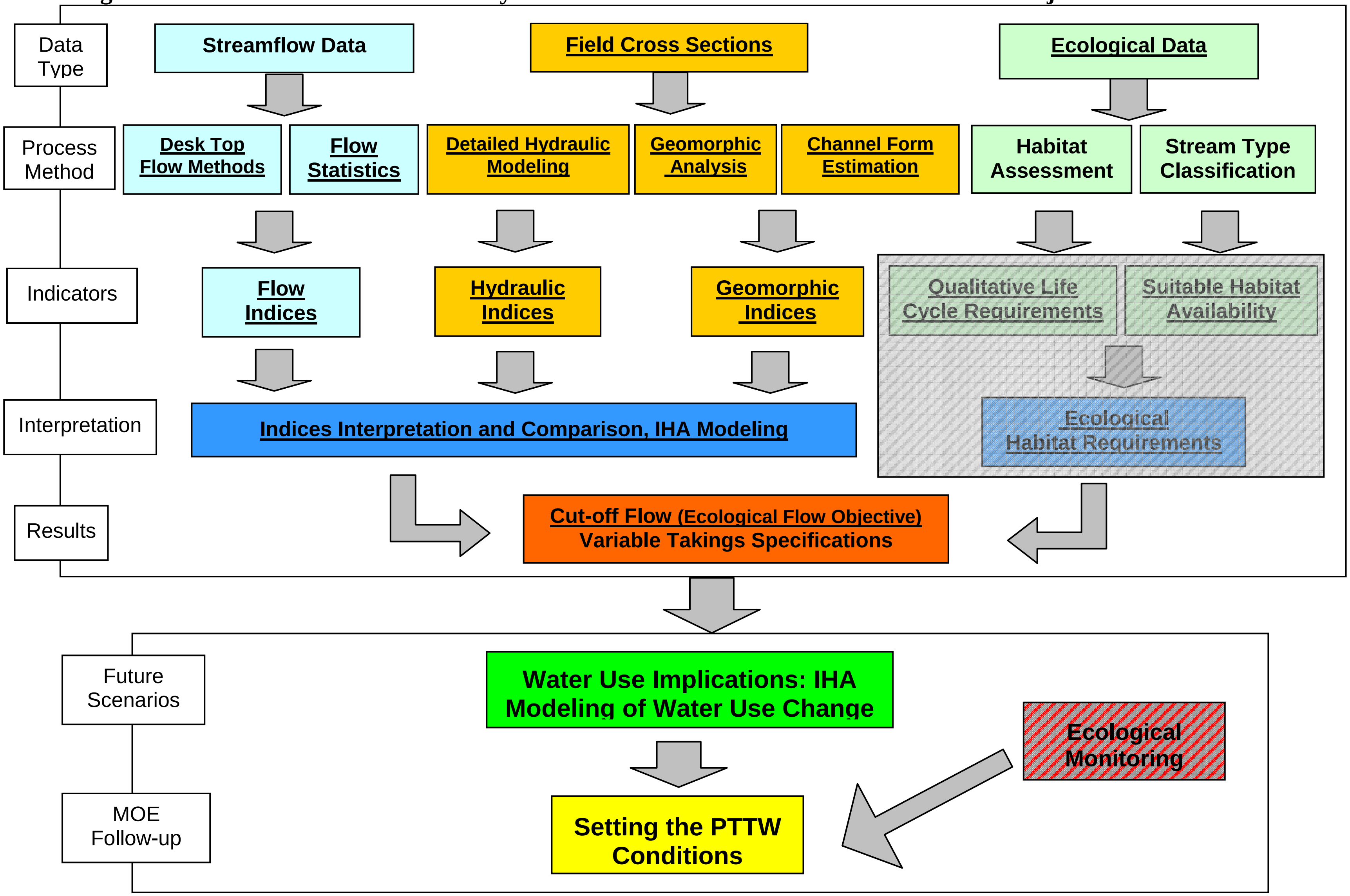
Flow Diagram A: Components of the GRCA Study and their Interactions



Flow Diagram A. ii) Inset for location of component data and results



Flow Diagram B: Process Flow Chart Taken by the GRCA for the Instream Flow Assessment Project



The process flow diagram begins with data at the top that was processed using either a model or another method to generate some indicators of flow, hydraulics, geomorphology or ecology. These indicators are compared against each other, to determine what the cut-off flows (minimum ecological flow objectives) and variable takings in that reach could be. IHA modeling for future scenarios are also used to supplement the determination of the taking specifications. All this information is taken into account when setting the PTTW conditions in an application, with the hope that ecological monitoring will also take place to verify that the taking protocol is not detrimental to the aquatic environment.

The four boxes that are greyed out are items or tasks that have yet to be fully established for the assessment of ecological flow requirements, but are items that, in the future, should be considered as part of any instream flow study.

The detailed process for assessment of ecological flow techniques included desktop methods as well as field measurements using hydraulic, hydrologic, geomorphic, flow and ecological techniques. Hydrologically based methods such as the Tennant or Tessmann methods are based on flows, and were used as a preliminary assessment of the condition of the study reach. Hydraulic modeling using the HEC-RAS model or the Ontario Flow Assessment Techniques (OFAT) tool provided the ability to generate results where long-term data was unavailable. Although some and tools are available, they generally are sufficient to complete a general scoping of issues, often additional work would be required. Geomorphic fieldwork, completed by Parish Geomorphic, generated geomorphologically-based flow thresholds to verify the results of hydraulic modeling, verify other desktop methods and most importantly provide geomorphic thresholds that need to be considered to maintain geomorphic functions of the stream. The *Indicators of Hydrologic Alteration* model was used to simulate water use scenarios and the implications associated with each scenario.

Chapter 7 in this report details the process illustrated by Flow Diagram 2. Index charts were developed for each pilot reach. The index charts integrate flow indices and statistics with hydraulic indices and geomorphic indices all in one chart. The index charts help integrate considerations and guide the interpretation for each study reach. In addition to flow index charts, percentile flow charts are also presented for each study reach. The percentile flow charts illustrate the flow variability within and across years in one chart. This illustrates the variability of the surface water resources in each study reach, which leads to the conclusion that a single minimum flow is not sufficient to describe the natural environment’s water needs. The natural variability of flow is important; the *Indicators of Hydrologic Alteration* (IHA) software applied in this report helps quantify the natural variability of key hydrologic parameters that need to be considered when analyzing the potential impacts of water takings.

Case studies of selected reaches are included at the end of Chapter 7. These case studies help illustrate how indices information developed for each study reach along with the IHA software can be applied to analyze potential impacts associated with specific water takings and how these environmental objectives can be integrated into Permits to Take Water. This study has demonstrated geomorphic field data collection can be integrated with hydraulic modeling needs to produce calibrated low-flow hydraulic models that can be used to model hydraulic habitat and link changes in flow with resultant changes in hydraulic habitat. Selected case studies help illustrate how changes in flow can be linked to changes in hydraulic habitat and how changes in hydraulic habitat can be quantified with hydraulic models.

Previous studies into the ecological response to low flows were limited, as it is a relatively new research topic. Methods for determining effects of water takings were examined in the Grand River watershed, but proved inconclusive. A third method which is gaining recognition, was tested in this study using stable isotope analysis to provide results based on energy flow in stream foodwebs. The life cycle requirements of fish throughout the year, based on flows and aquatic habitat availability, was used as a qualitative method for assessment in this study. This study highlights the challenges faced in attempting to monitor biological response. The stable isotope method offers some optimism, however the science, methods and approaches to measuring biological response require additional research and work.

The transferability of information from study reaches to the broader watershed is examined in Chapter 9. Tools such as OFAT are examined along with the concept of regionalizing parameters or indices. All streams are different and it is important to realize this fact. Physiography is one filter that can be used to group streams in a given area and help identify or qualify the extent or area to which information from a given study reach can be transferred. Strategically selecting pilot reaches in discrete physiographic areas is one approach that could be pursued to facilitate transfer of information from an indicator reach to a non-gauged reach. Transferred information should be used to scope issues and assess the need for more detailed investigations or analysis.

This study offers a process to estimate instream flow requirements and has provided a number of conclusions and recommendations to others who might attempt a study into ecological flow requirements in Ontario. In general, a range of environmental flows and thresholds with long-term monitoring is needed to properly describe the ecological flow requirements of a reach.

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List of Abbreviations

3D	Three dimension(al)
7Q10	Seven-day, Ten-Year Low Flow
BMI	Biomass Index
BOD	Biological Oxygen Demand
CA	Conservation Authority
cfs	Cubic feet per second (also symbolized ft^3/s)
CPOM	Coarse Particulate Organic Matter
cms	Cubic metres per second (also symbolized m^3/s)
D_{50}	Median bed material size
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
DO	Dissolved Oxygen
DEM	Digital Elevation Model
FPOM	Fine Particulate Organic Matter
GAWSER	Guelph All-Weather Sequential Events Runoff model
GLL	Gartner Lee Limited
GRCA	Grand River Conservation Authority
GRSM	Grand River Simulation Model
HEC-2	*Hydrologic Engineering Center* software package 2 (river hydraulics)
HEC-RAS	*Hydrologic Engineering Centers River Analysis System*
IFC	Instream Flow Council
IFIM	Instream Flow Incremental Methodology
IFN	Instream Flow Need
IHA	*Indicators of Hydrologic Alteration*
MNR	(Ontario) Ministry of Natural Resources
MOE	(Ontario) Ministry of the Environment
OFAT	*Ontario Flow Assessment Techniques*
OLWRP	Ontario Low Water Response Plan
ORSECT	*Ontario River/Stream Ecological Classification Techniques*
PHABSIM	*Physical Habitat Simulation System*
PPWB	Prairie Provinces Water Board
PTTW	Permit to Take Water
PWQM	Provincial Water Quality Monitoring
ROW	Region of Waterloo
Q_{ma} (MAF)	Mean Annual Flow
Q_{mm} (MMF)	Mean Monthly Flow
QUAL2E	*Enhanced Stream Water Quality* model
RVA	*Range of Variability Approach*
SIA	Stable Isotope Analysis
STP	Sewage Treatment Plant
UTM	Universal Transverse Mercator
WSC	Water Survey of Canada
YOY	Year-of-the-Young

Note: Descriptions in italics are names of programs or software

1.0 INTRODUCTION

1.1 General Background

Society's desire to have a healthy environment and sufficient water to meet human needs can be and often are conflicting objectives. This conflict can place stress on the natural environment that can lead to environmental degradation.

The Ontario Ministry of the Environment (MOE) has the mandate to issue permits to take water in the Province of Ontario. Permits to take water are required for takings that exceed 50,000 litres in a given day. While regulations are in place to permit water takings, the science around quantifying the environment's needs for the same water is evolving.

1.2 Study Rationale

Recognizing the need for better science and understanding of the natural environment's water needs, the MOE provided funding to Conservation Ontario to examine this issue.

The MOE requested that Conservation Ontario examine techniques available to evaluate the natural environment's water needs and investigate how these techniques could be incorporated into the current decision making process related to permits to take water.

The study focuses on two objectives: to determine the method or combination of methods for establishing instream flows that are best suited to conditions experienced in Ontario; and to develop a framework to apply these methods to manage takings in different watershed situations.

1.3 Study Approach

In response to MOE's request, Conservation Ontario issued a request for letters of interest to Ontario Conservation Authorities. Requests for proposals were issued to a short list of Conservation Authorities. After reviewing the proposals, three Conservation Authorities (CA's) were selected to carry out pilot projects on behalf of Conservation Ontario to satisfy the MOE request.

Pilot projects were established in Long Point, Cataraqui Region and Grand River Conservation Authorities. The selection of the 3 CA's was based on the varying information availability, watershed characteristics and water management issues. The intent was to provide a cross section of watersheds to test instream flow techniques in different areas of the Province.

The studies in each of the Grand River Conservation Authority (GRCA) pilot areas were organized into two components; Component A focused on testing instream flow methods and Component B focused on developing a framework or process to apply instream flow methods in different watersheds.

The goal of study Component A was to test, compare, and attempt to validate a number of different approaches for setting instream flow quantities in a variety of reaches and streams within each of the Authorities' jurisdictions. This component attempts to identify easy to use hydrologically based approaches for Ontario that give ecologically meaningful threshold flows.

The goal of study Component B – Assigning Instream Flow Requirements – is to develop a process or framework to estimate instream flow requirements within a given watershed to avoid adverse ecological impacts while trying to accommodate water users. This component will focus on the process of establishing instream flow thresholds and applying them in given watershed reaches within a number of watersheds in Ontario.

1.3.1 Study Approach in the Grand River Watershed

The study approach in the Grand River Watershed includes the following key components:

- A literature review of instream flow techniques applied in other jurisdictions and how these instream flow techniques may be formalized into an instream flow program.
- Development of a process to assemble, analyze and interpret flow information and subsequently apply flow based instream flow techniques to estimate thresholds for selected watersheds. This component focuses on desktop instream flow methods.
- Consideration of how flow information for ungauged locations could be inferred from gauged locations. Information provided by the *Ontario Flow Assessment Techniques* (OFAT) Software is compared to statistics calculated from observed flow data at the given study locations to assess the reliability/accuracy of estimates from OFAT.
- Documentation of the field methods used to collect stream cross sections to support the construction of detailed hydraulic models using *Hydrologic Engineering Centers River Analysis System* (HEC-RAS) and geomorphic analyses.
- Development of a process to construct, analyze, interpret and organize information from a detailed HEC-RAS hydraulic model to estimate hydraulic instream flow thresholds.
- Comparison of flow based instream flow thresholds with hydraulic based instream flow thresholds. This comparison attempts to investigate the ability of detailed hydraulics models to establish instream flow thresholds. Detailed hydraulic models may offer the opportunity to establish instream flow thresholds in areas where long-term flow information does not exist.
- Development of geomorphic based instream flow thresholds for each of the study reaches based on detailed geomorphic analysis. Geomorphic thresholds were created for each study reach for comparison against flow and hydraulic based thresholds.
- Comparison of flow based, hydraulic based and geomorphic based instream flow thresholds. Formulation of instream flow thresholds for given reaches. Consideration of other thresholds needed to round out the requirements for a given reach.
- Case studies of selected study reaches to investigate how instream flow methods could be applied to analyze and manage water takings in the case study reach.

- Discussion of ecological complexity and the challenge of validating flow, hydraulic and geomorphic based instream flow thresholds to ecological system response.
- Investigation of isotope methods as one alternative that could be used to monitor biological response. Application of isotope method to selected reaches along with a discussion of the application of this approach and its limitations.
- Investigation of methods that could be used to estimate instream flow requirements for ungauged watersheds.
- Summary of preliminary conclusions and recommendations.

1.4 Report Outline

The rest of the report will be as follows:

Chapter 2 provides the background and watershed context. Technical understanding of the watershed where the water taking is considered is fundamental. This section describes the Grand River watershed in general. The study reaches are described in more detail in Chapter 5.

Chapter 3 briefly describes other recent studies and key references discovered as part of this project.

Chapter 4 is a literature review by Dr. Andrea Bradford of the University of Guelph. It includes a description of alternative instream flow assessment tools and examines approaches used in other jurisdictions to implement an instream flow program. Chapter 4 also includes a discussion of the complexity of validating ecological response to flow and hydraulic based thresholds. This segment is presented by Dr. Jack Imhof, based on work by Dr. Mike Power, University of Waterloo. The interrelationships of aquatic ecosystems are highlighted as a complex and diverse environment.

Chapter 5 presents the detailed hydrology, geomorphology and aquatic ecology of each of the study reaches. The case studies of each reach are presented with details of the process for identifying instream flow requirements.

Chapter 6 outlines the current water uses and water taking permits in the given study reaches.

Chapter 7 presents the synthesis of information used to establish instream flow thresholds, and the development of ecological thresholds based on hydraulic and geomorphic results.

Chapter 8 discusses different techniques to assess the ecological response to low-flows.

Chapter 9 applies techniques and threshold protocols established in preceding sections within a watershed context to establish instream flow requirements for different subwatersheds.

Chapter 10 presents the conclusions and recommendations based on work completed in this report.

2.0 DESCRIPTION OF THE GRAND RIVER WATERSHED

2.1 The Grand River Watershed

The Grand River forms one of the largest drainage basins in the southwestern portion of the Province of Ontario. The main stream rises at approximately 525 meters above sea level and runs a course of 300 kilometres to Lake Erie. The total drainage area is 6965 square kilometres, 10% of the direct drainage to Lake Erie. Agricultural and rural land uses predominate with urban land uses concentrated in the central portion accounting for 5% of the total land use in the watershed. Most of the basin's 787,000 residents reside in this central area as described in Focus on Watershed Issues 1997.

The hydrology of the watershed is the product of the climate, geology, land use, topography and drainage systems. The flow response in the Grand River system is strongly influenced by the underlying geology and man made reservoirs that provide a measure of flow regulation.

2.1.1 Watershed Geology and Moraine Complexes

Geology is often referred to as the underlying physics of a watershed; it determines the tendency for water to runoff or enter the groundwater system. The geology of the Grand River watershed is illustrated by Figure 2.1.

The colouring scheme used in Figure 2.1 is significant: Oranges illustrate areas of gravel, yellows illustrate areas of sand, greens illustrate areas of till, blue areas illustrate areas of clay and purples illustrate areas of exposed bedrock.

The shading of tills from dark green to light green is used to reflect the different characteristics of the tills. Light green tills are looser tills and are more readily able to accept water; dark green tills are tighter tills and are less accepting of water. Till is a mixture of clay, silt, sand and gravel. Depending on the dominant material in a till it may be referred to as sand till, clay till, silt till or stony till. The composition of till can change dramatically across a till unit. For detailed descriptions of geology refer to Geology of Ontario, Ministry of Northern Development and Mines and specific local quaternary geology reports available from Ministry of Northern Development and Mines.

Infiltration capacity is the ability of soils to accept water. Table 2.1 from the Hydrology of Floods in Canada (Watt, 1989), details the infiltration characteristics of different geological units. Table 2.1 illustrates the variation in infiltration capacity between different geological units and how different types of land cover can affect infiltration characteristics. It is also important to consider seasonal fluctuations in soil infiltration characteristics. If ground is frozen, it has limited ability to accept water.

The geology of the Grand River watershed can be conceptualized into three distinct zones: the till plains in the northern portion of the watershed, the central moraine area, and the clay plain in the southern portion of the watershed. Each of these areas has different characteristics that affect the hydrology.

Table 2.1 Infiltration characteristics of geological units

Soil Profile Category	Net Infiltration (mm/h)					
	Ground Cover Condition					
	Bare Soil	Row Crop	Poor Pasture	Small Grains	Good Pasture	Forested
I	7.6	13	15	18	25	76
II	2.5	5	7.6	10	13	15
III	1.3	1.8	2.5	3.8	5	6.4
IV	0.5	0.5	0.5	0.5	0.5	0.5

Category I: coarse- and medium-textured soils over sand and gravel glacial outwash materials, coarse open till or coarse alluvial deposits
Category II: Medium-textured soils over medium-textured till
Category III: Medium- and fine-textured soils over fine-textured clay till
Category IV: soil over shallow bedrock (600mm or less)

[Source: Watt, 1989]

The till plains are typically less accepting of water; water either runs off or evaporates, and a limited amount of water enters the groundwater system except where tills are sandy in nature or are thin. Tills typically overlie fractured bedrock, which is the primary water-bearing unit or aquifer. Although the infiltration rate may be slow, over a large area the infiltration volume can still be quite significant. Prior to colonization vast wetlands existed in the northern till plains. Surveyor notes referred to these wetlands as described in the Grand River Conservation Report – Hydraulics. In the late 1800's, settlers implemented systematic drainage in the form of tile drains and municipal drains. Drainage allowed the land to be converted from wetland to agricultural land uses. This radically changed the hydrology in the northern portion of the watershed. The human response was to build reservoirs to try to replace storage on the landscape that was lost when the original wetlands were drained.

The central portion of the watershed is dominated by moraines and remnant outwashes of the last ice age. Figure 2.2 illustrates the moraine areas. The central moraine area is the most hydrologically complex area of the watershed. The soils and topography found in the moraines can more easily hold water therefore the tendency in these areas is for more water to enter the ground than run off. This area of the watershed is characterized by coldwater streams, strong base flows and high quality and quantities of groundwater. The groundwater system in the central moraine area is typically characterized by single or multiple overburden aquifers overlying fractured bedrock.

The third and final area in the watershed is the clay plain. The clay plain represents the old lakebed of Lake Warren. This lake existed at the time of the last glaciations. The clay soils are typically tight; the hydrology in the clay plain is dominated by high rates of runoff and limited infiltration. One characteristic of the clay plain is the well-developed natural drainage system. The groundwater system in the clay plain is typically characterized by clay over fractured bedrock.

Understanding the geology of a watershed where water takings may occur is important for several reasons. First, knowledge of the underlying geology provides context regarding how water flows in a given area and its linkages. This basic knowledge provides the initial screening of potential issues that might be associated with a water taking and how that taking is linked to the natural environment. The surface geology also implies the fluvial regime that may be present in the area of a potential water taking. This again allows for scoping of fluvial issues that need to be considered in different areas.

2.1.2 Topography

Topography also plays an important role in the hydrology of the watershed. Rolling or hummocky topography is often found in moraine areas. Large areas are internally drained with no connection to a watercourse. Water that flows into internally drained areas either recharges or evaporates. There are also instances where water runs off till areas onto outwash areas and infiltrates.

The volume of recharge in internally drained areas, or where water runs off till areas onto an outwash, may exceed annual precipitation. One instance of this is in the Alder Creek Watershed west of Kitchener where in some internally drained areas, the recharge rate is in the order of several metres annually. This was reported in the recent Alder Creek Groundwater Study completed by Waterloo Region in 2002.

In the Eramosa Watershed above Guelph, an estimated 30% of the drainage area above Watson Road is closed drainage systems as reported in the Eramosa Watershed Study – Hydrology Technical Appendix (GRCA,1998).

Topography affects the flow of water. An initial understanding of how water flows in different areas is important. Higher level information is needed to understand how water interacts with the environment and how water takings may affect this interaction.

2.1.3 Drainage Systems - Streams

The Ministry of Natural Resources (MNR) created a classified stream layer, which is presented in Figure 2.3. The coldwater or potential coldwater fisheries have a close association with the major moraines and outwashes found in the Grand River watershed.

The classified drainage layer, in combination with the stream order layer, can be used to scope the sensitivity of streams to water takings. For example, a first order coldwater stream represents a very sensitive complex habitat where water takings are likely to be impractical without dire consequences; however a 4th order cold water stream may have more resilience to water takings. This is an example of how these information bases can be quickly used to scope water taking issues.

2.1.4 Watershed Land Cover

A map illustrating land cover throughout the Grand River watershed is presented by Figure 2.4. This figure illustrates the variations in land use across the watershed. Land cover in the Grand River watershed is dominated by agricultural production, which represents 80% of the land cover in the watershed (Table 2.2). Early forests gave way to clearing and drainage by European settlers.

It is estimated that 60 to 70% of the original wetlands have been drained. This clearing and drainage dramatically changed the hydrology in the watershed. Present day wetland areas along with areas that may have supported wetlands in the past are depicted by Figure 2.5. This figure illustrates the vast areas that may have supported wetlands prior to land clearing and drainage. Clearing and drainage resulted in less storage capacity on the landscape and more efficient drainage systems conveyed water off the landscape more quickly to streams and rivers. This had the effect of increasing the magnitude and frequency of both floods and droughts.

The human response to the changed hydrology was to build reservoirs to replace some of the lost storage. Looking at the location of reservoirs with respect to geology, it appears that where till plains were cleared and drained, reservoirs were implemented on, or at the fringe of, the altered till plains. Major reservoirs regulate flows along several reaches in the watershed. Figure 2.6 illustrates flow regulated reaches in the Grand River watershed. A distinct aspect of the Grand River watershed is that the main river itself is highly regulated. This study investigates issues of instream flow considerations in a regulated system like the Grand River.

Table 2.2 Percentage of different land cover

Land Use Type	Area (ha)	% of Total
Water – Deep	4,212	0.6%
Water – Shallow or sediment	2,523	0.4%
Deep/shallow water marsh	792	0.1%
Meadow marsh	85	0.0%
Cattail marsh	0	0.0%
Hardwood thicket swamp	7,571	1.1%
Conifer swamp	2,659	0.4%
Open fen	174	0.0%
Dense deciduous forest/shrubs	68,638	10.1%
Dense conifer	9,460	1.4%
Dense conifer, plantations	148	0.0%
Mixed forest, mainly deciduous	8,219	1.2%
Mixed forest, mainly conifer	10,418	1.5%
Sparse/open deciduous cover	10,227	1.5%
Bedrock/gravel/sand	1,619	0.2%
Urban: industrial/commercial/roads/infrastructure	1,780	0.3%
Urban: residential	15,589	2.3%
Row crops and hay/open soil	482,953	71.3%
Pasture, abandoned fields, savannah prairie	44,286	6.5%
Alvar (from OBS mapping with 3 metre buffer)	224	0.0%
Roads (from OBS mapping with 3 metre buffer)	5,631	0.8%
TOTAL	677,207	100%

[Source: Ministry of Natural Resources Landsat Information, 1992]

2.1.5 Watershed Hydrology

Water budget modeling of the Grand River watershed has quantified areas contributing to recharge and runoff in the watershed (Figures 2.7 and 2.8). Figure 2.9 illustrates permitted water takings for agricultural irrigation.

The flow and water quality networks in the Grand River Watershed are illustrated by Figures 2.10 and 2.11. Figure 2.12 shows locations of completed subwatershed studies. Heavy reliance is placed on information from these resources in the current study.

The recharge, runoff, permitted takings and regulated reaches are important information that provides context when considering water takings and environmental needs. There are 16 of 26 sewage treatment plants located on regulated reaches of the Grand River Watershed. Water takings must consider the prior commitments made with respect to assimilation of treated effluent along regulated reaches when considering water takings.

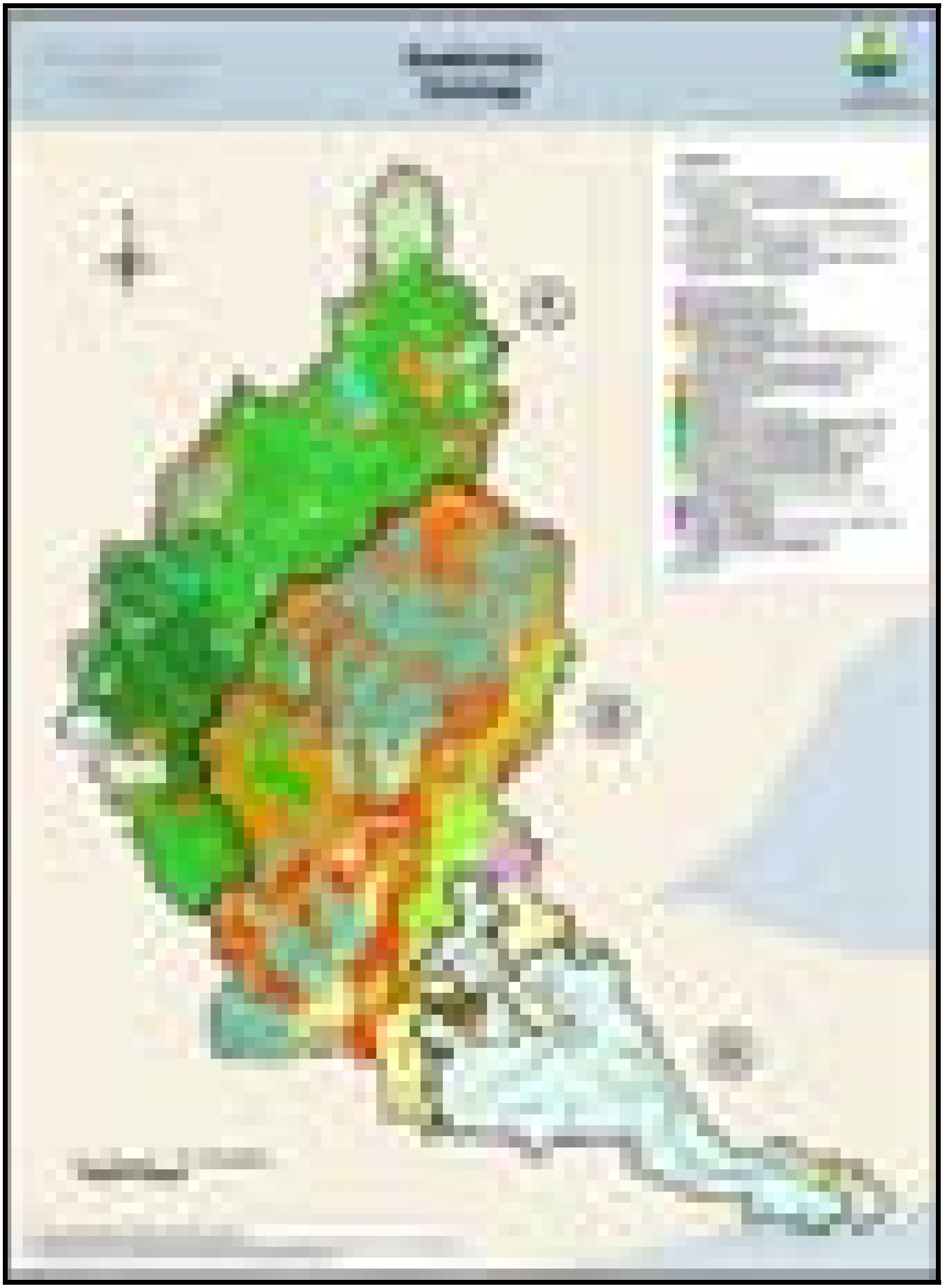


Figure 2.1 Quaternary Geology of the Grand River Watershed

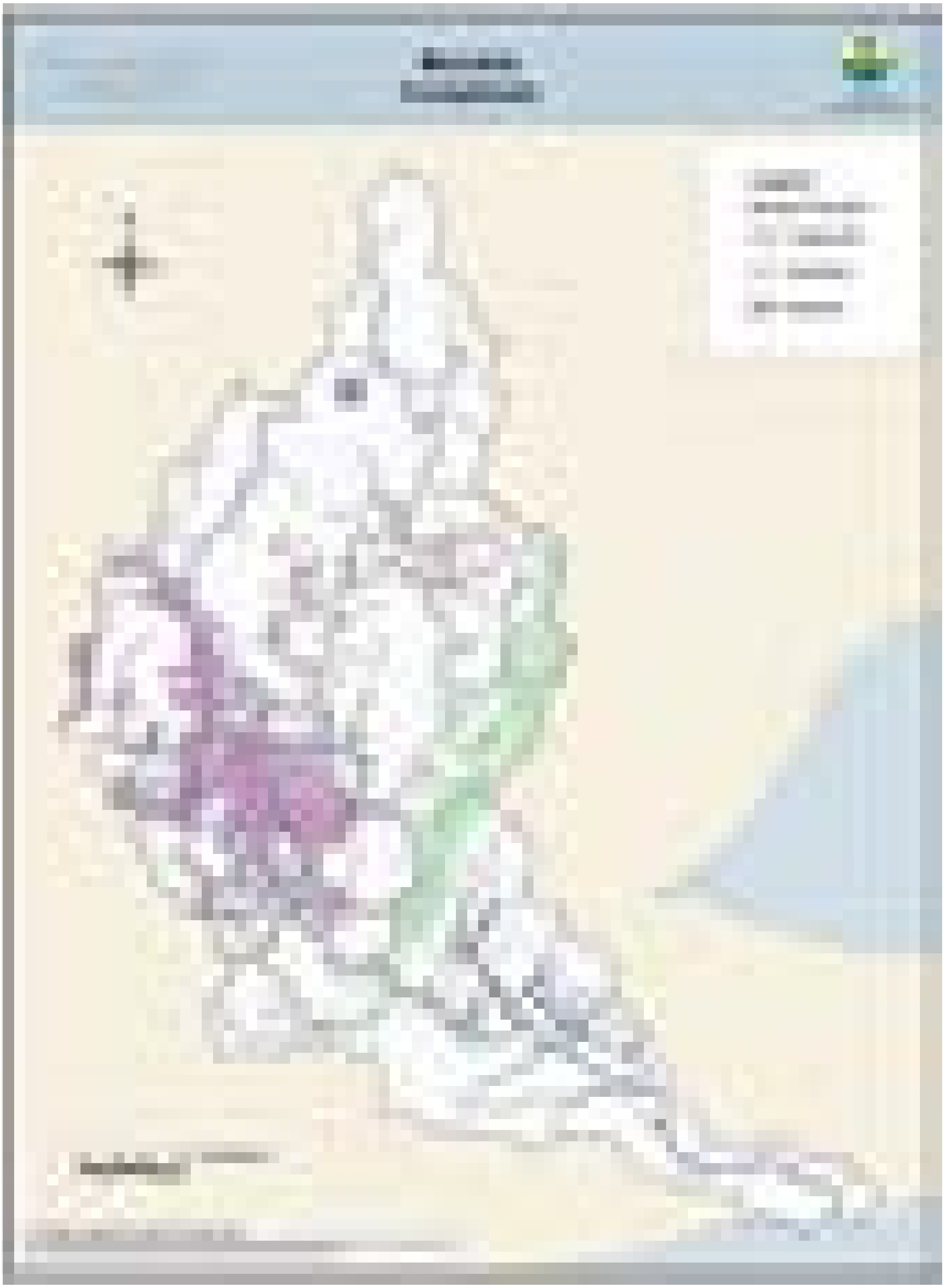


Figure 2.2 Moraine Complexes

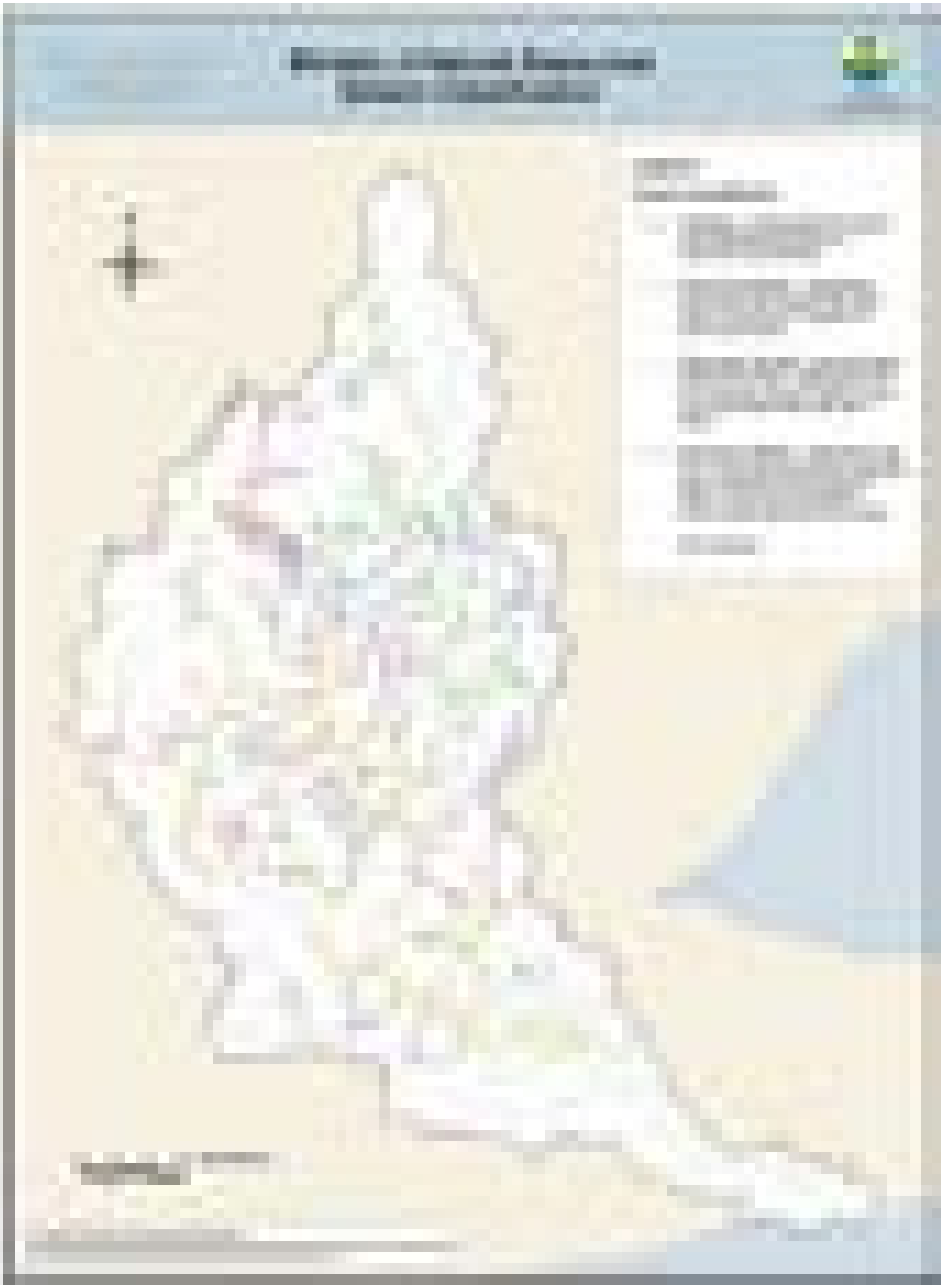


Figure 2.3 Classified Streams

Figure 2.4 Land Cover Across the Grand River Watershed

Figure 2.5 Map of Wetlands Areas and Areas of Historical Wetlands

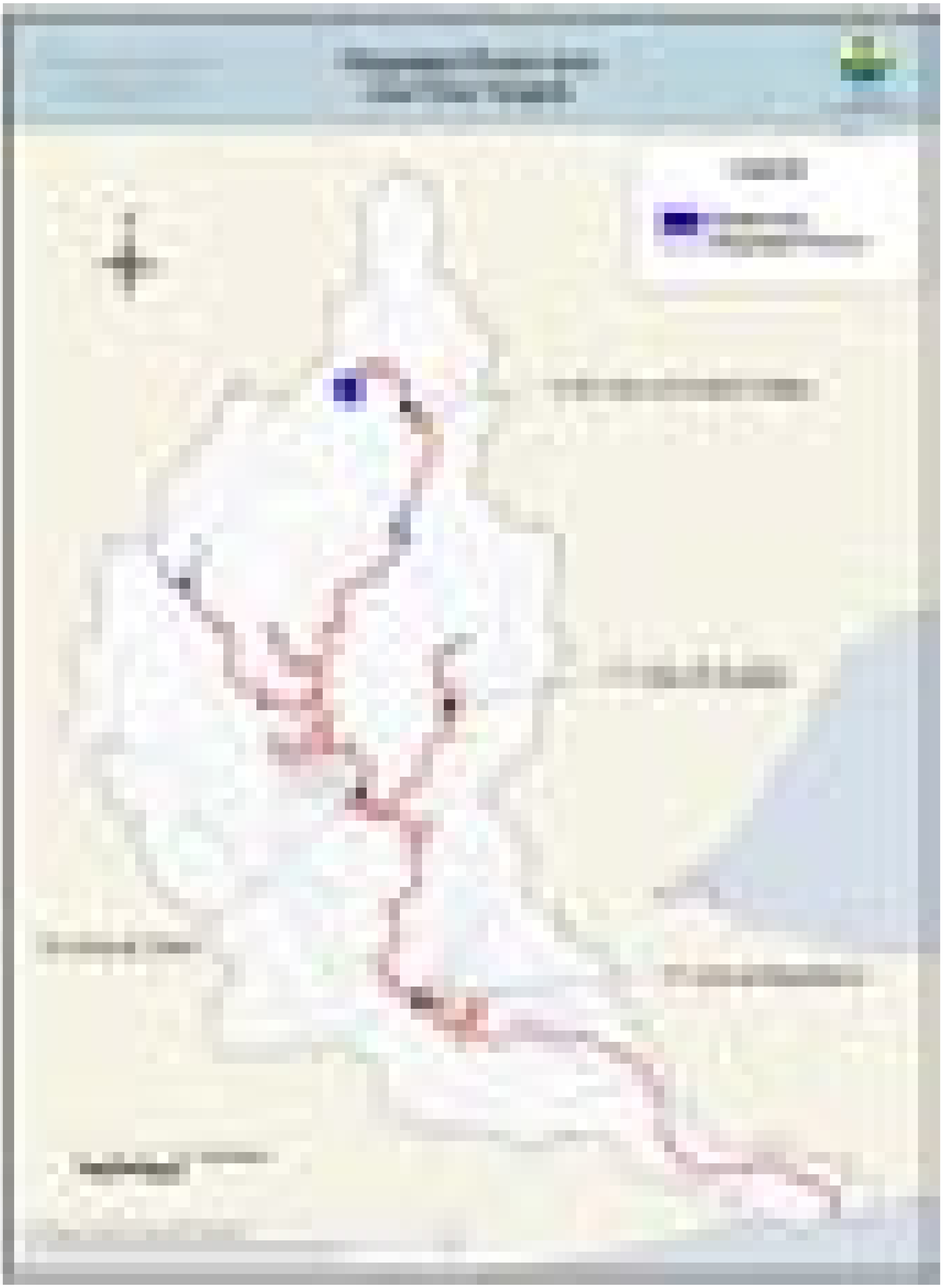


Figure 2.6 Regulated Reaches of the Grand River Watershed

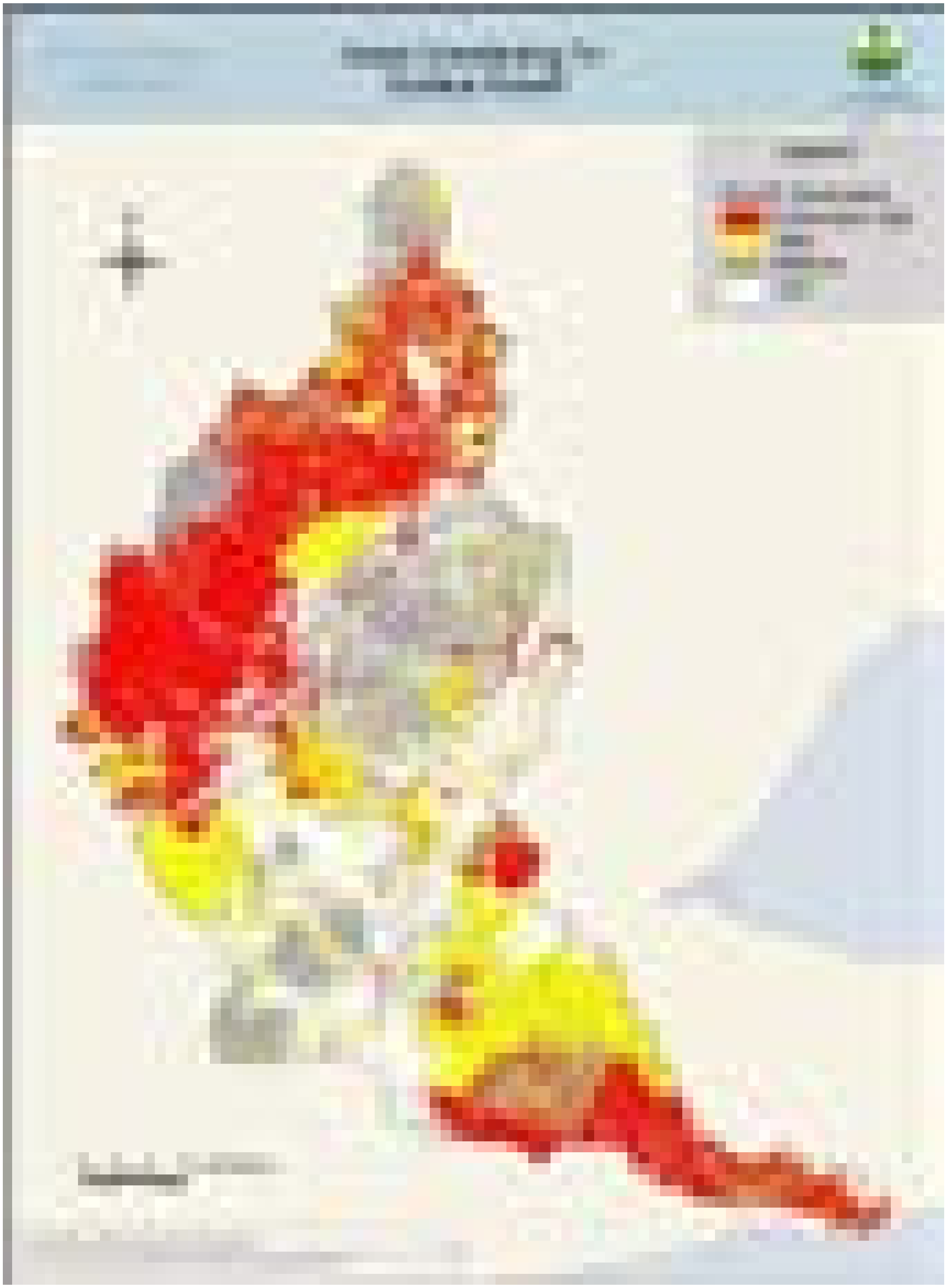


Figure 2.7 Map of Areas Contributing to Surfacewater Runoff

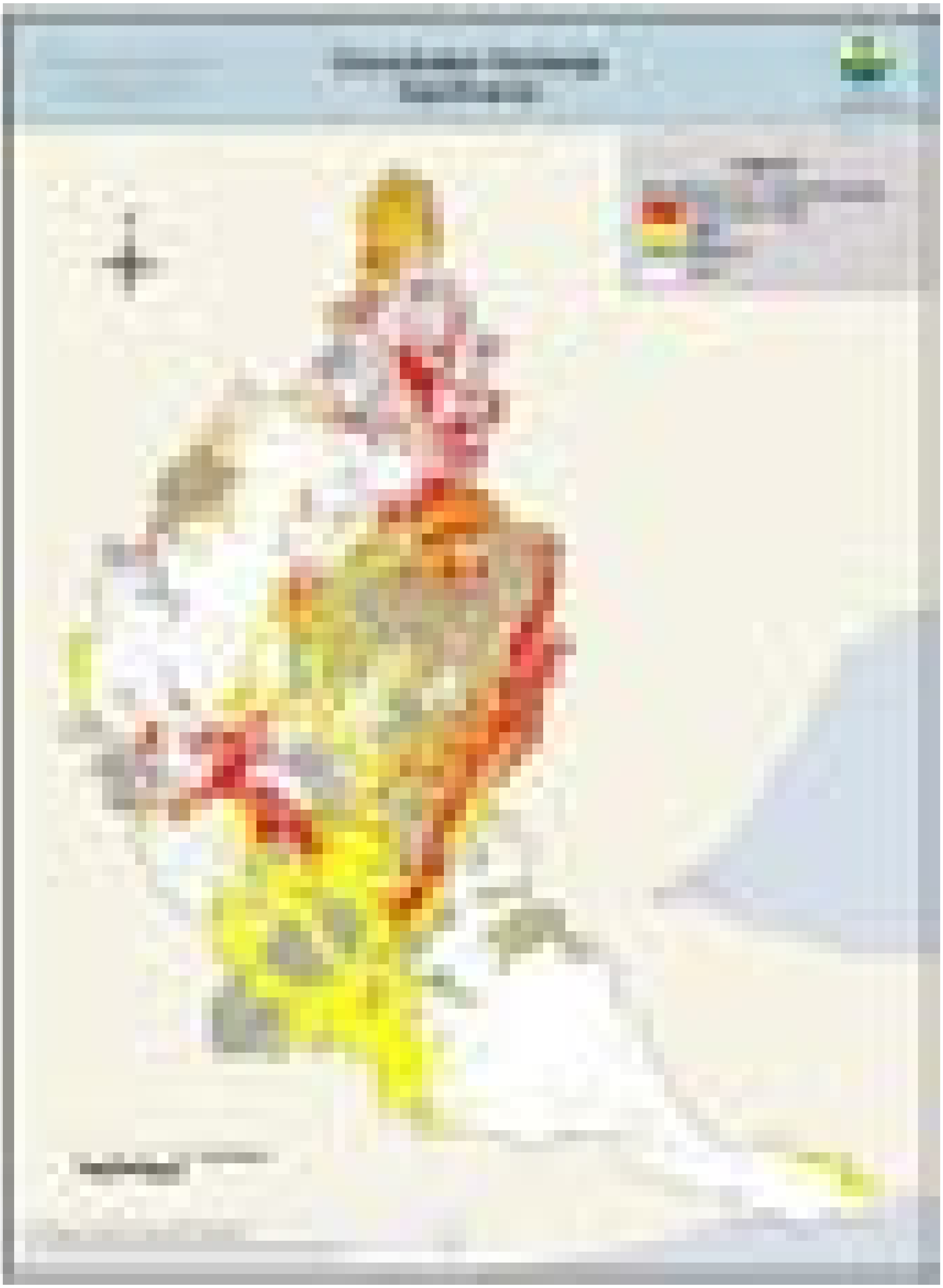


Figure 2.8 Recharge Areas in the Grand River Watershed

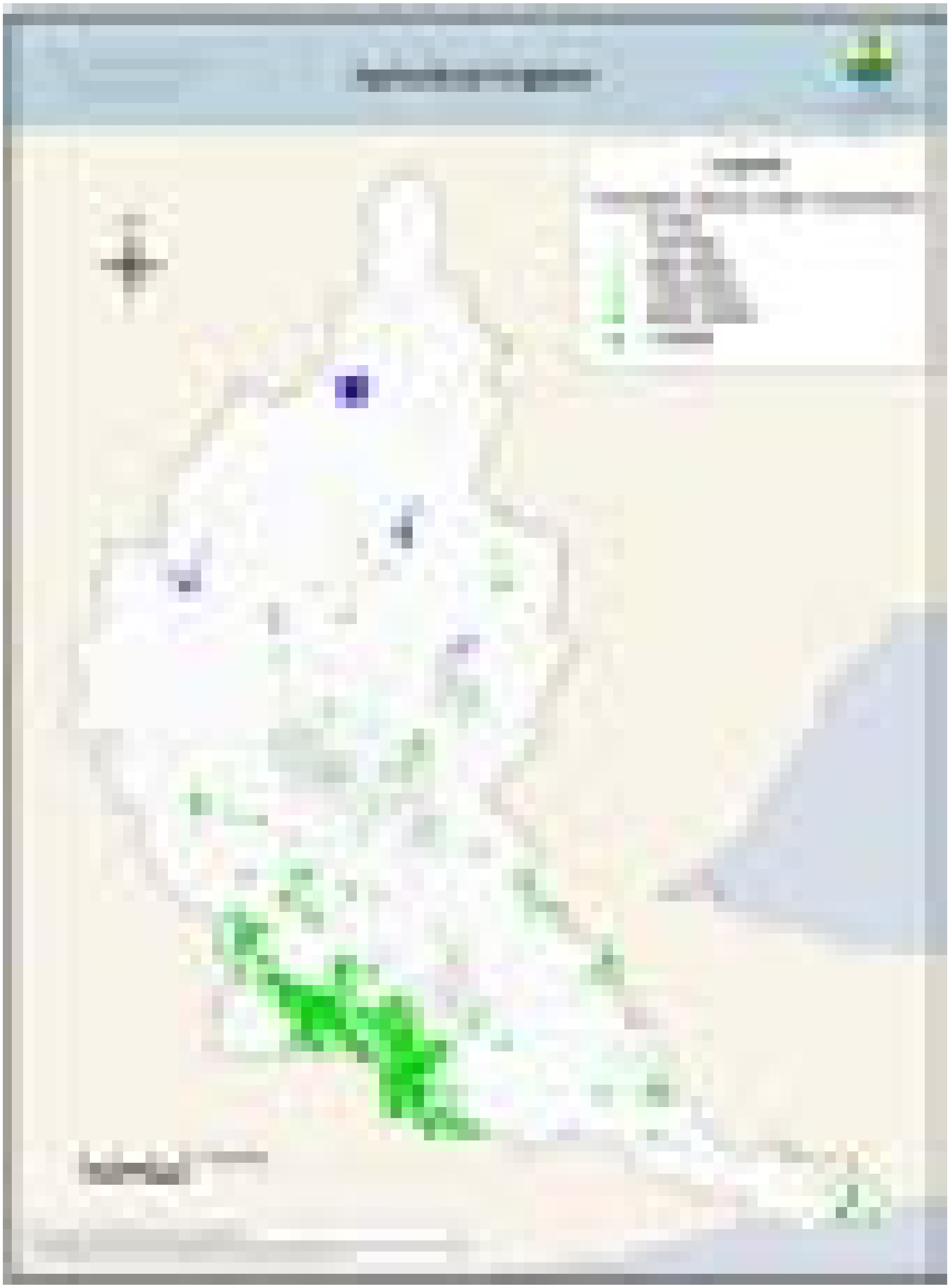


Figure 2.9 Map of Permitted Agricultural Irrigation Takings

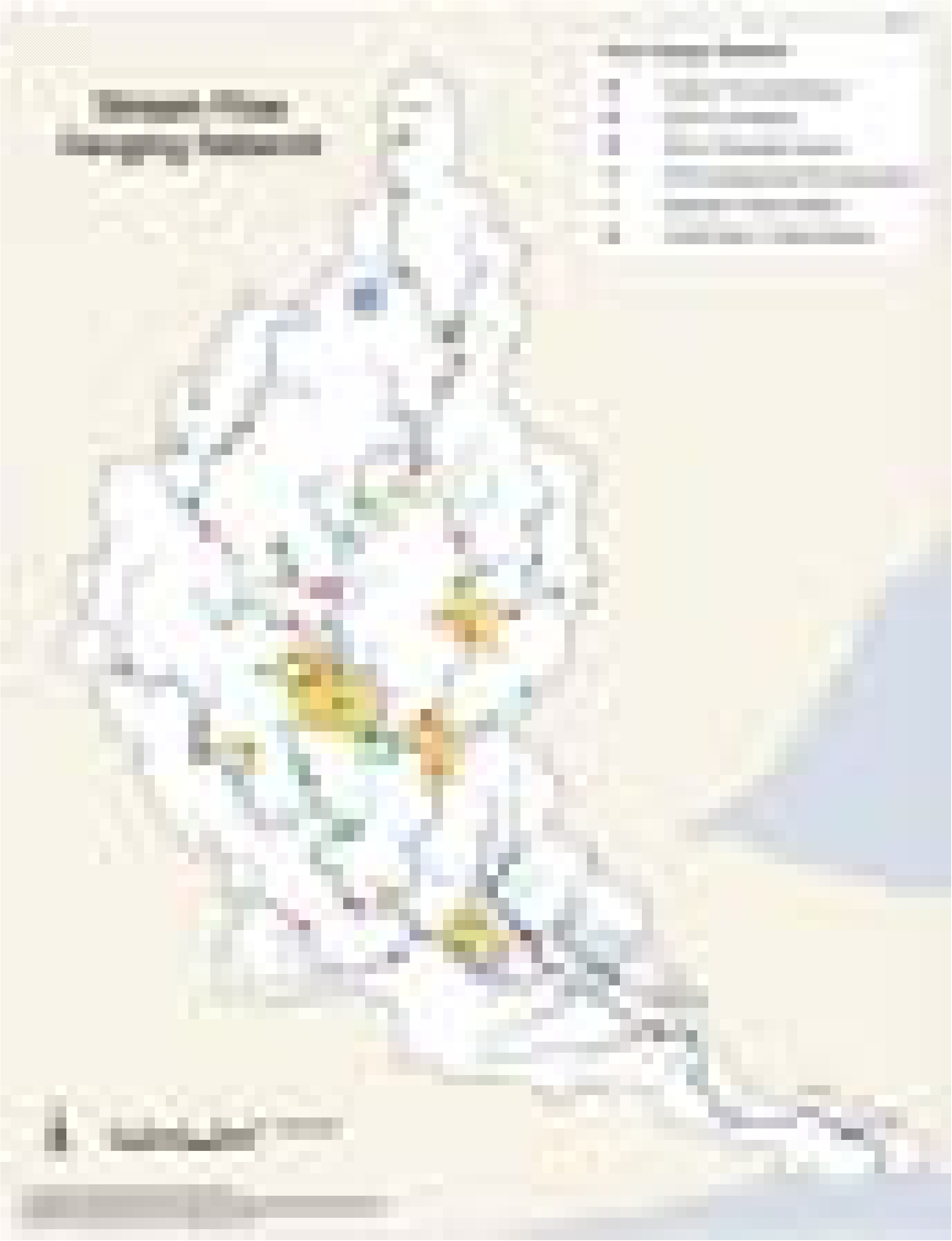


Figure 2.10 Stream Gauge Monitoring Network

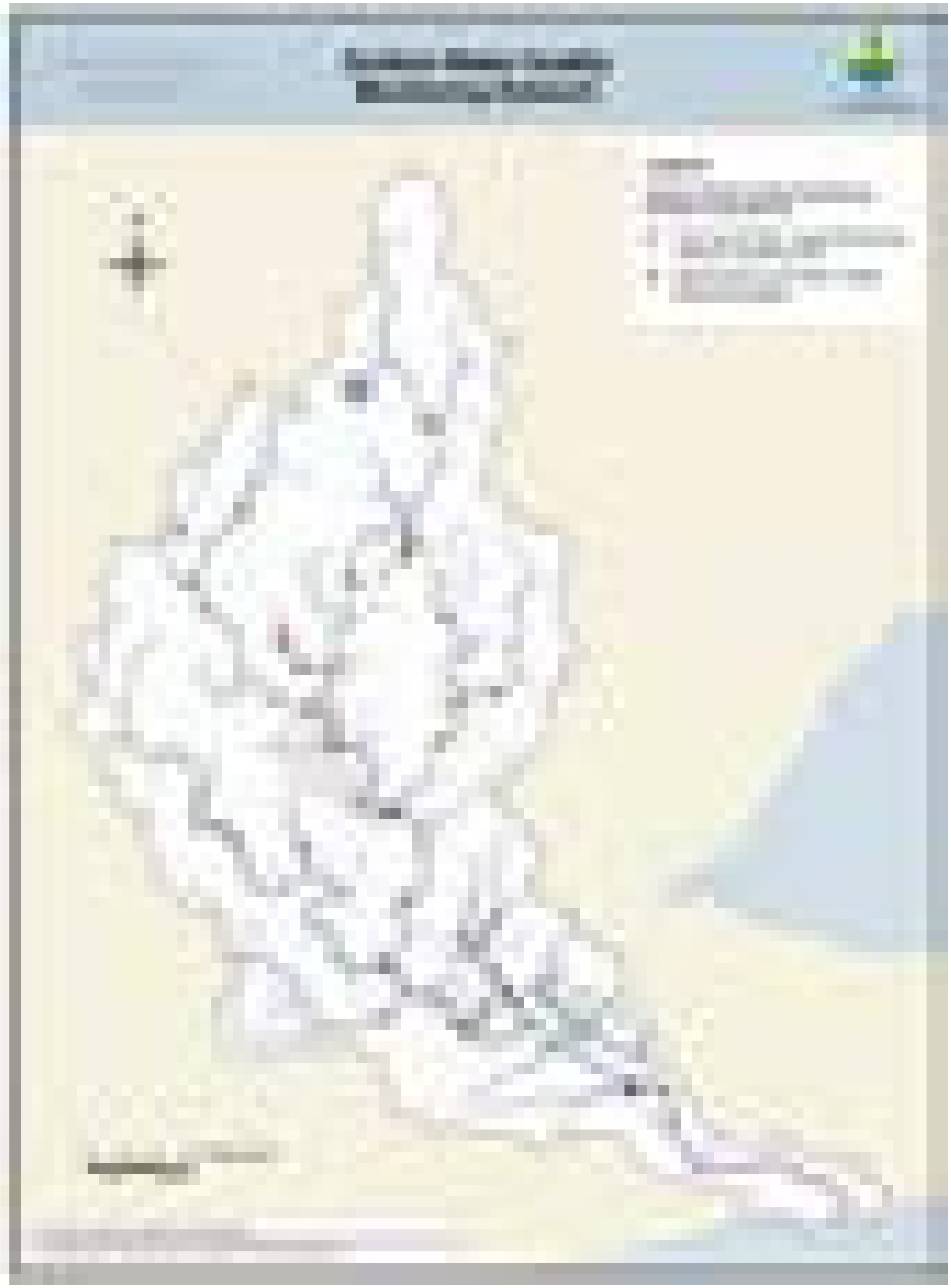


Figure 2.11 Surfacewater Quality Monitoring Network

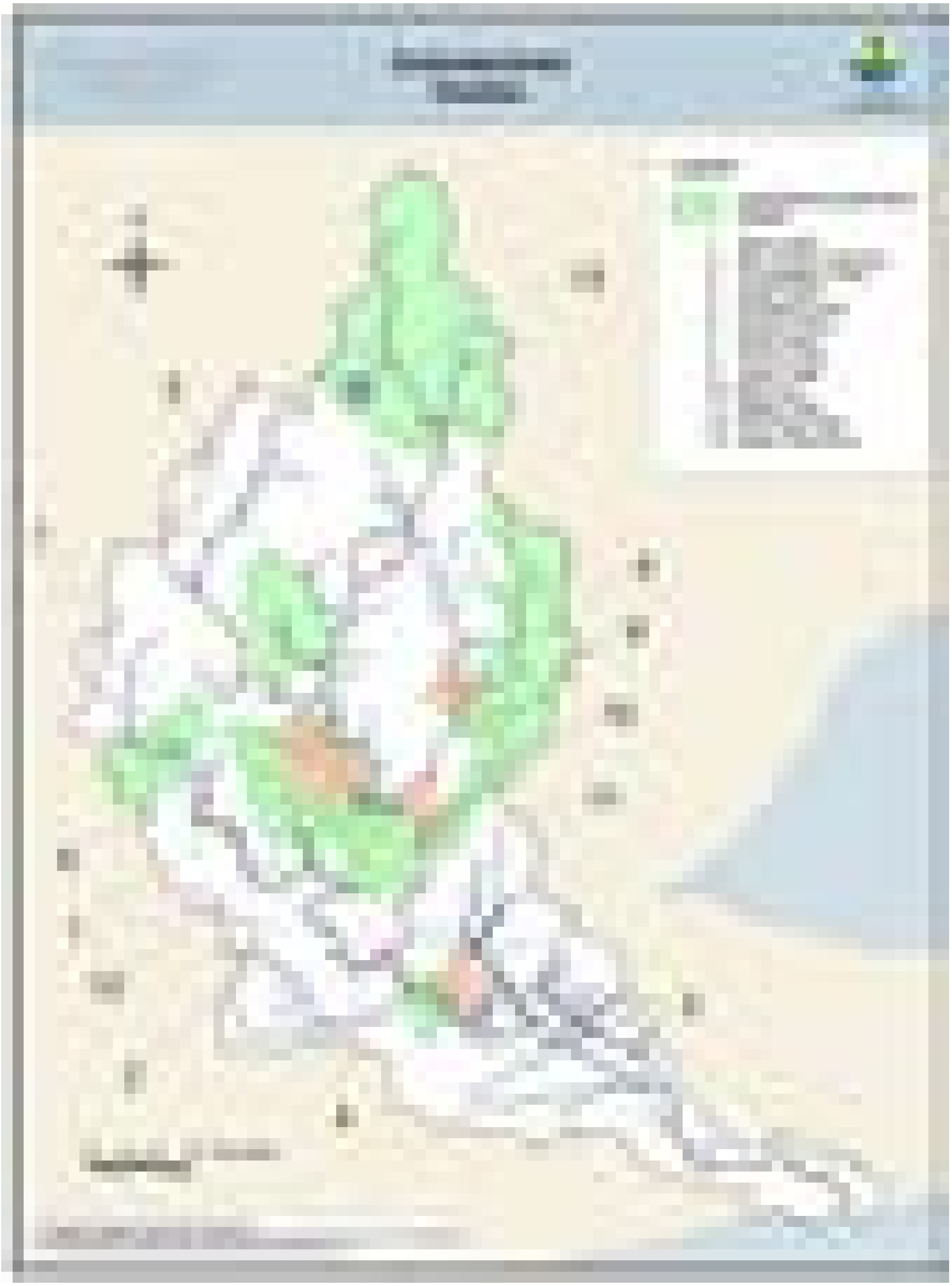


Figure 2.12 Locations of Subwatershed Studies

3.0 PREVIOUS STUDIES

The following chapter discusses the findings from previous studies and initiatives relating to instream flow requirements. A one page summary of each document will be provided.

3.1 Rivers for Life: Managing Water for People and Nature

Source: Postel and Richter, 2002

This is a text that is an easy-to-read and informative review of past and present water management initiatives, and the underlying reasons for the decision-making process. The focus is on the research and practice of ecological flow requirements across the globe. Negative impacts of human alteration of rivers, especially building dams, and restoration efforts are highlighted for various basins in the US, Africa and Australia.

Chapter 1 discusses the recent discovery by general society and governments that the alteration of natural river systems to suit human needs is often more destructive than productive. The river ecosystem, including the surrounding floodplain, are becoming recognized as a commodity that has value (aesthetically, economically, politically, etc.) or provides services to humans; a resource which would be very costly to replace, but is currently provided to us by Nature, freely. Structures like dams have been erected across the globe at an alarming rate, with detrimental effects on the natural flow regime, aquatic habitats and ecology.

Chapter 2 begins with a discussion of the history and development of the need to quantify how much water needs to remain in a river, based on ecological flow needs. It introduces some of the applied and scientific methods that were developed across North America and methodologies developed in Africa and Australia with knowledge from the earlier studies. Some focused on the effects of incremental water takings on the ecological community, others on restoring river ecosystems to more natural conditions. This chapter concludes with different stories of the applied practice of restoration of ecological flow requirements around the globe.

Chapter 3 discusses the policies for ecological flow requirements that have been set in place in different parts of the world, and how these policies are helping restore river ecosystems. The idea of eco-support allocation of water, essentially the need to accommodate all human and natural uses, is needed so that environmental needs are met while social and economic growth is not limited. This requires improvements in water productivity and efficiency and the social acceptance that the river has ‘rights’ to water.

Chapter 4 presents six different examples of water management and restoration efforts taken to improve the basin and deal with both human and ecosystem water demands. These basins include 3 in the continental USA, one in Australia, South Africa and on a Caribbean island.

Chapter 5 describes some of the government actions taken and some suggestions for striving towards ecological flow requirement goals and river management. It also talks about the World Commission on Dams.

Finally, the book concludes with an epilogue that describes the continuing barriers to good water management, and the steps and changes that humans and society must achieve to overcome these barriers. The authors declare that the time is now to "mobilize a global river restoration movement" and suggest some reforms that are necessary for the survival of the earth's rivers.

3.2 Instream Flows for Riverine Resource Stewardship

Source: Annear *et al.*, 2002.

This is a text that was compiled by 16 authors from both Canada and the U.S.A., of the views and recommendations of the Instream Flow Council, on the concept of instream flows. It lists several of the most commonly used methods for instream flow assessment, as well as describes the strengths and weaknesses, policies and recommendations that need to be addressed.

The Forward of this text, written by D.L. Tennant, provides a good summary. An excerpt is given here:

> Instream Flows for Riverine Resource Stewardship is by far the best and most comprehensive treatise on the subject of instream flows to date. The material represents an exhaustive treatment of a very complex and highly technical subject. It frequently, and appropriately, stresses the importance of addressing five riverine components (i.e., hydrology, biology, geomorphology, water quality, and connectivity) when developing, commenting on, or designing instream flow programs and recommending instream flow prescriptions. There is adequate warning and justification against the use of single-flow recommendations, like 7Q10, for fishery and riverine management. In addition to the riverine components, the authors stress the need to incorporate legal, institutional, and public involvement components in efforts to preserve fishery and wildlife resources. Because the science of instream flow is necessarily multidisciplinary, the authors emphasize that riverine management is most effective when all eight ecosystem components are integrated.

The authors of this text maintain that "there is no universally accepted method, or combination of methods, that is appropriate for establishing instream flows on all rivers or streams". The selection of a method or a combination of methods "is dependent on the water body and potential modification under consideration". Solid scientific basis should be used when prescribing instream flows, and one specific tool should be supported with other techniques to adequately protect instream flows for a river's needs.

3.3 Evaluation of Streamflow Requirements for Habitat Protection by Comparison to Streamflow Characteristics at Index Streamflow-Gaging Stations in Southern New England

Source: Armstrong *et al.*, 2004

A research study done by the three authors to determine streamflow requirements for (fish) habitat protection, in southern New England rivers. The text describes the background context to the topic, field methods used, descriptions of each method, and results of the study. The purpose was to characterize the flow regime using flow duration and flow statistics; assess the fish community composition and habitat; provide flow management targets at the 23 study sites based on hydrologic and hydraulic methods; and to evaluate these methods by comparison to the flow statistics.

Hydrological methods they used included the *Range of Variability Approach* (RVA), the Tennant method and the New England Aquatic-Base-Flow method. Hydraulic methods included the Wetted Perimeter method, and the R2Cross method, which used the HEC-RAS model to simulate hydraulic parameters.

One of the interesting ideas to pull from this report is their classification of fish species based on their habitat use. Macrohabitat generalists, like smallmouth bass and pumpkinseed, are fish species that use a variety of habitats during their life cycle, including lakes, rivers, and reservoirs. Fluvial dependents require running water for a portion of their life cycle, and include fish such as the common shiner and white sucker. Fluvial specialists are fish that require flowing water such as rivers and streams for their entire life cycle, and include rainbow, brown and brook trout.

In their study, by normalizing the data by the drainage area of the reach and by grouping based on geographic regions, they could characterize the Q_{50} discharges for a period of the year. A baseflow index and the percentage of sand and gravel could also be characterized. Regarding the fish community alteration, they could not directly relate it to flow; there were other factors contributing to the impairment of the fish community.

The authors concluded that based on the statistical summaries of their index stations and streamflow requirements, the five methods they tested could be used by water resource managers to guide other studies on streamflow determination for stream habitat protection.

3.4 A Review of Instream Flow Needs Methodologies

Source: Prairie Provinces Water Board, 1999

Due to the increasing attention for instream flow needs (IFN) in water rights allocation and management of river systems, the Prairie Provinces Water Board (PPWB) struck a committee to review the methodologies in use in the provinces of Alberta, Saskatchewan and Manitoba. The committee tested discharge, hydraulic rating and habitat preference models in all three provinces, and summarized the strengths and weaknesses of each one. Discharge methods, or desktop methods are the simplest models, and the PPWB tested the Tennant and Tessmann methods. The discharge models are quick, inexpensive, widely used. They require no fieldwork once validated for an area or stream type and should consider biological data in the validation process (ie. Observations of stream health related to various flows) The Tennant and Tessmann methods could be used as a reconnaissance level IFN method. Hydraulic rating methods describe the variation in a physical habitat parameter with a change in discharge at a specific location, and include the Wetted Perimeter Inflection Point method. These models are intermediate in complexity, site specific and well suited to studying biologically critical areas. Habitat preference models like the Instream Flow Incremental Methodology (IFIM) and the Physical Habitat Simulation System (PHABSIM) are the most complex, expensive (this report provides estimates of cost) and require much fieldwork, but there are beneficial tradeoffs, as they are able to quantify habitats spatially.

One of the points the PPWB stresses when dealing with ecosystem-based management with instream flow needs is the lack of consideration for aquatic organism preferences with the exception of high profile game fish. Flow conditions that suit game fish will not will not necessarily be adequate for non-game fish, aquatic insects, or other invertebrates.

In the recommendations for prescribing instream flows, the PPWB stresses caution in choosing an appropriate method, making conservative estimates and ensuring that field verification and monitoring are done with an adaptive management approach.

3.5 The Natural Flow Regime

Source: Poff *et al.*, 1997

The authors of this article present the concept of a natural flow regime, and its necessity in sustaining natural biodiversity and ecosystem integrity in rivers. The natural flow regime, or the natural dynamic character of flowing water systems, like rivers, are described by the characteristic pattern of a river's flow. To regulate ecological processes in river ecosystems, the five critical components of the flow regime are: magnitude of discharge at any given time; the frequency of occurrence, the duration of a specific flow condition; the timing or predictability of a defined flow magnitude, and; the rate of change or flashiness of the discharge.

The natural flow regime does produce variability in flows, from high flows for removing fine sediments from gravel beds and importing nutrients from the floodplain, to low flows that provide the chance for establishment of riparian plants. There is ecological significance to the duration of certain flow events (increasing persistence of tolerant, non-dominant species), timing or predictability of flow events (life cycle triggers), and rate of change of events (seed germination during slow floodplain water recession).

The discussion follows into the human related alterations that have affected the natural flow regime, and the morphological, biological and hydrological changes that can result. Alterations include damming, and land use activities such as timber harvest, wetland draining and urbanization, change sediment loads in the river, increase flood frequency and intensity and disrupt the dynamic equilibrium of the river.

This article provided many examples of the consequences of changing the natural flow regime. By sourcing other studies and researchers, the authors have provided sound evidence that there are biological and ecological consequences to changing the natural flow regime. However, these problems can be improved by working towards reestablishing the natural flow regime, perhaps by using incremental restoration efforts.

This article has provided the basis of knowledge and reasoning for instream flow studies, stressing that minimum flows are important, but also that a range of flows is necessary for stream ecosystem function and native biodiversity. Adaptive management, the monitoring of restoration actions and making modifications when needed, is critical. Specific goals need to be made for each river system based on the degree of alteration of the flow regime and other environmental variables, as well as the social and economic feasibility. These steps are keys to enlightened river management and restoration. Finally, the last suggestion that is given is that generally the river's natural ability to repair and maintain itself is probably the most successful and least expensive approach to river management.

3.6 Best Practices for Assessing Water Taking Proposals

Source: Gartner Lee Limited *et al*., 2002

This is the final report and the first of two steps to review the Permit to Take Water (PTTW) process for the MOE (the second step is the Instream Flows studies by the conservation authorities). The goal set out for this report was "to develop a set of Best Practices to guide the review and assessment of water takings in Ontario, acceptable to all stakeholders (proponents, regulators and the public)." The best practices were scientifically based to assess the impact and cumulative impacts of a water taking.

The research team gathered literature and information on the present practice in the provinces and states of Canada and the USA concerning the methods of monitoring surface and groundwater. The monitoring practices included measuring water quality and quantity, as well as several types of instream flow techniques that are currently being used. The report identifies the gaps and successes in Ontario based on the practices in other regions. It found that there was a lack of scientifically based assessments of the effects of water takings to the watershed, or for defining thresholds to protect fish and aquatic ecosystems.

The Ontario process for environmental monitoring and public consultation is similar to other jurisdictions, however there are aspects that could be pulled from elsewhere to strengthen these practices. The report outlines the current state of public or stakeholder involvement in environmental issues in Ontario through the Environmental Bill of Rights and the Ontario Low Water Response Plan (OLWRP), as well as in other jurisdictions in UK and USA. One benefit of the Ontario model is the electronic registry, but this public consultation needs to begin earlier in the process. There is a lack of more defensible scientific methods to date that need to be approached.

Finally, recommendations are provided in the report to improve the science, which will in turn give confidence to both regulators and the public on the decision-making process for water takings in Ontario.

3.7 Scientific Process for Lifting Ontario's Permit to Take Water Moratorium

(Draft for Discussion Purposes Only)

Source: AquaResource Inc., 2004

The PTTW moratorium was in response to the uncertainties of large water takings on the sustainability of Ontario's water resources. The issue of cumulative impacts of water takings in a watershed was unknown and required more scientific study. This study is in response to these issues with the PTTW program, and looked to review water budget methods to provide guidance on reviewing future applications. This report is being finalized under a new title: “Lifting Ontario’s Permit to Take Water Moratorium: A Method for Assessing Water Use in Ontario Watersheds”.

The spatial component of water takings in the Province of Ontario were characterized in this report by looking at watershed water budgets. The OFAT modeling tool was applied, which uses a geographic information system (GIS) and hydrologic models to estimate flow parameters and statistics in any user-specified watershed in Ontario. Part of the project was to show water demand and supply in Ontario, based on percent allocated by PTTW values. This was done on tertiary watersheds, for the average annual flow ($15Q_2$) as well as the summer low-flow ($15Q_{50}$). The authors are careful to point out the data limitations of the PTTW database, the inherent error that would be associated with estimating water use and supply, and make us aware of their general assumptions in calculation. The suggestion is that this technique be used just as a scoping tool, on a regional scale. Additional impact assessment work could follow, such as potential cumulative impacts, if there is a PTTW application in an already medium use area; potential high impact area applications would be rejected. This methodology would not replace existing local-scale impact assessments that are already a part of the review process, but to scope out new moratorium-type applications to further understand potential cumulative impacts at a regional scale. As a follow-up to this report, several refinements were suggested including sensitivity analysis of the data, further research into actual PTTW values and the causes of high water use.

3.8 Development of a Water Allocation and Water Taking Management Strategy for the Sixteen Mile Creek Watershed

Source: OMOE, 2000.

The Sixteen Mile Creek watershed is under the jurisdiction of Conservation Halton in the Regional Municipality of Halton. This report gives a good description of the watershed characteristics including land and water use and the hydrology of the watercourse. Much of the information about the watershed is taken from the Sixteen Mile Creek Watershed Plan (SMC-WP). The goal of this report was to develop a framework for surfacewater allocation and water management that could be applied to other watercourses in the Greater Toronto Area (GTA), by using Sixteen Mile Creek as a case study.

The water allocation strategies would serve the following purposes: provide background information on geo-hydrology, ecology, water use and land use for each site specific assessment; provide analysis of streamflow, water availability, use, aquatic habitat and biota on watershed and subwatershed scales; and utilize instream flow thresholds to recommend specific targets of water takings for each sub basin or reach.

The strategy completed for water takings in Sixteen Mile Creek made some general recommendations for the watershed, as well as more specific sub watershed level recommendations. For instance, watershed level recommendations included requiring water budget analysis for any new surfacewater taking proposals, including a schedule of withdrawal rates at each site for a high flow and low-flow condition. Methods to determine instream flows should be fully documented for the main channel and its tributaries, while any intermittent or perennial watercourses that have yet to be studied must first establish the instream flow threshold level before takings can occur. This statement implies that takings from lower order streams (i.e. 1st order streams) should not occur. The recommendations were geared more specifically to the Sixteen Mile Creek watershed, but other watershed studies would be able to pull ideas from this study on the water taking issues and concerns.

3.9 Hydrological Low-flow Indices and their Uses

Source: Pyrce, 2004

This is a summary report of the most common low-flow indices and instream flow methods. The author describes the differences between hydrological, hydraulic rating, habitat rating and holistic methods. This report is a good overview of the different hydrological indices, as it gives an explanation, uses or applications of the index, references and comparisons to other similar indices.

Hydrological methods use hydrological data (daily and monthly streamflow records) in simple desktop calculations for environmental flow recommendations. This report describes the Tennant method, as well as indices to measure magnitude (i.e. minimum monthly flows), frequency (i.e. low-flow pulse count), duration (i.e. annual minima of daily discharge) and timing (i.e. Julian day of annual minimum) of low-flow events. Also described in the hydrological indices is the use of exceedance percentiles (i.e. Q_{95}) and single low-flow indices including the 7Q10 flow. The locations of the methods that are used currently are also given, for the Province of Ontario.

Instream flow methods and baseflow methods are defined with reference to literature and other studies in Canada and the USA. The methods to predict low-flow indices on ungauged sites are also included.

The most common hydrological low-flow indices as described by the literature are the 7Q10, 7Q2, Q_{95} and Q_{90} flows. The most commonly used index in Ontario is the 7Q20 flow, which is used for wastewater assimilation capacity assessment with respect to sewage treatment plant design and to quantify severity of drought. The Tennant method is the most common instream flow method in Ontario.

3.10 Descriptive Inventory of Models with Prospective Relevance to Ecological Impacts of Water Withdrawals

Source: Limno-Tech, Inc. 2002

Funded by the Great Lakes Protection Fund, this report is a summary of relevant models for the ecological impact assessment of water withdrawals, based on literature, web-based searching and best professional judgment. The objectives were identifying key characteristics of each selected model including strengths and weaknesses, data requirements and applicability, which were all compiled into a descriptive inventory with supporting information. Five categories of models were reviewed including hydrodynamic/hydraulic; surfacewater quality; hydrology/watershed; ecological effects; and groundwater. A good feature of this report is that this report gives one-page summary descriptions on several selected models from each category, including their use and relevance. Another appendix gives a larger list of other relevant models to consider.

These are useful in comparing the models to each other and the selection of which model would be the most applicable for any situation.

A description of each of the five categories of these models is given in the report. Hydrodynamic models are concerned with water quality and transport of pollutants such as circulation, mixing and density stratification. These models use parameters of flow, physical properties of the channel and meteorological data, for example, in mass balance equations. Hydraulic models also use flow statistics and can simulate differences in composition and distribution of aquatic habitats during different flow regimes.

Hydrologic/Watershed models look at the entire watershed flow system including land and surface flows for managing water resources. They can be used to quantify other parameters such as sediments and nutrients contributed by the watershed.

Surfacewater Quality models analyze water quality problems and can synthesize inputs, reactions, physical transport and outputs of water quality parameters. These parameters can include chemical, biological pollutants and nutrients, for their predictive effects in surfacewater systems, or for their effect on aquatic life and habitat.

Groundwater models track sub-surface movement of water or pollutants, but have to consider surfacewater hydrology for inflows and outflows of the system. Geology, soil and topography parameters are also needed, and thus groundwater models generally require a large amount of information to understand water flow.

Ecological Effects models focus on the assessment of the aquatic system, and can examine or predict status of habitat, biological populations or communities. Changes in the flow regime can be modeled for the effects and responses.

4.0 LITERATURE REVIEW

This chapter includes a literature review, by Andrea Bradford, PhD, from the University of Guelph, of alternative instream flow assessment tools. A background is given on the natural flow regime and the importance of identifying the ecological flows needed to prevent disruption of geomorphic processes; meet water quality objectives; maintain connectivity, both longitudinal (e.g. for fish migration) and lateral (e.g. with floodplains and riparian wetlands); and sustain communities of aquatic organisms.. This is followed by a description of various assessment tools that may be used to make flow assignments within an ecological flow assessment framework.

This chapter also includes a contribution by Jack Imhof, National Biologist for Trout Unlimited Canada, on ecological relationships and the implications of water abstraction. The linkages that aquatic organisms have with their environment, and the complexity of interactions, are discussed in Sections 4.5 to 4.7. This chapter provides useful information on the rationale for assessing instream flow requirements. It leads into the application of the tools, which will be discussed in Chapter 5.0, and the assessment of the ecological flow requirements in Chapter 8.0.

4.1 Current Methodologies for Instream Flows

> *"The ultimate challenge of ecologically sustainable water management is to design and implement a water management program that stores and diverts water for human purposes in a manner that does not cause affected ecosystems to degrade or simplify. This quest for balance necessarily implies that there is a limit to the amount of water that can be withdrawn from a river, and a limit in the degree to which the shape of a river's natural flow patterns can be altered. These limits are defined by the ecosystem's requirements for water. Human extraction or manipulation that exceeds these limits will, in time, compromise the ecological integrity of the affected ecosystems, resulting in the loss of native species and valuable ecosystem products and services for society."*
>
> Richter *et al.* (2003)

There has been tremendous activity on instream (or ecological) flows around the world over the last decade, including numerous reviews of instream flow methodologies:

- Stalnaker *et al.*, 1995. "The Instream Flow Incremental Methodology: A Primer for IFIM". Author Affiliation: U.S. Department of the Interior, National Biological Service.
- Tharme, R. 1996. "Review of International Methodologies for the Quantification of the Instream Flow Requirements of Rivers". Draft report to the Water Resources Commission, Pretoria, South Africa.
- Jowett 1997. "Instream Flow Methods: A Comparison of Approaches". Author Affiliation: National Institute of Water and Atmospheric Research, New Zealand.
- Dunbar *et al.*, 1998. "Overseas Approaches to Setting River Flow Objectives". Author Affiliation: Institute of Hydrology, Wallingford, UK.

- Arthington and Zalucki 1998. “Comparative Evaluation of Environmental Flow Assessment Techniques: Review of Methods”. Author Affiliation: Centre for Catchment and In-Stream Research, Queensland, Australia.
- Prairie Provinces Water Board (PPWB) 1999. “A Review of Instream Flow Needs Methodologies”. Instream Flow Needs Committee, Canada.

More recently, 16 authors from state and provincial resource protection agencies in the U.S. and Canada, contributed to “Instream Flows for Riverine Resource Stewardship” released in 2002 by the Instream Flow Council (IFC) (Annear *et al*., 2002).

Gartner Lee Limited (GLL) *et al.* (2002) provided a review of instream flow methods in their report “Best Practices for Assessing Water Taking Proposals” for the Ontario Ministry of the Environment. The authors recommended testing and validating of several methods in different systems and under different water taking scenarios within Ontario. The recommendation was that “testing should be rigorous, long-term (>5 years) and involve water extractions that stress fish populations.” (GLL *et al*., 2002)

In response to the recommendations of GLL *et al.* (2002), this project is to have two components: the testing of instream flow methods and the use of these methods to assign instream flow requirements. The purpose of this literature review is to:

- review the instream flow requirements which need to be assigned;
- review the methodologies and methods which may be used to make these assignments; and to
- develop a framework to apply the existing methodologies in the current instream flow study

Although the need to better manage water takings in the Province of Ontario was the impetus for this project, determination of ecological flows is required for a variety of management purposes. In fact, a single water management issue cannot be considered in isolation; water takings, reservoir operation, urban development and stormwater management among other activities need to be managed in an integrated fashion. Management activities, other than control of streamflows, may be possible or necessary to maintain ecological processes. For example, stream restoration may be required before an altered channel can accommodate a historic flow which can ensure hydraulic connections between a river and its floodplains. Knowledge of ecological flow requirements could also be used to establish stormwater management criteria or post-development flow targets for developing urban areas.

Due to high demands and low-flow conditions during dry summer periods, management of water takings will be critical at these times. However, the potential effects of large takings (into storage) during the spring and the effects of abstractions on critical over-wintering habitat also need to be considered. The need to move beyond consideration of a single, minimum, threshold flow is discussed further in the following section.

4.2 The Natural Flow Regime

There is increasing recognition that hydrologic regimes with intra- and inter-annual variability are needed to maintain and restore the natural form and function of aquatic ecosystems. This, however, is at odds with traditional water management which has sought to dampen natural fluctuations in the interest of providing steady supplies of water for various instream and out-of-stream uses and for moderating extreme drought and flood conditions (Richter *et al.*, 2003).

Determining a single, minimum, threshold flow, to the exclusion of other ecologically relevant flows, is no longer an accepted approach to instream flow management. It is known that the minimum flow determined for one life stage of one species does not ensure adequate habitat protection, even for the species for which the threshold flow was established (Calow and Petts, 1992; Calow and Petts, 1994). A single flow value cannot simultaneously meet the requirements of all species in an aquatic community; variable conditions can allow different species to flourish at different times. What is appropriate is an interpretation of minimum flow as a parameter that varies over time in response to the needs of various stream functions. Another way to think about this is that minimum flows are not necessarily "low-flows." The minimum flow is the flow needed at a given time to sustain a given process, and may in fact be the "high flow."

In moving away from the flat-line flow regime, it is necessary to go beyond maintaining "means" or a subdued replica of the natural hydrograph because of the functions of extreme flows. As Poff *et al.* (1997) aptly explain, "Clearly half of the peak discharge will not move half of the sediment, half of the migration motivational flow will not move half of the fish, and half of an overbank flow will not inundate half of the floodplain."

There is a trend towards the use of the "natural flow regime" (Richter *et al.*, 1996; Poff *et al.*, 1997) as a basis for determining instream flow needs (Annear *et al.*, 2002). The approach considers flow to be a "master variable" determining the form and function of streams, and in fact, streamflow is strongly correlated with many physicochemical characteristics such as water temperature, channel geomorphology, and habitat diversity, which are critical to sustaining the ecological integrity of streams and rivers (Poff *et al.*, 1997). In some cases, the effects of flow are direct, in other cases the effects of flow are indirect and in essence, flow characteristics are used as surrogates for other instream conditions or ecosystem requirements (e.g. water temperature and concentration of dissolved oxygen).

Flow requirements can be specified in terms of the characteristics of the flows (i.e. magnitude, frequency, timing, duration, rate of change, and in some cases sequences of flows) necessary to sustain ecosystem functions (Richter *et al.*, 1996; Poff *et al.*, 1997; Annear *et al.*, 2002). Annear *et al.* (2002) suggest consideration of five categories of ecosystem functions: hydrology, geomorphology, water quality, biology, and connectivity as seen in Figure 4.1.

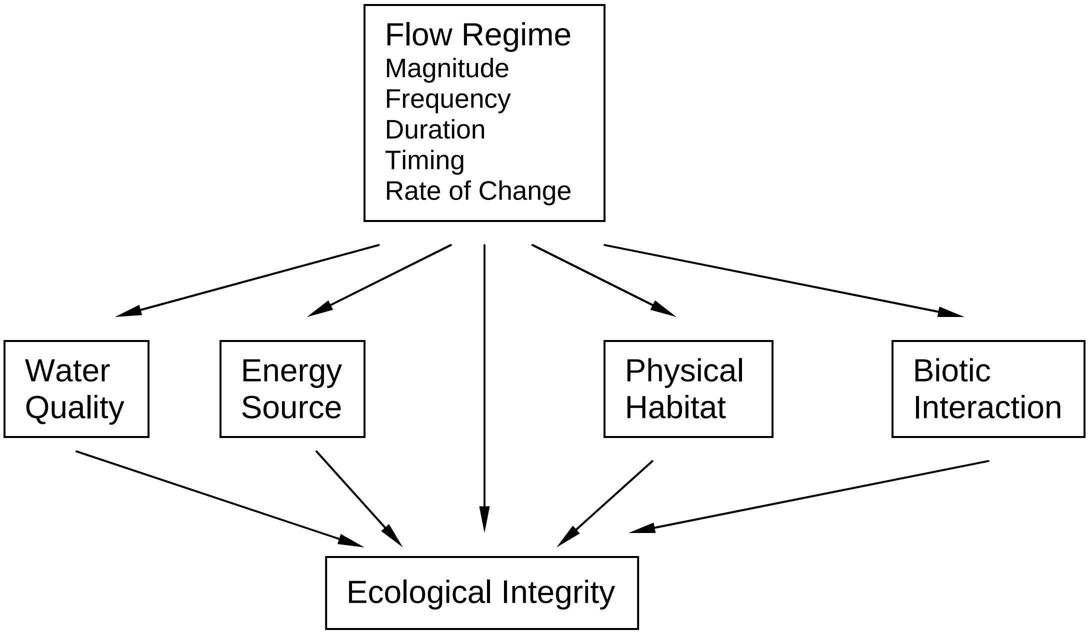


Figure 4.1: Direct and Indirect Influences of Flow Regime on the Ecological Integrity of Flowing Water Systems [Source: Poff *et al.*, 1997 after Karr, 1991]

4.2.1 Characteristics of the Flow Regime with Ecological Significance

Magnitude and Frequency

Flows of a particular magnitude occur with some frequency. Specification of a required flow threshold without jointly specifying how often flows of a particular magnitude is needed, or can be tolerated, has little meaning.

Droughts (infrequent low-flows) have a role in sustaining overall ecosystem integrity, with either negative or positive effects on individual species. Although natural droughts can benefit the aquatic community, frequent or prolonged low-flows will have negative consequences such as: physiological stress or mortality due to increased temperature and low dissolved oxygen (DO); disruption of fish migration; reduced invertebrate production; and increased predation by birds and mammals (Annear *et al.*, 2002). In other words a low-flow event of a particular magnitude may be healthy as long as it can be described as a stochastic event (say with a recurrence interval on the order of a decade), whereas flows of the same magnitude which become chronic or repeating (say with a recurrence interval on the order of one year) are likely to be unhealthy.

High flows may have negative effects on individual species (e.g. by displacing eggs and fry and limiting reproductive success) but are critical for sustaining ecological processes (Poff *et al.*, 1997):

- fine sediments may be deposited between coarser streambed materials and in the absence of flushing flows, species with life stages that are sensitive to sedimentation, such as the eggs and larvae of many invertebrates and fish, are negatively affected

- many channel features, such as river bars and riffle-pool sequences, are formed and maintained by discharges that can move significant quantities of sediment and that occur frequently enough to continually modify the channel
- flows that exceed the capacity of the channel (overbank flows) are important for maintaining riparian wetlands, providing connections to complex biophysical habitats outside the stream channel, and supporting biogeochemical processes
- high flows are required to import organic matter and woody debris (which provides high quality habitat) from the floodplain
- moderate flows are needed to maintain streambank vegetation and stability, although flows that periodically scour beds, banks, and floodplains provide opportunities for rejuvenation and diversification of plant communities and prevent encroachment of vegetation into the stream

Timing / Predictability

The life cycles of many aquatic and riparian species are timed to either avoid or exploit flows of certain magnitudes. The timing of events is important since migratory and reproductive behaviours must coincide with access to and availability of habitat. Human-induced changes in the timing of various conditions may cause reproductive failure, stress, or mortality of aquatic species. This is discussed further in Section 4.6.

Duration

Duration may refer to the period of time a particular flow event, or the conditions associated with an event, last (e.g. days a floodplain remains inundated by a ten-year flood), or may express the cumulative amount of time that particular conditions exist over some time period (e.g. the number of days in a year that flow is below some value). The duration of particular water conditions can determine whether certain life cycle requirements are met or can influence the degree of stress or mortality associated with extreme conditions such as floods or droughts.

Rate of Change

Rate of change is primarily a consideration with respect to flows downstream of dams and reservoirs, but rapid changes in streamflow have been observed in association with some water takings as pumps are turned on and off. The abruptness and number of changes may influence the degree of stress experienced by organisms. Many invertebrates lack the mobility to respond to rapidly changing habitat conditions; they may be subject to desiccation if they are unable to migrate with the shifting edge of water. The rate of floodwater recession is important to the germination of some plants whose roots need to remain in connection with the water table.

Poff *et al.* (1997) cite a multitude of studies that identify the characteristics of the hydrologic regime (magnitude, frequency, timing, duration, rate of change) important to particular species. The goal is not to optimize flow conditions for a single species, but rather to determine ecosystem requirements. The ecological response will ultimately depend upon how much the characteristics deviate from the natural regime. If the change is too great, the life cycle needs of native species may not be met, they may be displaced by non-native species and energy flow through the ecosystem may be modified.

Proponents of the natural flow regime approach do not suggest it is possible to maintain the natural hydrologic regime and meet human needs and demands. But, in areas of intense human activities where substantial departure from the natural regime has, or will, occur, in-depth understanding of ecosystem functions is needed to be able to determine the characteristics of the natural flow regime which need to be protected.

Therefore, to establish defensible ecological flow targets, there is a need to quantify the characteristics of the flow regime that have ecological significance. This must be a component of the overall framework. The *Indicators of Hydrological Alteration* (IHA) method discussed in the following section is capable of quantifying these characteristics.

4.3 Instream Flow Assessment Tools: Methods and Methodologies

Tharme (1996) distinguished between "methods" which are "procedures or techniques used to measure, describe or predict changes in important physical, chemical or biological variables of the stream environment" and "methodologies" which are "collections of several instream flow methods which are arranged into an organised iterative process which can be implemented to produce results." The following sections describe some of the methods that are used for determining instream flow requirements. Section 4.4 will discuss the methodologies.

In the various reviews of instream flow assessment tools, different categorizations of methods have been used. A common approach is to group the methods as historic flow (or hydrologic or discharge) methods, hydraulic methods, and habitat methods (e.g. Jowett, 1997; PPWB, 1999; GLL, 2002). Stalnaker *et al.* (1995) refer to a continuum from standard setting methods, which are essentially the historic flow methods that require the lowest level of effort, to incremental methods, which are the habitat methods that require the greatest level of effort.

Annear *et al.* (2002) use the Stalnaker *et al.* (1995) categories but add a third category for monitoring and diagnostic techniques. In their review, Annear *et al.* (2002) also groups the tools according to which type of ecosystem functions the tool addresses (hydrology, geomorphology, water quality, biology, or connectivity). Most of the historic flow, hydraulic, and habitat methods address the biological components of the aquatic ecosystem. Many of the monitoring and diagnostic techniques of Annear *et al.* (2002) cannot be used directly to assign instream flow requirements. Table 4.1 is a condensed list of the different methods discussed in Annear *et al.* (2002).

Table 4.1 Instream flow assessment methods by category

Method	Comments on Applicability
Hydrology	
Indicators of Hydrologic Alteration (IHA Method)	**RECOMMENDED IF** a natural flow record of daily streamflows can be developed. Parameters can be used to evaluate intra- and inter-annual variability that should be incorporated into the flow regime.
Range of Variability Approach (RVA)	**RECOMMENDED** When used in conjunction with the IHA Method. RVA method provides a typical range for statistics generated by the IHA Method.
Biology	
Flow Duration Methods	**RECOMMENDED IF** the underlying relation of hydrology to biology (habitat) is substantiated within the target region
Tennant / Tessmann	
Aquatic Base Flow	**NOT RECOMMENDED.** This approach, developed in the Connecticut River and then expanded to the New England area, should not be used in other regions
Seven-Day, Ten-Year Low-flow ($7Q_{10}$)	**NOT RECOMMENDED.** As a minimum flow standard to sustain aquatic life; $7Q_{10}$ lacks any scientific or common sense foundation and can be expected to result in severe degradation of riverine biota and processes.
Single Transect / Wetted Perimeter	**NOT RECOMMENDED.** May be used to check minimum flow recommendation for low-flow season on a site specific basis.
Physical Habitat Simulation (PHABSIM)	**NOT RECOMMENDED.** Life stage-specific habitat suitability requirements are not available for a broad range of species. May be used for specific projects to assess the habitat tradeoffs for one or two key species associated with alternative flow regimes.
Biological Response to Flow Correlation	Regression relationships would need to be developed. Can provide valuable info (especially general trends) where correlations are significant, but rarely capture all sources of variability affecting biological or habitat response.
Geomorphology	
Channel Maintenance Flows	RECOMMENDED IF applied by experienced personnel. Applicable for gravel alluvial streams because approach is based on bedload transport. The timing, duration and frequency of channel maintenance flows are also important aspects to include in an environmental flow regime.
Flushing Flow Determinations	RECOMMENDED IF applied by experienced personnel. Considerable knowledge is required to select an appropriate method to quantify the flushing flow required for a particular system. The timing and frequency of flushing flows are also important aspects to include in an environmental flow regime.
Geomorphic Stream Classification Systems	NOT RECOMMENDED. Classification systems do not provide estimates of ecological flow requirements. However, they can be used as a diagnostic tool (e.g. assist in identifying particular channel sensitivities).
Width/Depth Ratio	RECOMMENDED in conjunction with other methods. Breakpoints in width/depth vs flow curves can provide insight into flow thresholds which may have ecological significance.
Water Quality	
Stream Water Quality Models	**RECOMMENDED IF** water quality parameters may impose a constraint on in-stream flows.
Stream Temperature Models	**RECOMMENDED IF** stream temperature based flow prescriptions may be required.
Connectivity	
Floodplain Inundation	**RECOMMENDED FOR** floodplain reaches of rivers.
Longitudinal Barriers	RECOMMENDED for systems where barriers exist at various flows.

There is no single method or combination of methods that is appropriate for all conditions (Annear *et al.*, 2002). Jowett (1997) discusses the importance of understanding the "morphological implications and ecological assumptions that underlie methods, and the effect of these assumptions on the flow assessments." Selection of a method depends upon the (Annear *et al.*, 2002):

- present state of the aquatic ecosystem;
- nature and complexity of the management issue(s);
- level of controversy of a particular project or purpose;
- habitat homogeneity at various scales;
- data requirements of models; and
- expertise of the personnel.

Castleberry *et al.* (1996) caution that no method should "become a substitute for common sense, critical thinking about stream ecology, or careful evaluation of the consequences of flow modification." A select number of the methods as listed in Table 4.1 will be discussed below.

4.3.1 Historic Flow Regime (Hydrologic or Discharge) Methods

Historic flow methods rely on the recorded or estimated flow regime of the river. The instream flow requirement may be expressed as a fixed percentage of mean or median, annual or monthly flow. The requirement may also be based on the flow duration curve or an exceedance probability of a low-flow. This type of technique is intended to be based on a natural, or near-natural, flow record (Dunbar *et al.*, 1998; Annear *et al.*, 2002). It is possible to account for inter-annual variability by specifying different percentages (or exceedance probabilities) for normal, dry, and wet years.

Historic flow regime (or discharge) methods include:

- Tennant method (and Tessmann adaptation)
- Flow duration methods (e.g. Hoppe method, Lyon's method, Texas method)
- New England Aquatic Base Flow (recommends August median flow as a minimum instantaneous flow)

Please refer to Annear *et al.* (2002) for descriptions of these methods.

The Terms of Reference for the Instream Flow Requirements Pilot Projects included the Seven-Day, Ten-year Low Flow ($7Q_{10}$) method as a potential hydrologic method to be considered. The $7Q_{10}$ method is not an instream flow method but rather a hydrologic statistic used to identify the volume of water needed to meet point discharge water quality thresholds. Annear *et al.* (2002) concisely sums the method up: "As a minimum flow standard to sustain aquatic life, $7Q_{10}$ lacks any scientific or common sense foundation and can be expected to result in severe degradation of riverine biota and processes." In essence this method could create a perpetual drought condition during low-flow periods.

Dunbar *et al.* (1998) indicate that the required percentage or probability is typically determined by observations of the health of rivers, deemed to be of a similar type, combined with statistical analysis. Thus, effort must be invested to establish appropriate percentages or probabilities for various stream types. For example, see Box 1 for a description of how the flows recommended by Tennant (1976) were determined. Stream classification approaches may be used to identify “like” stream segments. The percentage determined for a stream type must have reasonably low variability between sites in order for there to be any validity associated with extrapolation of the relationship to other streams of that type.

Box 1: Tennant Method

Tennant (1976) described the “Montana Method”, which essentially recommended flows aimed to achieve various levels of environmental quality. The recommended flows were based on a qualitative assessment of the suitability of the physical habitat for various uses at these flows. Information (primarily width, velocity and depth) from 50 cross sections on 11 streams in Montana, Nebraska and Wyoming was used in the assessment. Tennant reported the average values for these parameters at various flows but did not provide any indication of the variance in the data. Because of variability in stream geometry, the flows required to maintain a desired level of habitat suitability cannot be expected to be constant from location to location. Hence, Tennant’s work must be repeated to determine appropriate flows for the stream types and species (or uses) of interest within a management area. The Tennant method can recommend more water than is naturally available during low flow months and recommends relatively low flow during high flow months (PPWB, 1999). Tessmann (1980) as cited in PPWB (1999) adapted the two-season Tennant approach to a monthly approach that better reflects the natural periodicity of flow.

There is a great demand for such simple, “rule-of-thumb” methods, and they are widely used. The methods only became simple tools once the investment was made in their assessment and they have proven to have merit. The use of arbitrary percentages or probabilities is not defensible. Adoption of values used in other jurisdictions without assessing the data upon which they are based and validation for the streams in the particular geographic and climatic area is not defensible. As stated in Annear *et al.* (2002, p209) with respect to flow duration methods, “Unless the underlying relation of hydrology to biology (habitat) is substantiated within the target region (which is seldom done), these techniques are inappropriate by themselves for establishing instream flow levels…”. The use of the August median flow in the Aquatic Base Flow method is another case in point. Use of this flow statistic rather than, say, the August mean flow or the September median flow, is somewhat arbitrary and this approach, developed in the Connecticut River and then expanded to the New England area, should not be used in other regions (Annear *et al.*, 2002).

As Jowett (1997) indicates, historic flow approaches will maintain the character of a river (i.e. a large river will still be relatively large compared to a small river). However, as Beecher (1990) cautions, “Using flow as the unit of measurement in an instream flow standard does not ensure a consistent level of resource protection. Neither a flow nor an exceedance flow has a consistent relationship to habitat or production across a range of stream types or sizes.” The morphological relationships between discharge and width, discharge and depth, and discharge and velocity will vary from reach to reach. So, a flow requirement based on a given percentage of flow will result in different hydraulic conditions in different places (Jowett, 1997). The percentage of flow required to protect a stream is expected to vary from headwaters to mouth.

Earlier comments with regard to the inadequacy of a single, minimum flow (i.e. flat line hydrograph) still apply. When maintained over much of the year, a given percentage of the mean annual flow or the August median flow (aquatic baseflow), will not sustain the integrity of a system in which these low-flow conditions would naturally occur less frequently and for shorter durations (Annear *et al.*, 2002). However, different flows can be recommended at different times of the year to mimic the natural hydrograph, at least to some extent, and to accommodate seasonal biologic needs (e.g. Tessmann adaptation of Tennant method).

The historic flow methods are referred to as "standard-setting techniques" by Stalnaker *et al.* (1995), because their appropriate application is to areas with a low intensity of use where detailed studies cannot be justified. In other words, they are used as planning, or screening level tools. The "minimum flow" set aside for the ecosystem would be conservatively high and essentially represents a trigger level for more detailed analyses.

Historic flow methods are a fundamental component of the instream flow framework; they will be used to scope the level of concern with takings in a given area and help identify where further, more detailed work is required.

4.3.2 Hydraulic Methods

Hydraulic methods relate various parameters of stream geometry to discharge. The hydraulic geometry is based on surveyed cross-sections, from which parameters such as width, depth and wetted perimeter are determined. Velocity is not usually considered in hydraulic methods (Jowett, 1997).

The most common hydraulic method is the Wetted Perimeter method. For streams with an approximately rectangular form, the wetted perimeter increases rapidly as discharge increases until the flow just covers the base of the channel and begins to be confined by the banks. The point of inflection, where the rate of wetted perimeter increase slows as discharge increases, is used to define the instream flow requirement. An alternative criterion for specifying minimum flow requirements is some percentage of habitat retention (Jowett, 1997). Annear *et al.* (2002) recommends that in setting a low-flow season requirement with the Wetted Perimeter method, the flow that covers at least 50% of the wetted perimeter should be specified for streams less than 15 m (50 feet) wide and the flow that covers between 60 and 70% of the wetted perimeter should be specified for larger streams.

The ecological basis of the hydraulic methods, which are based on stream width or wetted perimeter, is to sustain food production, such as habitat for periphyton and benthic invertebrates (Jowett, 1997). Gippel and Stewardson (1996), in a study of two headwater streams, found that invertebrate diversity and abundance were significantly reduced at the minimum discharge recommended by the Wetted Perimeter method (cited in Dunbar *et al.*, 1998).

If the point of inflection is used as a flow requirement, the resulting water depth and velocity at the cross-section will depend upon channel geometry, and so the ecological response will depend upon channel geometry. The flow required at a riffle to sustain food production will not necessarily provide suitable habitat for other species (e.g. no physical space for fish passage). PPWB (1999) indicate that "Measurements are usually taken at riffles because they tend to have more rectangular cross-sectional profiles than other stream habitat types, and tend to be shallower and therefore proportionately more sensitive to disturbance than other habitat types." The approach assumes that if the habitat requirements for riffles are satisfied, then the habitat requirements of other areas such as pools and runs will also be satisfied (Stalnaker *et al.*, 1995), which may well be a poor assumption.

For some cross sectional shapes, wetted perimeter may increase gradually with discharge so that no point of inflection is identifiable. Several studies (e.g. Gippel and Stewardson, 1996), have shown that determination of the inflection point is highly error prone and that instream flows determined from the Wetted Perimeter method vary considerable compared with those obtained using other methods (Annear *et al.*, 2002). Morphological relationships between flow and stream depth, width, and velocity might suggest that inflection points, as a percentage of average flow, might be similar for hydrologically similar streams. However, O'Shea (1995) found that even for rivers of the same size, points of inflection ranged between 40 and 100% of average flow. In O'Shea's study (1995) of 27 Minnesota rivers, it was found that the points of inflection, as a percentage of average flow, decreased with increasing stream size. As with discharge methods, hydraulic methods will retain the "character" of the river so that large rivers, at least in terms of width, will remain large rivers (Jowett, 1997).

Hydraulic methods are well suited to studying biologically critical areas (e.g. riffles), if they can be identified, but are limited in application because they are site specific (PPWB, 1999). Hydraulic methods are intermediate in cost and complexity. Site specific information is needed although, with the use of hydraulic models based on Manning's equation to compute stage-discharge relations, the field effort can be reduced from 10 or more visits to several visits at different discharges to make observations to confirm model output (Annear *et al.*, 2002).

Hydraulic methods are not usually used to assess seasonal requirements (Jowett, 1997). They are only useful for making flow recommendations for the low-flow season (Annear *et al.*, 2002), because they do not address inter- or intra-annual variability. Annear *et al.* (2002) recommends that application of the Wetted Perimeter method should be restricted to "bedrock-controlled high gradient streams with well-defined rectangular-shaped riffles and no significant floodplains." In other cases, it should only be used in conjunction with other methods.

As stated above, hydraulic methods are useful when used in conjunction with other methods. Knowledge of the hydraulics of critical reaches is useful to quantify the hydraulic impacts associated with specific management alternatives and provides another level of defensibility to the decision-maker. Hydraulic cross sections of sufficient frequency and spacing, organized in a hydraulic model such as HEC-RAS, offer the ability to consider implications of management strategies or water takings on a reach basis rather than just a single site. This type of approach is needed for the more complex habitat based modelling, which is discussed in the next section.

4.3.3 Habitat Methods

Habitat methods are an extension of the hydraulic methods (Jowett, 1997). The habitat methods establish flow requirements on the basis of the hydraulic conditions needed to meet specific habitat requirements for biota. Some habitat features such as depth and velocity are directly related to flow; other habitat features such as substrate and cover are indirectly related to flow. These habitat features are sometimes referred to collectively as hydraulic habitat. There is considerable evidence that aquatic species exhibit preference-avoidance behaviour for depth and velocity, as well as reach characteristics such as cover and substrate (Annear *et al.*, 2002). With changes in streamflow, the amount of habitat suitable for a particular life stage of a particular species also changes. The methods discussed here will be the Physical Habitat Simulation System (PHABSIM) model and the Instream Flow Incremental Methodology (IFIM).

Habitat methods require both biological and hydraulic inputs. Field measurements such as depth, velocity, substrate, and cover are taken at sampling points along stream cross-sections. These measurements are repeated at different flows. Water surface elevations are also needed to calibrate the hydraulic models. In the most common model used, the Physical Habitat Simulation System, biological input is in the form of habitat suitability criteria (estimated species responses to stream variables), which are developed by making observations of the preferences of a particular life stage of a species. When the hydraulic and biologic components are linked, it is possible to identify areas within the wetted stream channel that are suitable for the particular life stage of a species under various flows. Output from the model is the functional relation between hydraulic habitat and discharge, typically represented as a graph of weighted usable area (microhabitat) versus flow (Annear *et al.*, 2002).

Flows can be set (Jowett, 1997):

- To obtain optimum levels of fish habitat (e.g. Oregon)
- To retain a percentage of habitat at average or median flow
- To provide a minimum amount of habitat defined either as a minimum percentage of water surface area or as a percentage exceedance value on the habitat duration curve
- At the point of inflection in habitat/flow relationship

The method is usually limited to assessment of the magnitude of low-flows (maybe seasonally) but not duration or flow variability.

Annear *et al.* (2002) indicates that although it may be appropriate in some situations to determine an instream flow standard from the maximum habitat value from weighted usable area graphs for a single life stage of a single species, or by some aggregation technique of the maximum values for several species, the strength of the tool is its ability to identify trade-offs.

Castleberry *et al.* (1996) indicate that some participants at a 1995 workshop thought that PHABSIM should simply be abandoned, whereas others thought with modification and careful use, it could produce useful information. Participants at the workshop agreed that users of PHABSIM must account for:

1. Problems associated with using hydraulic data collected at transects to represent a river reach (using 2D cross sections to approximate 3D space)

2. Problems associated with developing suitability curves
3. Problems with assigning biological meaning to weighted usable area

Castleberry *et al.* (1996) also indicate that estimates of weighted usable area should not be presented without confidence intervals.

Although the relationship between flow and the amount of suitable habitat is usually non-linear, Jowett (1997) states, "In some rivers, the relationship between flow and habitat for flow-sensitive species is linear, especially in the low-flow range. In these cases, flow recommendations using percentage retention or exceedance for instream habitat are, in effect, the same as recommendations of hydraulic and historic flow methods that specify a percentage or exceedance value for flow or wetted perimeter."

Habitat suitability curves can be developed for different life stages of multiple species and the concept may also be extended to recreational uses. However, habitat requirements are not known for many species (Annear *et al.*, 2002). One criticism of the method is that habitat must be analyzed species by species, which may not account for habitat selection affected by interspecies competition (Stalnaker *et al.*, 1995). Other biotic factors are also not considered.

When considering multiple species, there can be conflicting habitat requirements with decline in habitat for one species corresponding to an increase in habitat for another. The analysis may be simplified somewhat by applying the concepts of indicator species or habitat guilds (a habitat guild is a group of species that exploit the same habitat in the same way). It is necessary to have good understanding of stream ecosystem and clear management objectives to resolve potential conflicting requirements.

Habitat preference models like PHABSIM often address only the spatial distribution of stream habitat, ignoring the dynamics of habitat through time. It is possible to link with time series of streamflow to assess habitat availability over time, but changes in channel geometry could affect such an analysis. Although the link between habitat and the actual response of biota remains tenuous, the use of hydraulic habitat as a surrogate for biological response is powerful because it can tie organisms of interest to a variable (e.g. discharge) that managers can control (Annear *et al.*, 2002). It should be evaluated over space and time at scales that are relevant to the organisms of interest.

PHABSIM does not incorporate temperature or other water quality parameters. Alteration of the flow regime will result in alteration of the temperature regime. It is known that small changes in temperature can have important ecological consequences (e.g. effects on egg maturation, incubation, and time of hatching and growth) (Annear *et al.*, 2002). Stream temperature can affect the suitability of habitat for certain life stages of some species.

The IFIM uses computer software to integrate microhabitat suitability (e.g. the variables included in PHABSIM such as depth, velocity, substrate and cover) and macrohabitat suitability (e.g. variables that vary longitudinally downstream such as water quality, channel morphology, discharge and temperature) into habitat units, which are then related to flow over time (Stalnaker *et al.*, 1995). The output, a habitat time series, displays the availability of suitable habitat for the period of record or interest.

The strength of IFIM is in the prediction of impacts and the assessment of tradeoffs. Whereas the standard-setting methods (historic flow and hydraulic), might result in a set of annual or seasonal minima, an incremental technique like IFIM might result in monthly or weekly flow envelopes within which the flow might vary depending upon other uses (Stalnaker *et al.*, 1995). The incremental change in habitat can be compared with benefits of resource use (Jowett, 1997). It does not provide minimum or optimum flow recommendations but rather serves as a basis for negotiations between water users (PPWB, 1999).

Annear *et al.* (2002, pp 302-303) states about IFIM:

> "Because of the inherent sophistication of this methodology, the potential for misuse is very high. The IFIM demands interdisciplinary expertise to run all components; practitioners commonly abuse the methodology by selecting single components (i.e. PHABSIM) and ignoring others (e.g. water quality, sediment transport, temporal aspects). Interpretation of the analysis requires astute biologists, who are familiar with the river, management goals, the species, and their habitat requirements."

Although beyond the scope of the current study, habitat based modelling has its place. Where water takings are stressing a sensitive environmental reach or feature and trade-offs have to be considered, habitat based modelling is an approach that may be considered. It may be useful to consider setting up a research reach in Southern Ontario where this approach could be applied and expertise with it application could be developed.

4.3.4 Other Assessment Tools

4.3.4.1 Hydrology

Hydrology is important from the perspective of opportunities. Hydrological analysis is needed to determine the "natural flow regime," or the flows which are naturally possible, as well as the degree of alteration resulting from existing conditions and water resources management. Hydrologic time series may be available from historic streamflow data. If no data are available from a gauging station, or there is an insufficient record, hydrologic simulation models and watershed characteristics and climate data may be used to synthesize hydrographs. In some cases it may be possible to establish relationships between gauged and ungauged streams in watersheds with similar surficial geology, area, topography, land use, etc.). Field data are needed to calibrate models and relationships. Hughes (2001) describes some of the hydrological techniques that have been used to support the Building Block Methodology and the determination of the "ecological reserve" for South African rivers.

Two other tools which may be used to assess the hydrology component include the *Indicators of Hydrologic Alteration* and the *Range of Variability Approach*.
Richter *et al.* (1996) provide 33 measures that define the ecologically relevant characteristics of the flow regime including the magnitude, duration, timing, and

frequency of extreme events and the magnitude and rate of change of flow conditions. For a data series (e.g. daily mean conditions), the values for each of the ecologically relevant hydrologic parameters for each year can be calculated and inter-annual variability (represented by central tendency and dispersion for each parameter) characterized. Comparisons of inter-annual variability for pre- and post-impact data series or for altered and reference site data series may be made. Results may be expressed as a percentage deviation of one data series relative to another. Where pre- or post-impact records are nonexistent, include data gaps, or are inadequate in length, data reconstruction or estimation procedures are needed. The IHA can be used for establishing baseline hydrologic conditions, for monitoring and assessment of projects, and for alternatives analysis (by comparing pre-project hydrology with proposed project hydrology) (Annear *et al.*, 2002). It does not, however, provide instream flow requirements.

The RVA is an extension of the IHA and assumes that the full range of natural variability in the hydrologic regime is necessary to conserve aquatic ecosystems (Annear *et al.*, 2002). Appropriate ranges of variation for each of the 33 indicators of hydrologic alteration are identified and used as initial targets, particularly for river systems in which the hydrologic regime has been substantially altered by human activities. These targets are intended to be refined by means of an adaptive management approach that includes long-term ecological monitoring. Particular attention should be paid to the geomorphic condition of the stream. Restoring only the hydrologic regime in a channel that has been geomorphologically altered may not be in the best interest of aquatic ecosystem integrity; these channels may not be able to handle the natural flow regime without restoration of the channel itself.

In Ontario, the MNR has developed the OFAT tool. This tool has the ability to report watershed characteristics and provide flow estimates at both gauged and ungauged sites. This tool will be assessed as part of the current study and may offer the ability to easily transfer information from a gauged site to an ungauged site as suggested in the above.

4.3.4.2 Geomorphology

The Terms of Reference for the Instream Flow Requirements Pilot Projects included the Geomorphic Stream Classification System, Channel Maintenance Flows, Bankfull Discharge, and Flushing Flow as potential geomorphic methods to be considered.

Flushing Flow is needed to remove accumulated sediment from riverine habitats. According to Annear *et al.* (2002), “Flushing flows are a management tool commonly used for improving spawning gravel quality and fish reproductive success, increasing food production, maintaining pool depth and diversity, and preserving channel complexity by preventing channel encroachment, keeping secondary channels functioning, and preventing embeddedness.” Flushing will be achieved when flows are high enough to result in streambed mobilization. There are empirical, sediment transport modeling, and office-based hydrologic methods for developing flushing flow recommendations (Reiser *et al.*, 1989; Annear *et al.*, 2002). Such recommendations are appropriate where sediment input will likely exceed the sediment transport rate such that deposition will occur. However, if channel maintenance flows are provided, they will fulfill the flushing function as well. Recommendations should specify the timing, duration and rates of hydrograph rise and recession in addition to the magnitude and frequencies of the flow (Arthington and Zalucki, 1998).

Channel Maintenance Flows are intended to maintain the physical characteristics of the stream channel. This is achieved when the flow regime can transport the quantity and size of sediment imposed on the channel without aggradation or degradation. Annear *et al.* (2002) describe a bedload-based method for quantifying channel maintenance flows that may be applied to gravel-bed, alluvial streams. Annear *et al.* (2002) indicate that whereas significant bedload transport in gravel-bed streams begins to take place at moderate discharges approaching bankfull flow, “sand-bed channels transport sand-sized sediment and adjust their form and resistance constantly through a large range of flows.”

Rosgen’s Geomorphic Stream Classification System (1985, 1994, 1996) is useful for determining existing stream channel conditions and “predicting” and monitoring the effects of changing flows on channel form, function and stability. Determination of bankfull elevation is one of the most critical steps, and if well done, can allow calculation of bankfull discharge. However, this method is not used to recommend instream flows. The Rosgen system, as with all other geomorphic classification approaches, tend to simplify complex, natural systems. Accordingly, the use of the Rosgen system or any other classification is not recommended as a method for instream flows.

4.3.4.3 Water Quality

Water quality in a stream is related to the timing, quantity, and quality of water from various sources, either natural or manmade. Given a particular loading of a contaminant, its concentration in a receiving stream will be directly related to flow (dilution potential). For quality standards specified as concentrations, the concentration resulting from a given mass loading may be conservatively determined by using an absolute minimum flow (e.g. $7Q_{10}$ but this is not meant to be a flow target!). For many contaminants, managing the loading (rather than relying on dilution) is critical and the ecosystem’s water quality requirements for various chemicals must be determined and appropriate water quality targets set (i.e. flow surrogates are not appropriate).

Annear *et al.* (2002) describes the Enhanced Stream Water Quality model (QUAL2E), a one-dimensional stream water quality model that simulates up to 15 water quality constituents, including temperature, DO, nitrogen (N, organic, ammonia, nitrate, nitrite), phosphorus (P, organic and dissolved) and biological oxygen demand (BOD) as a function of discharge. This appears to be similar to the Grand River Simulation Model (GRSM) used by the Grand River Conservation Authority.

Temperature is one of the most important environmental factors in flowing water, influencing fish migration, spawning, timing and success of incubation, maturation, growth, inter- and intra-specific competition and proliferation of disease and parasites (Annear *et al.*, 2002). Temperature increase causes a decrease in oxygen solubility; at the same time the oxidation rate increases, further depleting dissolved oxygen. The combination of higher temperatures and lower dissolved oxygen can have significant ecological consequences, for example a shift to less desirable types of algae and decreased efficiency of oxygen use by fish (Annear *et al.*, 2002).

Stream temperature models (e.g. one-dimensional heat transport models), which predict the daily mean and maximum water temperature as a function of discharge, stream distance, and environmental heat flux, are also available (Annear *et al.*, 2002). For areas where water temperature issues are evident, water temperature models are an appropriate tool to derive temperature-based flow requirements.

4.3.4.4 Connectivity

The inter-relationships between climate, watershed, hydrology, geomorphology, biology and water quality determine the flow and distribution of energy and matter in river ecosystems. Connectivity may be considered in four dimensions: longitudinal, lateral, vertical and temporal (Vannote *et al.*, 1980; Ward and Stanford, 1983; Junk *et al.*, 1989; Jungwirth *et al.*, 2000).

For floodplain reaches of rivers, two-dimensional hydraulic models and the floodplain inundation method may be used to develop discharge-inundation relationships. The method requires topography, hydrology, stage-discharge relations, and knowledge of the inundation needs of the flood-dependent biota.

Longitudinal connectivity may be assessed by performing hydraulic evaluations of barriers such as culverts at different flows. Velocities may be compared to fish swimming speed. Knowledge of swimming and leaping ability of species of interest is required.

The next generation OFAT will include a sub-component called the Ontario River/Stream Ecological Classification Techniques (ORSECT). This tool allows barriers to fish movement to be easily identified and the drainage layer to be dynamically segmented to identify reaches between barriers. This tool also allows reach segmentation based on a range of criteria that can be specified by the user. For example, reaches can be segmented based on geology or slope or a combination of both. This tool is just becoming available, but would be extremely useful with respect to characterizing and classifying different reaches from an assessment and analysis perspective. Again, this may offer the ability to transfer knowledge from one reach to another and allow the ability to better scope fieldwork.

4.4 Instream Flow Assessment Methodologies – Frameworks

The quantification of environmental flow requirements can be approached in two ways (Arthington and Zalucki, 1998):

- Bottom-up – the environmental flow regime is built up by flows requested for specific purposes, from a starting point of zero flows; and
- Top-down – the environmental flow regime is developed by determining the maximum acceptable departure from natural conditions.

Most of the methodologies that have been applied are bottom-up approaches:

- Instream Flow Incremental Methodology (Stalnaker *et al.*, 1995)
- Building Block Methodology (Tharme, 1996)
- Holistic Approach (Arthington *et al.*, 1998)

The bottom-up approach appears to be preferred in environmental flow assessments around the world. These methodologies are vulnerable to lack of data and limited understanding of processes such that some critical component of the flow regime may be left out. It has been noted that the more that is known about a river system, the closer the recommended flow regime is likely to come to the natural regime (Arthington *et al.*, 1998). Defining the overall objectives of the environmental flow regime and the capacity for human uses is a challenge with the approach.

Arthington *et al.* (1998) propose the “benchmarking” approach as a methodology within which alternative environmental flow scenarios may be related to different ecological end-points for a river. Key descriptive flow statistics are compared for pre- and post-development flow scenarios. Limits on the acceptable deviation from the natural flow regime are identified by comparison with other river systems that have been degraded through specific types of resource uses.

The most rigorous approach may be to work in both directions: develop an environmental flow regime using a bottom-up approach and then check against a top-down assessment (Arthington and Zalucki, 1998).

Establishing ecological flows within a framework of adaptive environmental management has been suggested by various authors (e.g. Castleberry *et al.*, 1996; Arthington *et al.*, 1998; Richter *et al.*, 2003). Castleberry *et al.* (1996) concluded that no scientifically defensible method exists for defining instream flows needed to protect particular species of fish or aquatic ecosystems and recommended an adaptive management approach that involves three elements:

1. Conservative (i.e. protective) interim standards (including a reasonable annual hydrograph as well as minimum flows), set based on whatever information is available but with explicit recognition of its deficiencies;
2. A monitoring program that allows testing of the interim standards (active manipulation of flows, including temporary imposition of flows expected to stress components of the aquatic ecosystem, may be necessary); and
3. An effective procedure by which interim standards may be revised in light of new information (i.e. interim commitments of water that are irrevocable are inappropriate).

The Prairie Provinces Water Board (1999) embraced this approach.

Richter *et al.* (2003) provide a six-step framework for managing river flows for ecological integrity:

1. Estimating ecosystem flow requirements (based on the characteristics of a stream's natural flow regime), making explicit all assumptions and hypotheses about flow-biota relationships, other non-flow related variables that affect biota, and the influence of flow on other ecosystem conditions such as water quality)
2. Determining human influences on the flow regime using hydrologic simulation models
3. Identifying incompatibilities between human and ecosystem needs both within and among years
4. Collaboratively searching for solutions to reduce conflicts (such as demand management or changing the timing or location of human uses toward greater compatibility with natural hydrologic cycles)
5. Conducting water management experiments designed to resolve critical uncertainties, test hypotheses formulated in Step #1, and to test solutions implemented from Step #4.
6. Designing and implementing an adaptive water management plan recognizing that water management must be perpetually informed by monitoring, carefully targeted research, and further experimentation to resolve new uncertainties and allow continual improvement in management approaches.

Arthington *et al.* (1998) present a "best practice framework for holistic environmental flow assessments." It has many similarities to the framework set out by Richter *et al*. (2003). Papers by Richter *et al.* (2003) and Arthington *et al.* (1998) both underscore the importance of generating and testing hypotheses to advance our understanding of ecological flow needs. Without this, Arthington *et al.* (1998) indicate, "environmental flow strategies will continue to be based on surrogate measures of biological requirements and ecological processes. Both frameworks also allow consideration of non-flow related influences and management strategies.

One of the differences in the approaches relates to stakeholder input and early definition of constraints. Arthington *et al.* (1998) allow for a scoping stage after completion of background studies to consider constraints before significant efforts are put into quantifying flows which may not be deliverable. Richter *et al.* (2003) believe that "initial estimates of ecosystem flow requirements should be defined without regard to the perceived feasibility of attaining them through near-term changes in water management."

Within the Arthington *et al.* (1998) framework, a three-tiered system of environmental flow assessment is nested:

- Level 1: Watershed-wide reconnaissance of development options, opportunities for restoration, and preliminary assessment of environmental flows
- Level 2: Watershed or sub-watershed scale assessment of environmental flows for feasible development options and/or restoration
- Level 3: Detailed assessment of special issues at all spatial scales

The effort and time required increases as the spatial scale of assessments decreases, and more focused and quantitative assessments are necessary. In Australia, a streamlined "habitat analysis method", which usually does not involve original fieldwork, has been used for watershed-wide assessments. Aquatic habitats are identified and key flow statistics are used to describe the flows that will maintain the habitats. Biological "trigger" flows and some larger flows to maintain geomorphology and floodplain connectivity are added. This approach is considered to be preferable to reliance on the Montana Method and flow duration curve analysis, which have traditionally been used for reconnaissance level analyses.

For Level 2 assessments, the Holistic or Building Block methodologies are used and the methods used to assess the requirements for channel structure, invertebrates, fish, and aquatic and riparian vegetation) are more detailed and quantitative. If life history information does not exist for key species, field surveys over at least 18 months should be anticipated. Some recommendations will be based on limited data and professional judgments. Hypotheses about flow-ecology relationships should be referred to the third level of the assessment hierarchy for further investigation. PHABSIM is mentioned as one tool that might be employed for specific purposes at the detailed level of assessment. Short-term experimental releases or stresses may need to be applied to assess flow requirements in many watersheds. Detailed investigations can be expected to take from 2 to more than 5 years.

4.5 Ecological Relationships and Water Abstraction

To begin the discussion on ecological requirements, an introduction on previous research into water abstraction and potential impacts to aquatic ecosystems is completed in a general overview of previous research. Several scales of influence – from the entire watershed down to the river reach itself – have been shown to change the assemblages of the biota instream. The characterization of certain life stages of a variety of fish are presented to clarify the effects that potential water abstraction would have on these critical periods for fish. This is followed by the characterization of biotic instream water requirements based on life cycle ideals for a variety of fish species. Several figures are presented to conceptualize the life cycle requirements of several species of fish based on the time of year of occurrence.

4.5.1 External Influences on the Instream Biotic Community

Over the last 30 years, scientists and water managers have been trying to determine the potential impacts of water use and water abstraction on aquatic ecosystems (i.e. Orsborn and Allman, 1976). In that time period, many approaches have been developed and tested, as just previously discussed in the last few sections. In almost all instances, these approaches have used hydrologic and/or hydraulic parameters and metrics to determine changes to river channel capacity from water abstraction. Biological responses have been inferred using a variety of approaches, as previously discussed in this chapter and as will be discussed in Section 8.4.

The regulation of water use and the management of river systems for aquatic life require an understanding of:

- relations between the structure and functions (process responses) of physical systems;
- how the animals and plants use these structures as habitat;
- how animals respond to varying flows in relationship to channel structure and water quality; and
- where these important features are likely to occur within a watershed (Naveh and Liberman, 1993) and their relative sensitivity.

Managers must also understand and be able to predict how proposed changes in land management, water use and land use will affect physical and chemical processes operating within watersheds and their rivers so that these processes and their controlling factors can be protected. Such information is necessary in order to facilitate protection, remediation or rehabilitation strategies for a watershed.

The consideration of all the various elements that relate the aquatic community responses to permanent and/or seasonal changes in natural low-flow conditions demonstrates that the process is extremely complex. The following section discusses how aquatic animals use their aquatic environment. The difficulty of relying on a physical-based assessment process is discussed and an argument is proposed for the need for a focussed multi-year study to explore the response of aquatic communities and their food web to manipulations in natural flow variability.

4.5.2 Aquatic Organisms and Their Environment

The difficulty faced by ecologists and biologists is trying to understand the consequences of altering the normal range in flows in a particular river. There appears to be relationships between the physical habitat features found in a particular river, the spatial distribution of these channel forms and how and when animals require these habitat features. Most research on these issues in the past have been within-discipline studies. There is a strong need for more collaborative work between physical and biological scientists in order to understand some of these processes (e.g. Gordon *et al.*, 1992). There is also a strong need for further interaction between terrestrial and aquatic biologists and ecologists in order to understand the linkages and interactions between terrestrial systems and aquatic systems at various scales (i.e. valley and stream; upland interactions; floodplain interactions, and; riparian zone interactions) especially as relates to food web characteristics of aquatic systems and their importance in maintaining the trophic structure of a particular river.

An understanding of physical processes, such as streamflow, that control aquatic habitat, is essential if we as a society wish to protect the overall well-being of aquatic systems. An understanding of the physical processes operating at certain scales will improve the effectiveness of management and rehabilitation efforts. For example, excessive streambank erosion could be a site issue (e.g. overgrazing by cattle), a reach issue (e.g. channel modifications upslope that disrupted the meander pattern), a watershed level change (e.g. change in hydrology due to agricultural drainage), a landscape level change (e.g. climate variability) or a mixture of all of these processes. Without understanding the linkages of formative processes (causes) to the forms created by these processes (responses), it is difficult to be effective in management or analysis of the problems.

Since aquatic animals live in water, the most essential condition to their survival is sufficient water in a river in order to ensure that they can live, grow and reproduce. Loss of water for a short period of time in a river system could be equated to asking space shuttle astronauts to survive in the space shuttle for a few hours without air and space suits.

Aquatic ecosystems exhibit a wide range of compensatory responses to various environmental changes (Evans *et al*., 1990). Therefore, the understanding of the responses of aquatic ecosystems to chronic changes in flow patterns requires several years of measurement in order to differentiate between normal compensatory behaviour, and changes that are occurring to the system based upon human-induced changes in low-flow volumes.

4.5.3 Aquatic Communities and External Watershed Influences

Although aquatic animals, such as fish, inhabit specific locations in a stream at various times of the year, the processes that create the habitats they use are influenced by larger scale processes that operate at landscape (e.g. weather patterns), watershed (e.g. surficial geology), and reach levels (e.g. channel morphology). Therefore we must examine the implications of changes to river flow and volumes at several spatial and temporal scales in order to understand the implications of changes in flow and volume on aquatic systems. Although hydrologists have understood the importance of spatial scale, it is only relatively recently that ecologists have considered the issue of scale (e.g. Vannote *et al.,* 1980; Frissell *et al.,* 1986).

Schumm and Lichy (1965) suggest that at fine scales, physical forces acting on a site appeared to be disruptive, however if viewed at a larger scale exhibit a trend towards some quasi-equilibrium state (Leopold *et al.,* 1964; Bormann and Likens, 1979; Allen and Hoekstra, 1992). Therefore, in order for biologists and ecologists to understand the implications of physical change on aquatic organisms living in flowing water, we must understand various processes and their effects within the appropriate temporal and spatial scales (O'Neill, 1989). Hierarchical systems tend to be nested (Allen and Starr, 1982; O'Neil *et al.,* 1986; Allen and Hoekstra, 1992), a term referring to the control that coarser-scale variables have on finer scale variables. It is therefore important to define the cause/response linkages between different scales. This is not a simple matter given the complexity of ecosystems. Table 4.2 is modified from work done by Frissell *et al.* (1986) and demonstrates the role of scale in aquatic ecosystems (see also Appendix A, Table A.1).

Table 4.2 Cause and effect of different scales on the aquatic habitat in streams

Scale	Causes		Effects	
	Condition or State	Processes	Physical Response	Habitat Changes
Watershed	Climate: precipitation and snowmelt regimes	Runoff, infiltration, evapotranspiration	Change in recharge rates, surface and subsurface runoff	Stability and diversity of habitats
	Landcover change	Erosion, infiltration	Change in flow regime, sediment load and bank slope	Volume of living space, and riparian and floodplain vegetation, biomass
	Slope and Geology: slope stability	Slope and channel erosion	Change in sediment load, entrenchment, valley slope	Changes diversity of stream types and controls diversity of habitat potential
Reach	Runoff flows	Erosion, deposition and respiration	Changes channel geometry, nutrient exchange, migratory access	Changes water quality including temperature; water quantity and depth
	Vegetation Community	Bank cohesion, vegetation change, erosion, deposition, flow velocity	Bank stability, organic inputs to stream, channel complexity	Creates shelter, provides nutrients, changes water temperature
	Slope, energy gradient	Erosion, deposition (lateral)	Changes channel sinuosity, width:depth ratio	Changes diversity of habitat including riffles and pools
	Sediment Size and Load	Channel stability, erosion, deposition	Change in sediment load in stream	Changes habitat structure diversity and stability
Site	Flow Velocity	Erosion, deposition	Formation of bed and bank, channel shape	Sites of spawning, resting, refuge, determines volume of living space
	Slope (water surface)	Erosion, deposition, transport	Change in substrate characteristics such as riffles to pools	Differentiates life cycle requirements and activities such as feeding and reproduction
	Bank Cohesion, Sediment size	Friction, erosion, deposition	Changes channel shape, bank slope, riffles and pools	Changes benthic (bed of stream) habitat; refuge
	Large Woody Debris	Friction, velocity, erosion, deposition	Changes bank slope, width/depth ratio, shading	Changes refuge and spawning areas; temperature moderation

[Source: modified from Frissell *et al.* (1986); Imhof *et al.* (1996)]

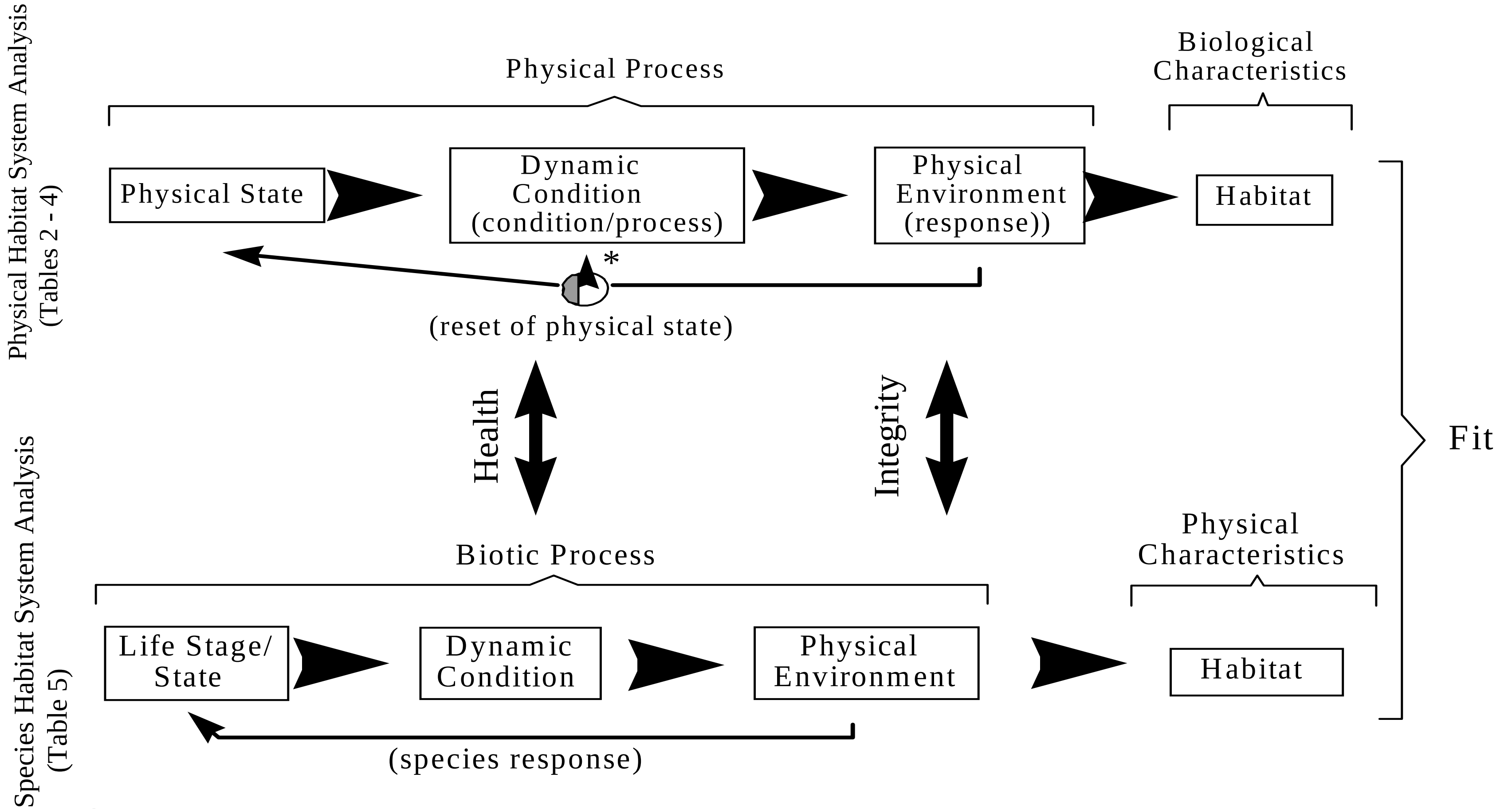
Managers must be able to synthesize information and develop general relationships of ecosystem functioning in order to place specific problems in appropriate spatial, temporal and analytical context (Allen and Hoekstra, 1992; Naiman *et al.*, 1992). For example, water allocations from a watercourse can occur at specific points in a river. Modest water abstraction at one location may not have a noticeable impact on the aquatic community in part because the animals may compensate for changes in low-flow volume in a variety of ways. However, numerous small amounts of water abstracted from a river may, cumulatively, over a reach of river or over time, have a major impact on the robustness and resiliency of the aquatic community.

Frameworks that develop and explain the relationship between physical environments and how animals use them at various scales can be useful in understanding the implications of flow change on physical habitat and the potential implications to animals in rivers.

In the model described in Table 4.2 and illustrated in Figure 4.1, Imhof *et al.* (1996) have selected processes that operate across scales and thus define critical linkages such as: run-off generation; sediment load and transport; erosion/deposition; and vegetative interaction/succession (see also Tables A.2 to A.4 in Appendix A). These processes are defined in terms of the physical variables, features and attributes that are manifested at the scales of watershed, reach and site (Allen and Hoekstra, 1992; Harris, 1994). Information that is relevant for each scale is placed into a specific category, which are: state; condition; process(es); response; and habitat. These categories are defined as follows:

State - The normative characteristic (i.e. static) of the system for the specific scale being examined (i.e. climate; e.g. humid, north temperate*).
Condition - The variations of the particular normative characteristic (i.e. weather; e.g. precipitation regimes*).
Process(es) - The operations of the particular system (e.g. run-off generation*).
Response - The physical response/forms of the system to the processes (e.g. drainage density*).
Habitat - The habitat measure for the effect created by the process controlled by the state (e.g. potential habitat volume in the channel*).

The model proposed here uses certain processes to describe cause and response within and between scales (as suggested by Allen and Hoekstra, 1992; Harris, 1994; Fitzgibbon and Imhof, 1994). This conceptualization is familiar to those who are involved in modeling watershed flow and sediment regimes. However, it requires going a few steps further and modeling the responses of streamflow and channel form to runoff and sediment load changes in the system at different scales and linking these to models of habitat systems at the appropriate spatial scale. For example, changes in the sediment regime at a watershed scale are manifested by soil loss and gullying. At a reach scale the same phenomenon can be seen by changes in channel gradient, substrate and channel form. At the site scale, sediment regime changes can be seen in adjustments to cross-sectional shape of the channel, patterns of erosion and deposition, flow characteristics (i.e. depth and velocity) and habitat (i.e. shelter/living space).



* Splitter, dividing an input into 2 or more parts (see Talbot & Gessner 1973).

Figure 4.1 Flow chart models demonstrating the major elements of the physical habitat and species habitat analyses

Figure 4.1 illustrates a framework for linking a physical habitat framework to a life stage/state framework. Analysis of the information in Table 4.2 in relation to information in the other tables can be used to identify potential habitat availability. Where particular habitat features are limited in time and space they are termed "critical" habitats. Where these particular features are missing, they represent a lack of fit of the species with its physical environment. Flow charts are also used in this model to describe the types of questions to be asked of the information to determine if the physical environment at specific scales is still suitable for the life stage requirements of an animal or community (see Appendix A, Figure A.1).

Two major analytical components are necessary in order to determine how well a particular species is suited to a stream within a particular watershed: knowledge of the life history requirements in space and time; and knowledge of the availability of physical habitat features in space and time. In order to understand how an animal will respond to changes in condition, the various spatial scale physical and chemical processes operating in the river system must be related to an animal or animal communities life stage/state requirements. Fausch *et al.* (1988) examined habitat variables important in the prediction of fish biomass. They suggest there are strong relationships between physical habitat dynamics and biotic use.

4.6 Watershed Hydrology and the Life Stages of Fish

4.6.1 Fish Migration

Fish move around in rivers more than biologists first thought. It is only in the last 10 years as telemetry tags became useful for aquatic studies that biologists have been able to track the movements of riverine fish of various sizes. Results from many studies have demonstrated that even fish considered relatively sedentary (e.g. brown trout) can move many kilometres in a day, week or season. These movements can be in response to feeding, thermal refuge, spawning and over-winter habitat or any combination of these aforementioned factors.

The flow patterns and flow pathways of a river system control the movement of fish to various portions of the river system and access of fish into small tributaries of large rivers (i.e., longitudinal pathway, large scale effects). There are windows of opportunity during high flow events that regulate the movement of migrating fish into small tributaries. The larger the order of the main stream in relation to the smaller tributaries, the narrower the windows become.

Windows of access also occur in relation to fish migration and movement within a river exhibiting a low-flow and high temperature event. In some instances, fish, especially coldwater fish, will move distances to seek out groundwater discharge zones in order to survive the high stream temperatures. The depth of water in riffles can become an issue in the ability of these animals to seek out thermal refuges under these circumstances.

On an annual basis, the characteristics of the flow regime will act as a qualifier of habitat availability and suitability within the channel. It is important to examine the watershed hydrology as an aid to determine habitat characteristics for a particular reach of stream. Although a stream channel may contain the same surface area of spawning gravels, between spawning periods, it is the annual flow regime that will determine the overall habitat availability for all life stages. An analysis of both hydrological event characteristics and flow regime characteristics is important to understand the ability of the channel/valley system to provide all requirements of various life stages. Life stage requirements are not only dependent on the order of the stream within the watershed, but also on the type of stream channel within the watershed.

General and standard life history stages are used, similar to those used in Habitat Suitability Index models (e.g. Raleigh *et al.*, 1984): reproduction; nursery; juvenile; and adult. As well, life state variables are also used: overwinter refuge; feeding; and migration. When considering the connections between habitat and biotic use, four items are important to consider:

Life stage/state	-	Normative activity (e.g. reproduction) of a species. This includes a specific stage of a species' life cycle plus activities common through the entire life cycle (e.g. feeding);
Dynamic Conditions	-	Those conditions that change rapidly to affect life stage/state activities;
Physical Environment	-	Those conditions that must exist over long periods of time to support habitat (e.g. hydrologic; geomorphic; hydraulic);
Habitat	-	Those spaces which have appropriate forms and conditions to support life stages/states.

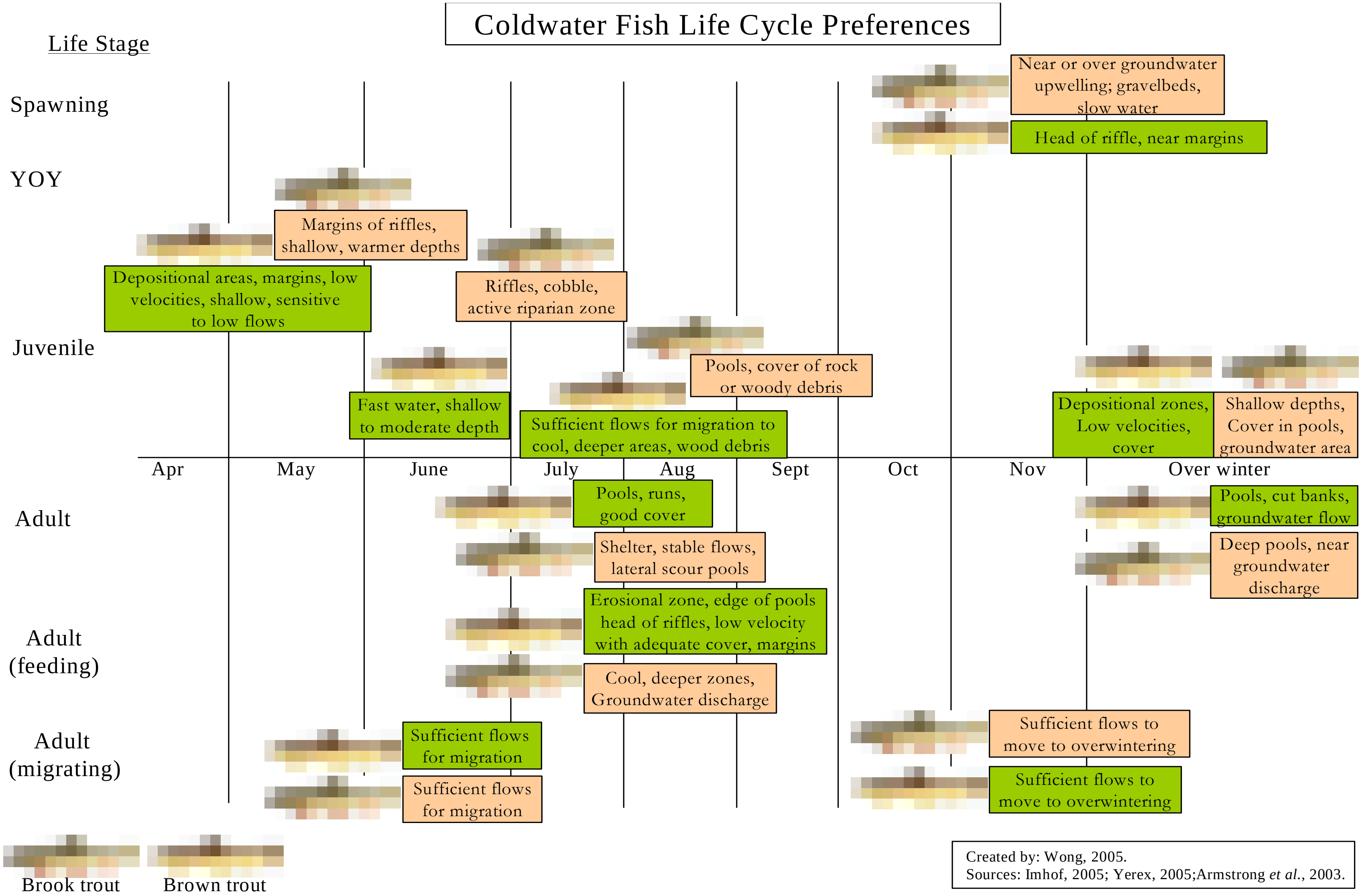
The physical habitat requirements at certain life stages of fish can be linked to the timing of occurrence during the year. Life stages and streamflows were the basis for two figures that show the relationship between life stages of fish throughout the year, and the hydrological requirements at that life stage. The species were separated into coldwater fish species (Figure 4.2), including brook trout and brown trout; and warmwater fish species (Figure 4.3), including smallmouth bass, walleye and northern pike. These figures can be used as qualitative assessments of life cycle requirements to assess the importance of maintaining flows at certain times of the year, and the implications of low flows at certain life stages for several fish species.

To comprehend the information presented in these two figures, the grid shows a timeline for the year, with spring on the left side and continuing through to the over-wintering period, which lasts from approximately December to March, on the right side. The vertical axis lists the different life stages of fish that have been known to have hydrological and habitat requirements. The placement of the fish and descriptive boxes on the grid crosses when the timing during the year (horizontal axis) and the life stage (vertical axis) meet. The hydro-ecological requirement of that life cycle stage, which occurs at the particular time, is described in the coloured box below or adjacent to the fish. For instance, smallmouth bass individuals require 2 weeks of water cover for spawning, which occurs from mid-May until mid-June. Personal communication with J. Imhof (National Biologist, Trout Unlimited Canada, 2004), provided much of the information, supplemented with research by Armstrong *et al.*, (2003).

For the coldwater species, it can be see in Figure 4.2 that brook and brown trout have very similar requirements as adults. The life cycle requirements before the fish reach the adult stage however, are very different, and the key factors of hydrology and preferential habitat locations in the river are characteristic to the species. For example, the hatching of brown trout tends to be earlier in the spring than for brook trout.

Although there is not as much information for the habitat preferences of the warmwater fish (Figure 4.3) as there are for the coldwater species, a considerable amount of information still exists. There was sufficient information to characterize three warmwater fish species for most of the life stages. There is, however, a lack of information for non-sport fish species that will require more research to determine what the requirements of the entire ecology of the stream would be, not just the high profile fish species.

The information in the two figures could be used to complete a scoping level assessment of the impacts water takings might be expected to have on a fishery. At the least, the figures illustrate that ecological requirements are dynamic depending on the stage in the life cycle and time of year.



Created by: Wong, 2005.
Sources: Imhof, 2005; Yerex, 2005;Armstrong *et al.*, 2003.

Figure 4.2 Hydro-ecological life cycle preferences of coldwater fish during the year.

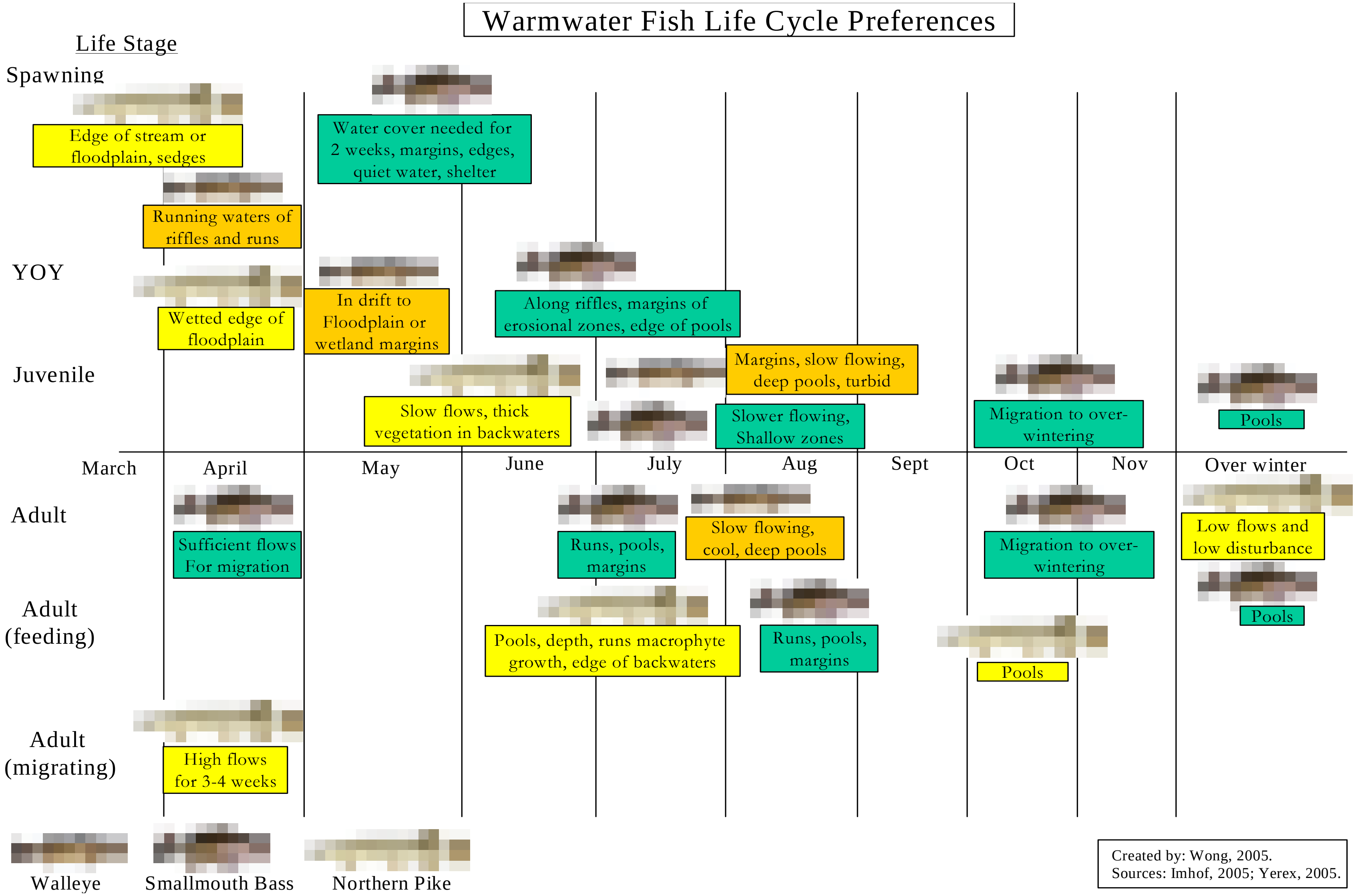


Figure 4.3 Hydro-ecological life cycle preferences of warmwater fish during the year.

4.6.2 High Flow Regimes and Fish

High flows in most stream systems are a natural occurrence. High flows occur when large quantities of water swell river channels because of specific weather conditions such as severe storm events and rapid melting of winter snows. These flows result when the land no longer has sufficient ability to hold, absorb or store the water. During the most frequent weather conditions, the amount of high flow in a watershed will be governed by a number of factors including the surficial geology and soils of the watershed, the topography of the land, the land cover and land uses of the watershed. These factors then influence the relative importance of the individual components of the hydrological pathway (i.e., surface runoff; evapotranspiration; interflow; and groundwater recharge/discharge).

Changes in the overall water budget of the watershed or sub-basin can have repercussions on channel morphology, bank stability, flood elevations, flood frequencies, water quality, aquatic habitat and fish communities. In general, the more quickly a stream section, sub-basin or watershed responds to storm events, the more likely that the watershed will lose important fish communities, de-stabilize the channel, banks and floodplain and degrade water quality.

Fish use high flows to adjust their position in streams. Fish movement usually occurs during the rising or descending limb of the hydrograph. Fish movement occurs in the main channels and between the main channels and tributaries. During normal low-flow conditions, small tributaries do not have sufficient water depth for spawning fish to move into them or for juveniles to move out. Timing of high flows in tributaries compared to the main stream can be critically important in the movement of animals in and out of these smaller system.

4.6.3 Groundwater Regimes and Fish

For many years, stream biologists have observed a strong positive relationship between the discharge of groundwater to streams and stream fish (Blackport *et al.*, 1995). Nevertheless, only recently have the relationships been explored scientifically. Some recent work in this area includes work done Bowlby and Roff (1986), Cunjak and Power (1986), Sowden and Power (1985), and Witzel and MacCrimmon (1983). In addition to fish, groundwater has also been identified as important, in general, to stream health (Hynes, 1983; Bilby, 1984; Meisner *et al.*, 1988).

While there is still much to learn, several important relationships between fish and groundwater have been demonstrated, including:

A) Groundwater discharges create and maintain baseflow regimes in streams, and hence control the quantity of living space, cover and food for fish.

B) Site-specific groundwater discharge patterns generate opportunity for reproduction and provide thermal refugia during temperature extremes.

C) Groundwater moderates stream temperatures during critical times of year (midsummer and midwinter), and maintains temperatures to a level suitable for thermally sensitive fish species.

Many factors control the "productivity" of fish and related communities in streams:

- quantity of water and its source (i.e., surface vs. shallow groundwater vs. regional groundwater);
- its delivery to the stream;
- its affect upon water quality;
- the frequency of various flow patterns;
- the magnitude of exceptional flow patterns; and
- the duration of these exceptional patterns

All these elements have a major control on fish habitat and aquatic communities. Streamflow is a combination of overland flow, interflow (flow below the ground surface but above the water table) and groundwater discharge. However, it is the constant discharge of groundwater that maintains baseflow in streams during periods of little or no precipitation. Baseflows maintain the typical habitat or space available for species; the biota in a reach will adapt to the space or habitat generally available.

4.6.4 Channel Characteristics and Fish Habitat

There are numerous characteristics within stream channels that are important for fish and fish communities. The patterns and stability of riffle:pool or step:pool sequences create habitat conditions for shelter, food, space and reproduction. The quality of pool area defined by depth, extent, location, and complexity provides shelter, feeding and over-wintering for many species of fish including, trout species, smallmouth bass, northern pike, walleye, muskellunge, sturgeon, suckers, and minnows. Riffle areas provide shelter and feeding habitat for some species like sculpins, darters, dace, hog suckers. For other species such as trout, salmon, and walleye, riffles provide feeding and reproductive habitat. Therefore the form and pattern of a river are important features in determining use and distribution of fish. This is especially important for some species of fish that appear to exhibit adaptation of body form for certain physical areas in streams in order to take advantage of preferred habitat. As habitats are simplified and the planform of the river deviates from one of stability, these specialists are often lost from the system.

Longitudinal shifts in fish community structure (i.e., presence/absence, population structure, dominance, abundance) have been explained by the River Continuum Concept (RCC) and Serial Discontinuity Concept (Vannote et al. 1980) (SDC). At a large scale, distribution of fish communities appears to be controlled by the watershed’s geology and climate. However, the specific distribution of individual species within a particular community appears to be controlled by stream order, the location of the stream section within the context of the drainage network, and structural characteristics of rivers and streams. For example, some fish species require the diverse characteristics of habitat found in headwaters, other species prefer more stable flow patterns for critical life stages found in larger rivers, while other species require floodplains for spawning. These habitat preferences are also linked to other attributes such as thermal gradients, hydraulic gradients, nutrient gradients, channel complexity and physical space. These variables are not always controlled by the size of a stream, its order or location in the watershed but often by changes in local geology, slope, groundwater intrusions, and sediment loading, etc. In this way there are strong relationships between the biota found within a channel/valley system and specific physical functions of the system.

4.7 Implications Of Changes In Historical Or Natural Flow Patterns And Volumes To Aquatic Organisms

Stress can be placed upon fish through natural extreme fluctuations in flow both from an event standpoint (i.e., 1:25yr flood; 1:25yr drought baseflow) and from a regime standpoint (i.e., changes in the "normal" daily, seasonal or annual flow characteristics of frequency, magnitude and duration). Poff *et al.* (1997) coined the phrase, “natural flow regime” to stress the fact that animals living in flowing water have evolved to cope and exploit the natural flow regime of streams. Refer to the discussion of natural flow regimes in Section 4.2.

Headwater streams of first (lst) and second (2nd) order are more sensitive to daily and seasonal fluctuations in flow because of the characteristics of their channel structure (i.e., relatively shallow pools and refuge areas). If minimum low-flow events occur more frequently (compared to historical trends - i.e., changing from irregular to frequent events) this can lead to loss of spawning success, loss of juvenile fish and depletion of adult fish. In effect, the annual minimum baseflow ultimately controls the maximum potential productivity of a stream or river system by determining the annual minimum living space for aquatic biota.

Medium order streams (3-4 order) usually have deeper water refugia and because flow is contributed by a larger stream network, they may have more variability in flow but low-flow characteristics are not as variable in relation to channel characteristics as in headwater systems. Large order streams (i.e., 5-8 order) have dampened flow patterns that generate longer high and low-flow durations. Major droughts also affect these channels but the return periods are less frequent (i.e., 20-50 year for 5- 8 order streams versus 2 - 5 years for 1 - 2 order streams). Therefore, small coldwater tributaries and to a certain degree mixed water tributaries on the Grand River, are very susceptible to alterations of their annual lowflow or baseflow (i.e., Butler Creek; Swan Creek; Hanlon Creek). Larger coldwater streams and subwatersheds are less susceptible to occasional annual lowflow extremes but are vulnerable to larger, longer-term lowflows (i.e., Eramosa River; Blue Springs Creek; Whitemans Creek). In summary, stream order is significant: a lower stream order generally infers greater sensitivity to change and a reduced ability to accommodate water takings.

4.7.1 Linking Hydrologic and Hydraulic Approaches to the Ecology of Streams

Naiman *et al.* (1992) review the general principles related to classification and assessment of rivers. They suggest that several characteristics are very important components of any classification system developed for rivers and watersheds:

- longitudinal and lateral linkages;
- changes occurring in physical features over time;
- boundaries between apparent patches that are often indistinct;
- geomorphic and ecological characteristics that vary spatially from headwaters to mouth and temporally in response to disturbance patterns.

Naiman *et al.* (1992) and others (Gregory *et al.* 1991; Kaufmann *et al.* 1994; Fitzgibbon and Imhof 1994) also suggest that the development and relationships of these measurements pose a problem for classification systems of rivers and watersheds. However, these requirements for habitat linkages and habitat variability are also identified as essential for the long-term maintenance, vitality and resiliency of streams and watershed ecosystems (Naiman *et al.* 1988; Kay 1991a, 1991b; Naiman *et al.* 1992; Kaufmann *et al.* 1994).

Frissell *et al.* (1986) propose a hierarchical framework which extends from watershed to stream system, segment system, reach system, pool:riffle system to the micro-habitat system (Table 4.1 and Appendix A, Table A.1). Vertical and lateral dimensions are discussed but linkages and interactive pathways are poorly defined especially between the channel and its floodplain and riparian zones (see Naiman *et al.* 1988). This inadvertent omission must be addressed (Imhof *et al.* 1991; National Research Council 1992; Naiman *et al.* 1992; Petts 1992). Newbury (1999, pers. comm.) also suggests that all normal flow ranges provide important hydraulic habitat attributes to river systems and are needed by animal communities for their full life cycle.

In general, the relationships identified in Figure 4.1 suggest that the physical nature of the watershed, the location of the stream in the watershed and the streams form and hydrologic and hydraulic character all conspire to create certain physical forms and regimes that are exploited by the population of animals living in that particular stream. Table 4.3, from Newbury, suggests a strong role for all natural flows in the creation and maintenance (and in some cases limitations) of habitat for animals in a stream. Other researchers (Roussel *et al*., 1999; Heggeness, 2002) have further studied brown trout for their preferences of flow during the summer (Table 4.4). The depth and focal water velocity (velocity at fish nose) preferences are described as the mean and median, as well as the range.

Armstrong et al. (2004) looked at the different habitat requirements of fish to compare to the flow regime. Streamflow requirements for fish were studied in New England for a variety of species that were categorized into 3 classes on the basis of their habitat uses. *Macrohabitat generalists* use a broad range of habitats, and are fish species that can complete their life cycle in lakes, rivers, and reservoirs, such as pumpkinseed, smallmouth bass and redfin pickerel. *Fluvial dependents* need access to streams or flowing-water habitats for a specific life stage, but otherwise can be found in lakes, rivers or reservoirs, and include common shiners and white suckers. *Fluvial specialists* require flowing-water habitats throughout their life cycle and are common only to streams and rivers, such as brook, brown and rainbow trout. They supported that "the native biodiversity and integrity of river ecosystems can be sustained by maintenance of the natural pattern of flow variability that created to that diversity" (Poff *et al.*, 1997).

Table 4.3 Example of a hydraulic habitat model for streams for three natural flow states: Annual High Water, Moderate Flow and Low Flow.

FLOW	FORM $^{(a)}$	ABIOTIC FUNCTION	BIOTIC FUNCTION
HIGH (short term, pattern and channel forming, gradually-varied)	Alternate thalweg 100 Helical circulation (meandering) 80 Plunging profile 80 Swifts/rapids 20	Meander migration, bank erosion, pointbar construction, substrate partitioning, sediment transport, debris accumulation, floodplain saturation	Cover development Detritus transport Spawning bed development Nursery habitat creation
MODERATE (recurring, persistent, pattern inherited, locally-varied)	**Pools/glides (inherited)** Uniform 60 Partitioned states 40 Shear planes 5 Eddy trains 10 V & H rotation 25	Sediment re-sorting Detritus accumulation	Up, down, and lateral mobility Food accumulation Food circulation Cover
	Riffles/runs (inherited) Mixed state 100 Convergence 20 Separation 5 V & H rotation 55/20	Transparency Aeration Local scour	Benthic insolation, oxygen, food concentration, reproduction, refugia, fish passage
LOW (recurring, long-term, pattern inherited, locally-varied)	**Pools (inherited)** Still (stratified) 95 Wind circulation 5	Storage Persistence Groundwater storage	Thermal and light refugia (over summer and over-winter)
	Trickles, seepage (inherited) Mixed states 100	Aeration Continuity	Connectivity

[From Newbury, 1999, pers. comm.]

Table 4.4 Flow and depth measurements for brown trout at (base) summer flows

Summer Flow Needs	Heggeness (2002)		Roussel *et al*. (1999)
	Mean (cm/s)	Median	Range (cm/s)
Focal Water Velocity	14	10	15-45
Depth	11	10	25-45

[Source: Heggeness, 2002, Rousell *et al*., 1999]

The life stage/state model suggests that it is not only the physical and chemical nature of a system that is exploited by animals for various aspects of their niche and life cycle, but also the processes (biotic and abiotic) associated with these forms that provide opportunities or limitations for survivorship of populations in streams. Therefore, simple cause:effect relationships are rare when examining the impact of a stressor on a natural system. The actual response of the population or a species in the river may be dictated by the interplay of a variety of variables operating together. The response will also be coloured by the time of year, state conditions at that time of year and the stage or state in the animal or populations life cycle.

The above discussion illustrates the concern expressed by Power (2004), who states, "The variability and diversity of possible responses complicates documenting the nature of causal-linkages when attempting to determine the possible effects of a stressor (e.g. water removal) on target populations." Heggeness *et al*. (1996) also found that "there is no such a thing as 'the' suitable minimum flow; the effect of reduced flows will vary with stream structure, the hydro-physical variables in question and the fish species." Therefore, in order to truly understand the possible responses of a target population to changes in flow resulting from water removal or another stressor(s) will require a better knowledge of the important niche variables that make up the niche axes of a population in relation to the nature and operation of the stressor, the existing population regulation mechanisms and their inter-relationship in effecting a population response (Power, 2004). "More studies are needed to elucidate possible spatial and in particular temporal variations in fish habitat selection. Care must be taken in aggregating habitat suitability data into single-valued functions." (Heggeness *et al.*, 1996).

5.0 PILOT REACH CHARACTERIZATION AND HISTORICAL DATA

This chapter provides a detailed description of the 8 pilot reaches of this study. The characteristics, including hydrology, stream morphology and aquatic ecology, of each reach are described. A summary of the data collection, analysis and case study work for instream flow assessment is given. The case studies provide the reach-specific approaches used to examine instream flow requirements and highlight the differences between reaches. For information on water uses and water taking for each of the pilot reaches, please refer to Chapter 6.0.

5.1 Pilot Reaches – Application of Instream Flow Approaches

The purpose of conducting a detailed study of pilot reaches was to test the application of instream flow approaches to these reaches. The application of instream flow approaches is intended to examine methods that may be used to estimate the amount of water needed to maintain the viability of the aquatic ecological system.

5.1.1 The Study Areas

Selected sites in the Grand River watershed were classified by watercourse size, sensitivity and available data. Eight sites in the Grand River watershed were selected for potential investigation (Figure 5.1). Some sites had existing hydraulic and hydrologic information readily available, reducing the level of effort required to analyze these sites and allowing additional effort to be focused on sites where less information existed. The pilot reaches are listed below with some attributes and concerns outlined. Each site is described in detail in the following subsections.

Large River Sites

- **Grand River at Blair**
    - Upstream drainage area: 2592 km^2
    - River regulation, available data, possible species at risk, water taking
- **Grand River Exceptional Waters Reach**
    - Upstream drainage area: 5157 km^2
    - River regulation, species at risk, up to date data
- **Nith River at Canning**
    - Upstream drainage area: 1016 km^2
    - Available hydraulic model, long-term flow information, some biological data

Intermediate River Sites

- **Eramosa River**
    - Upstream drainage area: 242 km^2
    - Water taking (municipal), flow variability, available data, subwatershed plan completed

Small Stream Sites

- **Blair Creek**

    - Upstream drainage area: 15 km^2
    - Urban impacts/landuse change, subwatershed plan completed
- **Whitemans Creek**
    - Upstream drainage area: 414 km^2
    - Water takings, high quality coldwater stream
- **Mill Creek**
    - Upstream drainage area: 84 km^2
    - Aggregate extraction, land change impacts, subwatershed plan completed
- **Carroll Creek**
    - Upstream drainage area: 45 km^2
    - Available data, agricultural impacts

5.1.2 Availability of Historic Flow, Environmental Data and Relevant Reports

A summary of information available at each site is provided by Table 5.1. The small streams are all coldwater fisheries; the larger watercourses are all warm water or mixed fisheries. Historical benthic information exists at all sites except Carroll Creek.

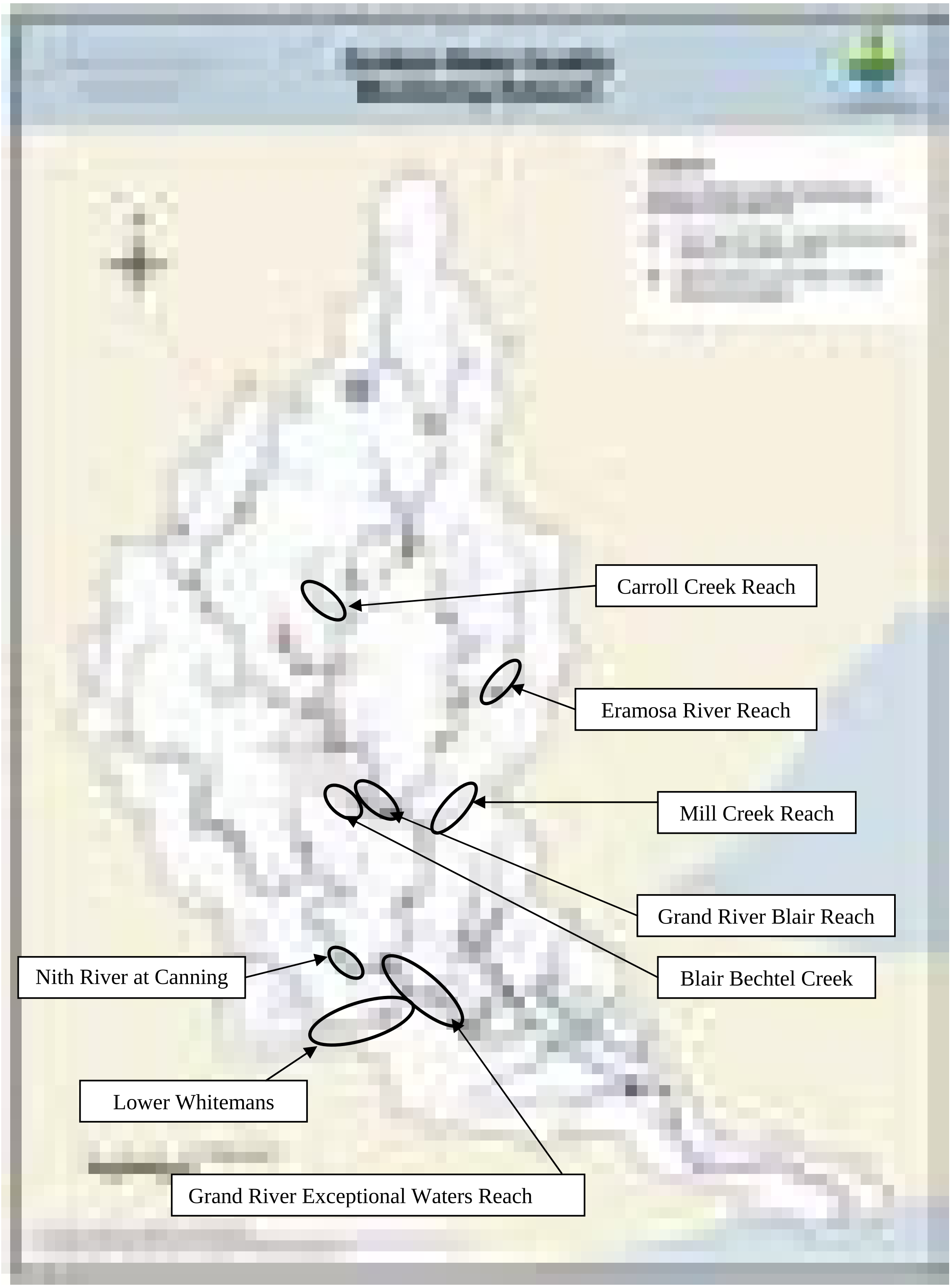


Figure 5.1 Pilot Study Reaches for Instream Flow Methods

Table 5.1 Information availability for the pilot study reaches

	Large River			Intermediate River	Small Stream			
Site	Grand River at Blair	Grand River at Exceptional Waters	Nith River at Canning	Eramosa River	Blair Creek	Whitemans Creek	Mill Creek	Carroll Creek
Flow Information								
Regulated Flow	Yes	Yes	No	No	No	No	No	No
Record Years	54	54	54	38	8	41	12	6
To WSC Standard								
Subwatershed or Basin Plan Information	Yes	Yes	No	Yes	Yes		Yes	
STP Influence	Yes	Yes	No	No	No	No	No	No
Water Taking Influence	Yes	No	Yes	Yes	No	Yes	Yes	No
Provincial Water Quality Information	Since mid 1960's	Since mid 1960's	Since mid 1960's	Since mid 1960's		Since mid 1960's		
Continuous Water Quality Information	Temp, pH, COND, DO				Temp.		Temp.	Temp.
Continuous Water Quality Model	Yes							
Aquatics Information		Yes		Yes	Yes	Yes	Yes	Yes
Cross Section Information	HEC-2	Detailed	Hydro Dynamic Model	HEC-2	HEC-2	No	HEC-2	Detailed

5.2 Grand River at Blair Pilot Reach

This is an impacted reach on the main and central portion of the Grand River. The Grand River at Blair reach is probably the most stressed river reach in this study, due to anthropogenic influences. Analysis of long-term Provincial Water Quality data suggests this site has not been improving, while other reaches have shown improvement since the mid 1970's (Cooke, 2004). This reach is affected by the Region of Waterloo water taking and effluent discharge from the Kitchener sewage treatment plant (STP) immediately upstream of this reach.

The reach is bounded by the Doon stream gauge – operated by the GRCA – immediately upstream of the reach, and the Grand River at Galt stream gauge located downstream of the reach. The Speed River, a large tributary, joins the Grand River mid-way through this reach.

This is a regulated reach of river; in excess of 60% of the upstream drainage area is regulated by upstream reservoirs. These reservoirs are operated to reduce floods and to maintain a minimum summer low-flow of 9 m^3/s, between May 1st and October 31st. The low-flow target is intended to maintain flows for effluent assimilation and water supply. The minimum flow target is currently a flat line flow target that was established as part of the Grand River Basin Water Management Study, GRIC 1982.

The water taking by Waterloo Region from this reach is currently an intermittent taking, meaning water is taken for only a portion of the day. The intermittent nature of the taking at the present time can cause fluctuations in flow of $\pm$ 0.9 m^3/s, or approximately 10% of the low-flow target through this reach of river.

A continuous water quality monitoring station, a continuous water quality model, and a long-term Provincial Water Quality Monitoring (PWQM) site exist for this reach. The Grand River at Blair reach is nutrient-rich; aquatic plant growth in the summer period can cause large daily variations in dissolved oxygen. Historically, minimum dissolved oxygen values could dip below the provincial objective of 4 mg/L during summer warm spell periods. The aquatic plants have an additional effect on the river hydraulics by backing water up in the order of 0.3 (m). The littoral zone on the fringe of the river can be affected by accumulation and decomposition of aquatic plants, creating anoxic conditions (Yerex, 2004, pers. comm.).

5.2.1 Field Program for the Grand River at Blair Reach

The field program included the collection of geomorphic cross sections and substrate data for use in estimating geomorphic thresholds for this reach. The geomorphic cross sections also provided base information used to construct a HEC-RAS model, which can model the low-flow hydraulics through this reach.

Detailed hydraulic cross sections were collected for a portion of this reach in the fall of 2002. This information was integrated with more recently collected cross sections as part of the current field program. The locations of the cross sections can be seen in Figure 5.2.

Staff gauges were installed upstream and downstream of this reach and were used to develop rating curves to calibrate the HEC-RAS model. Due to the influence of aquatic vegetation (weeds), both weed affected and non-weed affected HEC-RAS models were developed for analysis purposes.

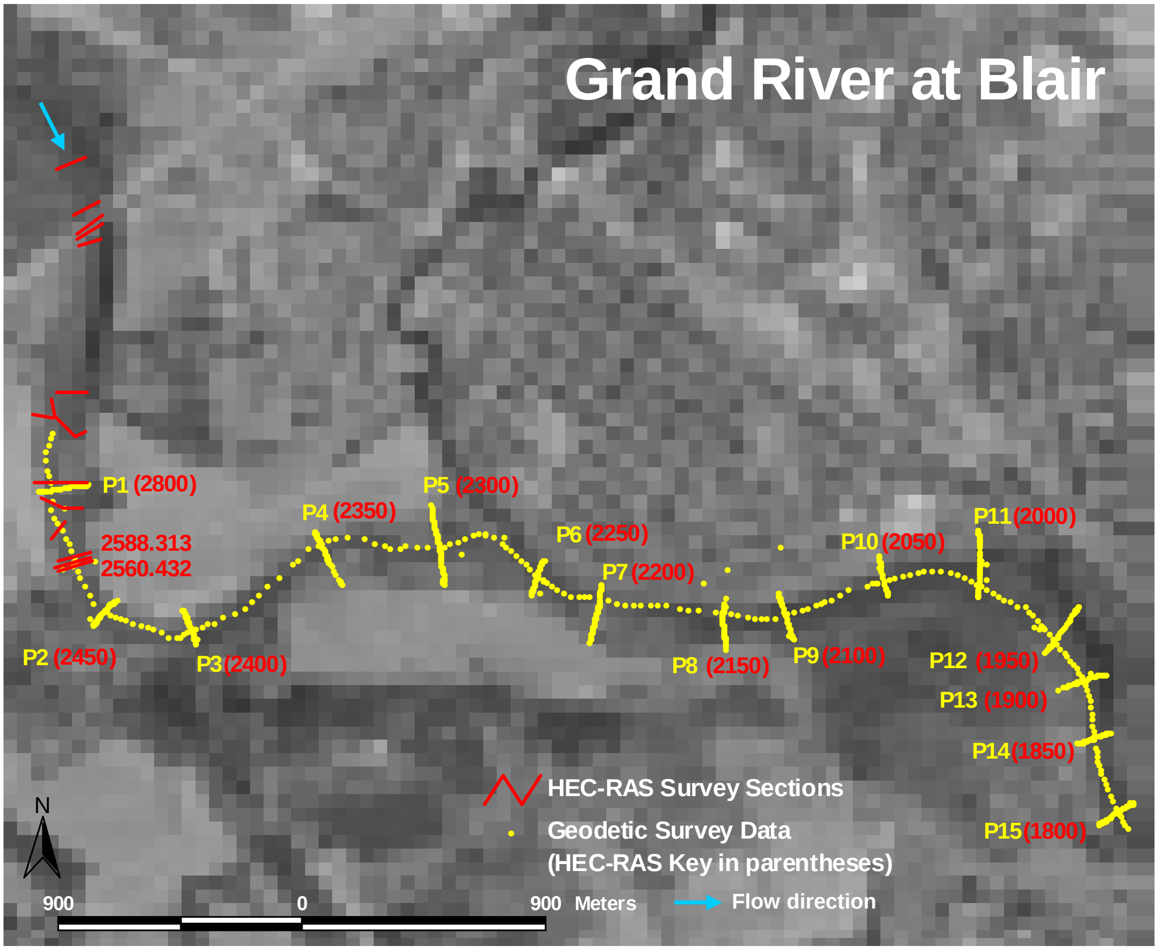


Figure 5.2 Geodetic and other cross sectional profiles on the Grand at Blair Reach

5.2.2 Case Study

Analysis of the Grand River at Blair reach will provide an example of implementing instream flow approaches on a regulated reach of river and will investigate how these approaches could be put into operation. The largest surfacewater takings in this watershed are the major reservoirs, operated by the Grand River Conservation Authority. The effects of these takings on this reach were analyzed using the IHA software. This case study will be combined with the Grand River Exceptional Waters reach to investigate how takings and regulation affect each reach.

5.3 Grand River Exceptional Waters Pilot Reach

The Exceptional Waters Reach is located in the central lower portion of the Grand River, which stretches between the Town of Paris and the City of Brantford. The reach is bounded at the top by the Penman's Dam in Paris and downstream at Cockshutt Bridge in Brantford. The river valley is a part of the Carolinian forests of Southern Ontario and is known for its biodiversity and uniqueness of habitats. This reach provides habitat to several species such as smallmouth bass, walleye, northern pike, brown trout and rainbow trout. Significant groundwater contributions occur along this reach.

The watershed area upstream of this reach is essentially a large portion of the Grand River watershed. Approximately 30% of the upstream area in this reach is regulated by major reservoirs; therefore the effects of regulation are less dominant in this reach than in the Grand River Blair Reach, where greater than 50% of the upstream drainage area is regulated by upstream reservoirs. Comparison of the reaches together will provide a better indication of the effects of reservoir regulation and water taking on different reaches of the main Grand River.

Low-flows in this reach are regulated by upstream reservoirs. As part of the Grand River Basin Study, GRIC 1982, a low-flow target of 17 m^3/s is maintained at Brantford. The minimum flow target is intended to ensure sufficient water is available to assimilate treated effluents from sewage treatment plants and to provide sufficient water for water supply purposes. Water takings for aggregate washing occur along this reach. The City of Brantford municipal water taking occurs immediately downstream of the Exceptional Waters reach and upstream of the Brantford stream gauge station. This gauge station has a period of record dating back to 1948; however the record is affected by the addition of two major reservoirs, Conestogo Dam in 1957 and Guelph Dam in 1976, and the changes in reservoir operating policies over this period. The current reservoir operating policy has been in place since 1978, therefore the 1978 to 2003 period of record was used for analysis purposes.

Hydraulic habitat assessment work, relating habitat to the aquatic community that is dependent on this habitat, has been completed in this reach of river. This information was collected for different objectives; work completed as part of this study built on the previous fieldwork.

Previous hydraulic information was collected during low-flow periods in 2001, when over 100 cross sections were collected. It was noted during the collection of this field information that fringes of the river were anoxic due to the breakdown of aquatic vegetation (Yerex, 2004, pers. comm.). Collection of the cross section information was difficult even during low-flows. Some pools were not accessible and benchmark information had to be brought in from far outside the reach. The work completed in 2001 was, as such, more a study in developing a process or approach to collecting cross section, flow velocity and aquatic data in a large river setting. Considerable effort had to be spent organizing, checking and structuring the previously collected information for use in the current study.

Another aspect of this reach is its affinity for ice jams. Ice jams are common due to the frazil ice that can be created in the reach of river immediately upstream of the Exceptional Waters reach between Cambridge and Paris. Frequent ice jams have the ability to reset habitat in this type of reach that could be classed as an active fluvial reach.

5.3.1 Field Program for the Exceptional Waters Reach

The field component for this reach consisted of organizing the previously collected information and referencing this information to a proper survey datum. Once the information was referenced to a common datum, cross sections were extracted. These cross sections were used to complete geomorphic analysis and to construct a detail HEC-RAS model for this reach. Field reconnaissance was completed to tie temporary bench marks into surveyed bench marks and to collect substrate information to facilitate the calculation of geomorphic parameters. Observed water elevations were also extracted from previously collected information and used to check the accuracy of water elevations produced by the HEC-RAS model constructed for this reach of river.

The Exceptional Waters reach was further divided into 2 sections, one above and the other below, the outlet of Whitemans Creek. The reach was divided to facilitate the collection and processing of the information for this larger river reach and to account for the addition of tributary flow from Whitemans Creek, a significant coldwater tributary. See Figure 5.3 for the survey locations on the Exceptional Waters reach.

5.3.2 Case Study

This study investigates, from a hydraulic perspective, the flows needed to flush the fringes and how these flows relate to the current low-flow target for this reach. Analysis similar to the work on the Grand River at Blair reach will be carried out to determine the influence of major reservoirs on this reach and how instream flow requirements for this reach can be operationalized.

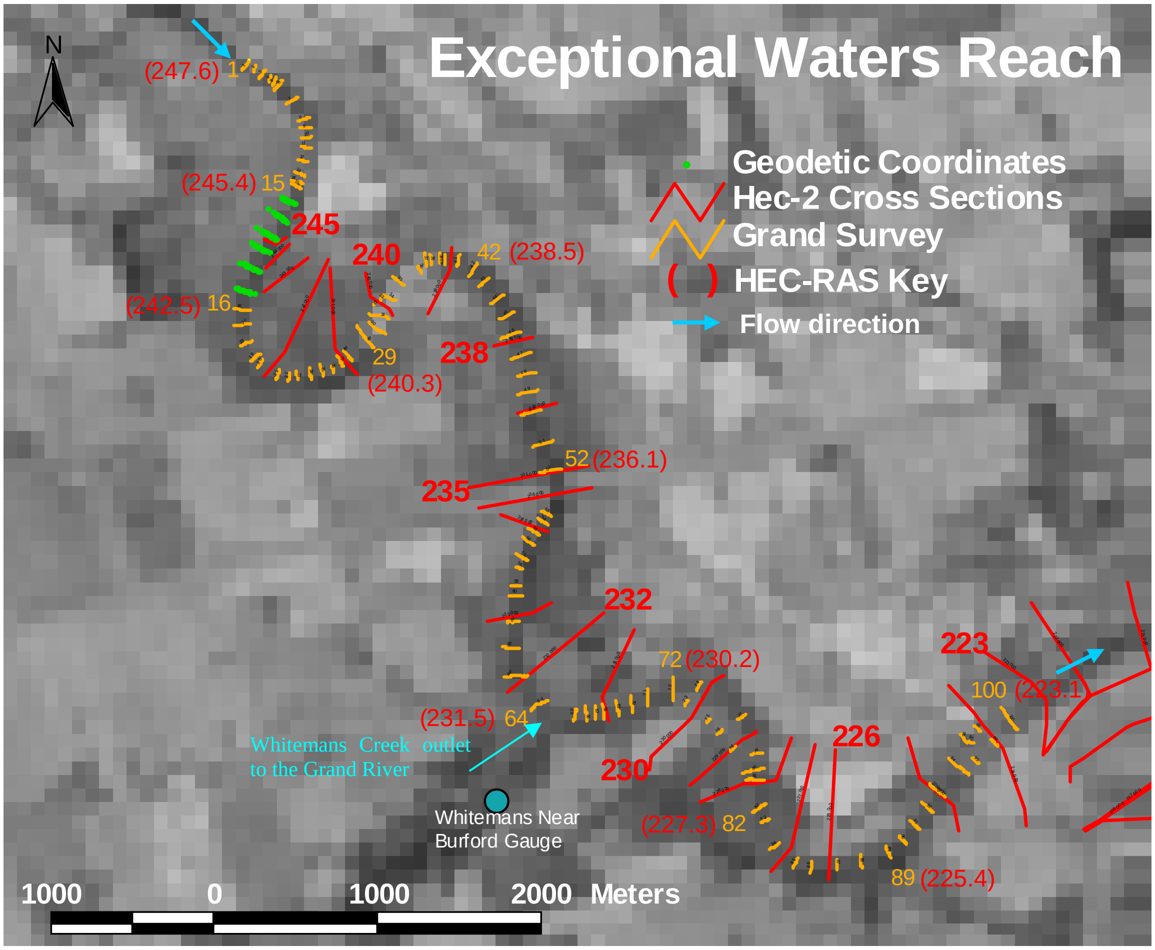


Figure 5.3 Cross section locations for the Exceptional Waters Reach

5.4 Nith River at Canning Pilot Reach

The Nith River is one of the major tributaries of the Grand River, draining one sixth of the Grand River Watershed. The Nith River flows through the western side of the Grand River watershed, and outlets just below the central portion of the watershed in the Town of Paris. The northern half of the Nith River Watershed is till plain and the southern half is primarily granular material associated with the Waterloo Moraine and the Norfolk Sand Plain. The southern portion of the basin has agricultural water taking pressure and the Waterloo Moraine is the principal source of the Region of Waterloo's municipal water supply. This reach could also be classed as an active fluvial reach.

The watershed area is comprised mostly of agricultural lands, but also includes the Towns of New Hamburg, Plattsville, Ayr and Paris. Water quality in the Nith River is generally considered fair to nutrient-rich, based on nitrate and phosphorus levels (Cooke, 2004). This is likely due to the intensive agricultural sector in the watershed and a low percentage (around 10%) of forest cover across the watershed. This subwatershed is one of the most intensively agricultural regions of the Grand River watershed. The Nith River supports migratory fish species and resident warmwater fish including smallmouth bass, pike, rainbow trout, walleye, carp and some species at risk. There are significant groundwater contributions in the lower reaches of the Nith River downstream of New

Hamburg. During summer low-flow periods, in excess of 3 m^3/s of groundwater discharge can enter the lower half of the Nith River.

A stream gauge has been operated near the village of Canning by Environment Canada, dating back to 1948. This is an unregulated watercourse and is one of the Ontario Low Water Response indicator gauges. A long-term monthly water quality station also exists at this site.

In 2001 and 2002, Environment Canada conducted research to construct a hydrodynamic model of the reach surrounding the gauge (approximately 1 km upstream and downstream of the gauge). Environment Canada intended to pilot the use of the model to estimate the level (stage) versus flow rating curve at this site. The hydrodynamic model can also be used to report on other hydraulic characteristics of the channel at this location. It is uncommon to have the density of bathymetry information present at this site. Bathymetry information was available on approximately a 1 to 2 metre grid over the kilometre of river surveyed by Environment Canada. This reach is unique given the long flow record and detailed hydraulic information.

5.4.1 Field Program

The first component of the field program for this reach included constructing a detailed digital elevation model (DEM) for the entire 1 kilometre reach. The DEM, provided by Environment Canada, was primarily a below-water DEM. An above-water DEM was created using orthophotography. The two DEMs were merged to create a seamless above- and below- water DEM over the 1 kilometre study reach. Cross sections were extracted from the seamless DEM and a HEC-RAS model was constructed.

The detailed and HEC-RAS cross sections for the Nith River at Canning reach can be seen in Figure 5.4. A closer look at the detailed cross sections can be seen in Figure 5.5, as well as the location of the stream gauge station.

In the late summer of 2004, a geomorphic survey was completed by *Parish Geomorphic*. The purpose of this survey was to collect geomorphic cross sections and substrate information to facilitate calculation of geomorphic parameters and to check the bathymetry information provided by Environment Canada. The geomorphic survey also included a longitudinal profile used to check the calibration of the HEC-RAS model developed for this reach.

5.4.2 Case Study

A case study was completed that compared flow, hydraulic and geomorphic indices for the Nith River at Canning pilot reach. A naturalized flow series and impacted flow series was analyzed with IHA software. Issues associated with analyzing cumulative takings were investigated. A comparison of information available from the hydraulic model was compared with spatial information available for this reach to analyse the benefits a detailed DEM provides versus what can be derived from a detailed hydraulics model.

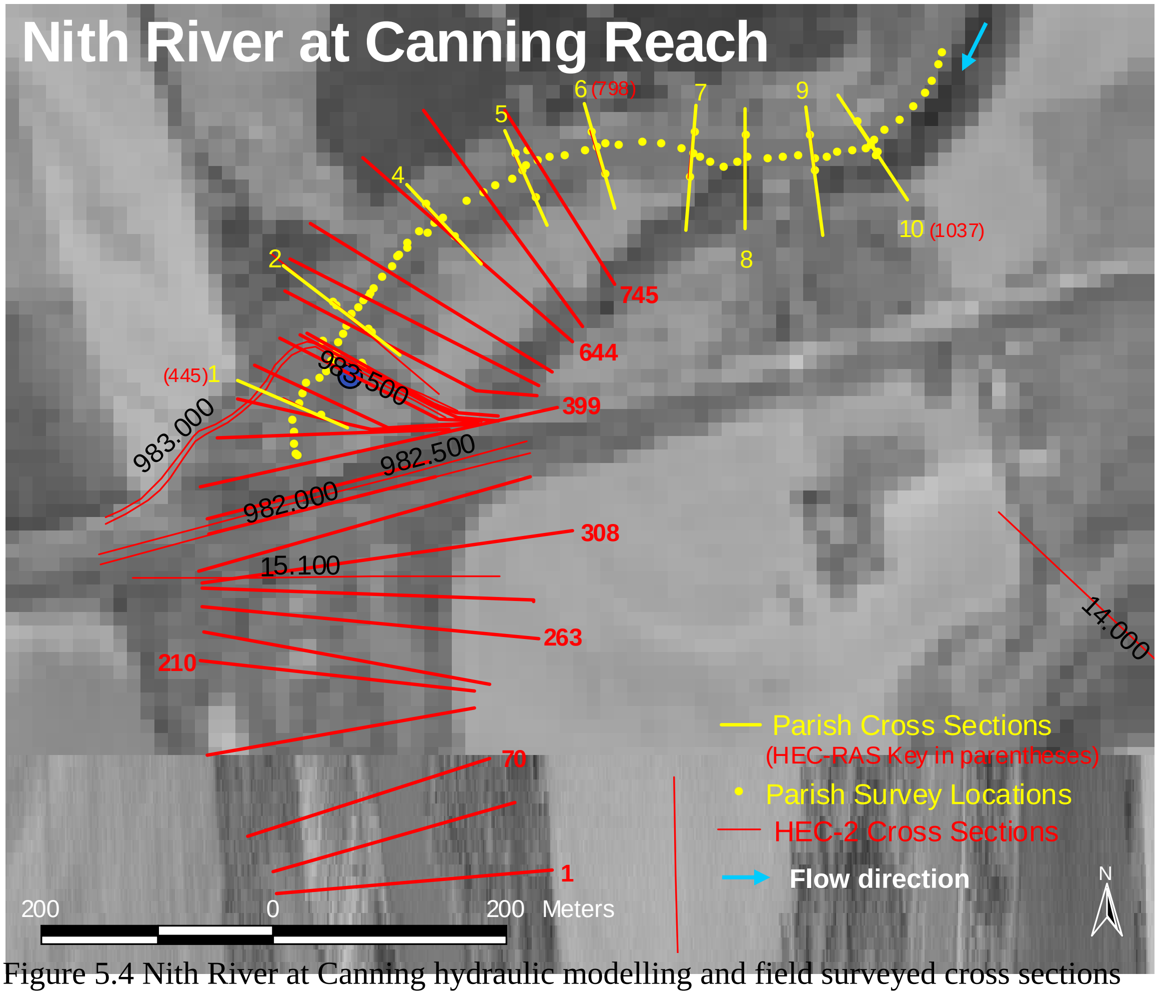


Figure 5.4 Nith River at Canning hydraulic modelling and field surveyed cross sections

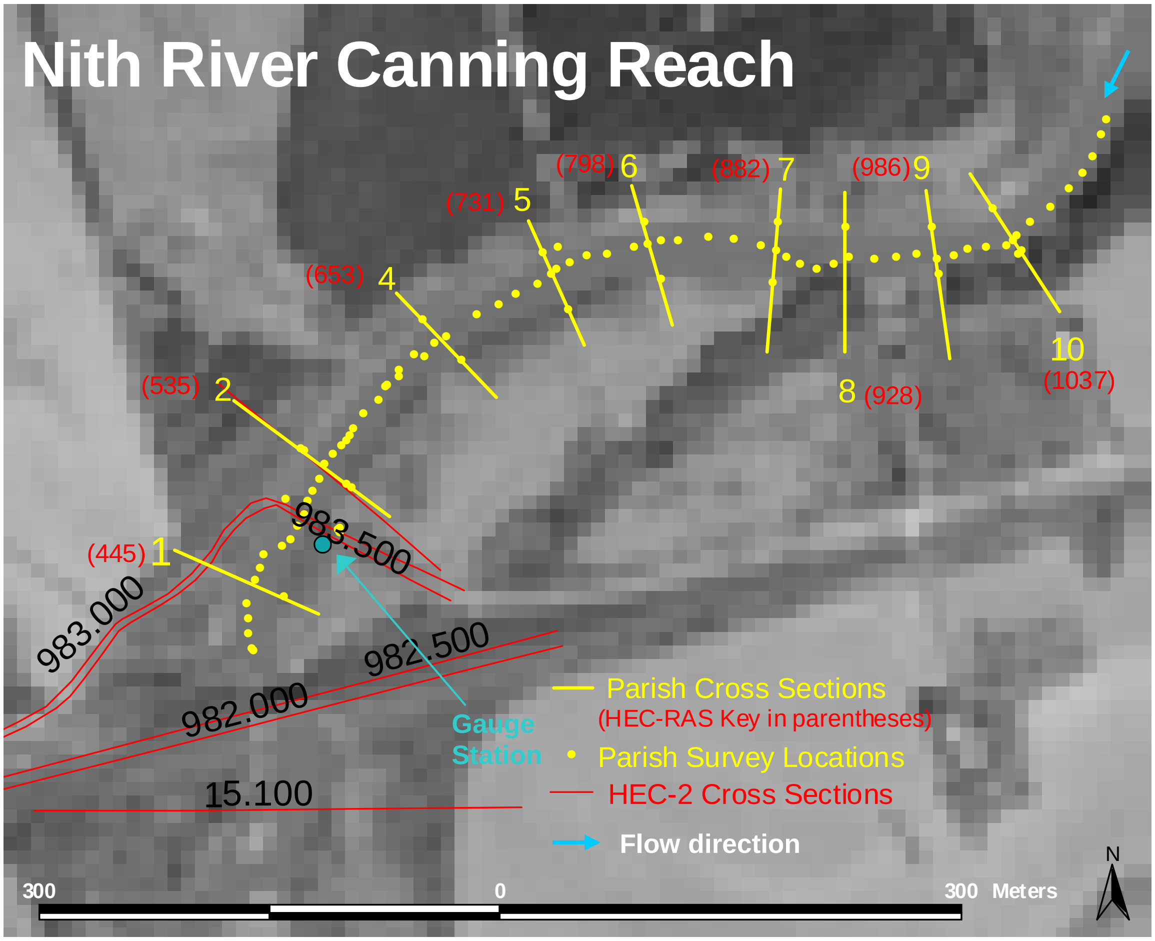


Figure 5.5 Cross Section Survey Locations on Nith River at Canning Reach

5.5 Eramosa River Pilot Reach

The Eramosa River is located on the eastern side of the Grand River Watershed just northeast of the City of Guelph, joining with the Speed River in the city. It is a medium sized river with significant groundwater discharge. The headwaters of this river are in the northwest portion of Erin Township, and drain a significant portion of the Orangeville Moraine and the Paris Moraine. Water quality in the Eramosa River is generally high, even during the summer months. However, due to the dependence on the water table, this river is extremely vulnerable to droughts and water takings. In recent years, due to lower than average rainfall, flows have receded to Level 3 Low Water conditions, which have lowered the amount of groundwater recharge.

The City of Guelph has a municipal surfacewater taking permit used to recharge a shallow groundwater collection system that forms part of the City of Guelph Municipal Water Supply. With the exception of the City of Guelph taking, this river has limited permitted water takings.

The Eramosa River watershed has the most extensive network of forest habitat in the watershed. Valleys between the numerous hills of the Guelph Drumlin field are typically covered by large forests, while the lowest elevations are swamps and floodplain areas.

The Eramosa River Reach (Figure 5.6) is just above Watson Road in Guelph, where a stream gauge is located. This is a good example of an unimpacted system that is facing increased demands for water taking. This is also a long-term PWQM site.

The Eramosa River valley is a previous glacial meltwater channel. The river channel itself is incised in the bed of the meltwater channel. The characteristics of this reach make it a less active fluvial channel than other study reaches.

5.5.1 Field Program for the Eramosa River

The field program for the Eramosa River reach primarily consisted of collecting geomorphic cross sections, profiles and substrate information. The geomorphic information was used to complete geomorphic analysis for this reach and to provide the basis for a detailed HEC-RAS model.

The HEC-RAS model for this reach was calibrated against the Environment Canada Watson Road gauge station data and against the profile information collected as part of the geomorphic survey.

Relevant information was extracted from the Eramosa Subwatershed plan and water supply studies for this reach.

5.5.2 Case Study for the Eramosa River

A case study was completed on this reach, which examined impacts of taking. The IHA software was applied to analyse the changes in the hydrologic and hydraulic parameters in response to existing or potential water takings upstream of this reach. This case study provides an example of how instream flow techniques can be applied along with issues associated with cumulative takings.

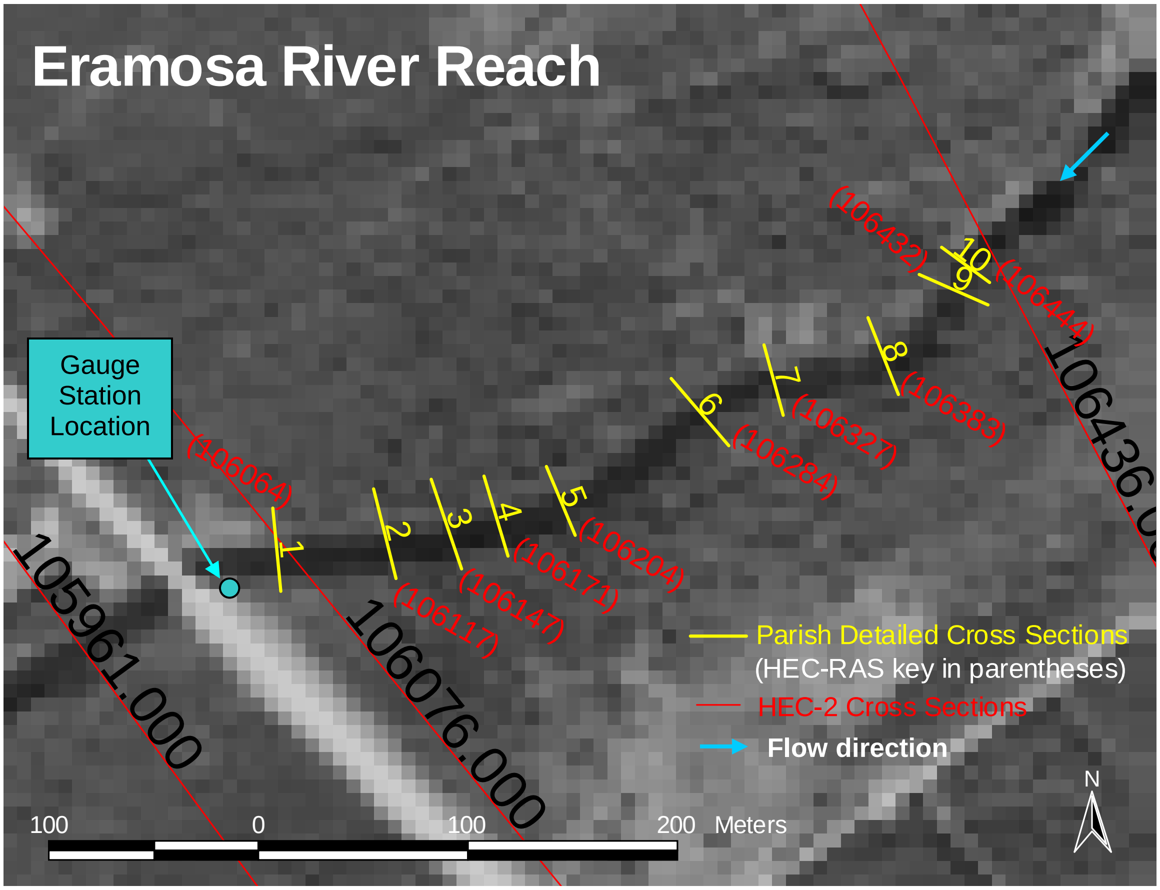


Figure 5.6 Locations of Eramosa River Detailed Cross Sections

5.6 Blair Creek Pilot Reach

The Blair Creek reach and subwatershed is located in the central portion of the Grand River watershed. Blair Creek runs through the southern portion of the City of Kitchener, on the southern flank of the Waterloo Moraine. This is a small, coldwater tributary of the Grand River and is the smallest subwatershed of the pilot reaches, with a drainage area of 14.86 km^2.

Currently, there is limited direct surfacewater runoff. The predominant underlying geology is coarse granular material and there are also several internal drainage areas that are not directly connected to the stream. In addition to a shallow surfacewater aquifer that drains to this stream, the regional groundwater aquifer associated with the Waterloo Moraine discharges to this stream. The combination of limited surfacewater runoff and regional groundwater discharge act to reduce the variability of streamflow. This stream can be characterized as a very groundwater driven stream within an urban area undergoing development. The substrate material in this stream is very fine. Relatively small changes to streamflow can change the fluvial characteristics of this stream that will result in channel adjustment. The reach can be classed as an active fluvial stream.

An extensive study has been completed for this subwatershed along with detailed groundwater and surfacewater models. Large portions of this watershed are scheduled for development within the City of Kitchener or in designated aggregate extraction areas. A stream gauge has been operated on this watershed since 1998.

The Blair Creek subwatershed study identifies concerns related to the management of water resources in this subwatershed. The subwatershed is currently going through some major landuse changes that have potential to negatively impact the hydrology and ecology of the subwatershed.

This study site was chosen to examine how instream flow techniques could be applied to an urbanizing watershed. Instream flow requirements are needed to manage both water takings and urban impacts in this watershed. Land development in this watershed will have to maintain groundwater recharge. This will be a challenge; instream flow requirements will be one of many criteria used to set post-development objectives.

5.6.1 Physical Attributes of the Blair Creek Watershed

The Blair Creek 1997 Subwatershed Report included only a portion of the watershed, and also incorporated the adjacent Bechtel and Bauman Creeks in the subwatershed studies. The study provides some background information on the physical attributes of the watershed. A brief description of the Blair Creek subwatershed is given here.

Blair Creek is a groundwater-fed, coldwater stream that supports aquatic species such as brook trout in certain reaches. The watershed area contains provincially significant wetlands and other natural areas of scientific and aesthetic interest. There is concern that the development in certain areas will negatively affect the fishery, the wetland areas and surpass the available water supply of the watershed. Thus, the comparison of the current watershed conditions to a synthesized future watershed condition, of projected urbanization, will be the basis for the case study for this reach.

The attributes of the soils differ across the watershed. They include hummocky soils, well drained soils and soils that are dense and have low infiltration capacity. The Waterloo Moraine encompasses the headwaters of Blair Creek, and is characterized by sands and gravels, as well as sand/silt tills, and sandy loam soils with medium permeability. This area will promote sizeable infiltration and moderate runoff patterns. The Roseville Swamp creates another functional unit, as a poorly drained and flat region of the watershed. This area is important for attenuation of runoff from the watershed; and as a region of baseflow conveyance to the creek, especially during dry periods. The Blair Creek Wetland area is also notable for considerable groundwater inputs to the stream and thus supports a self-sustaining brook trout fishery in this portion of the creek. Further, more detailed information can be found in the Blair Subwatershed study (CH2M Gore and Storrie *et al*., 1997).

5.6.2 Field Program

The geomorphic fieldwork was completed by field crews from *Parish Geomorphic.* Full geomorphic studies were completed in December of 2003, including long profiles, cross sections, and flow and substrate analysis. The study site can be seen in the purple circle in Figure 5.4.

Figure 5.7 Detailed geomorphic field location on Blair Creek

A detailed HEC-RAS model was developed from the cross section information collected by *Parish Geomorphic*. This model was calibrated to the water level information collected as part of the Parish survey. Detailed cross sections for the Blair Creek reach are shown in Figure 5.8. The key to the hydraulic modeling of the cross sections by HEC-RAS software are also shown on the map.

This reach also serves as a pilot reach to investigate the application of stable isotope analysis. Mike Power of the University of Waterloo collected isotope and benthic samples through this reach for analysis and testing of the ecological condition of the reach using this method. Stable isotope information was also collected for analysis from Bechtel Creek, an adjacent ungauged tributary, as part of this study.

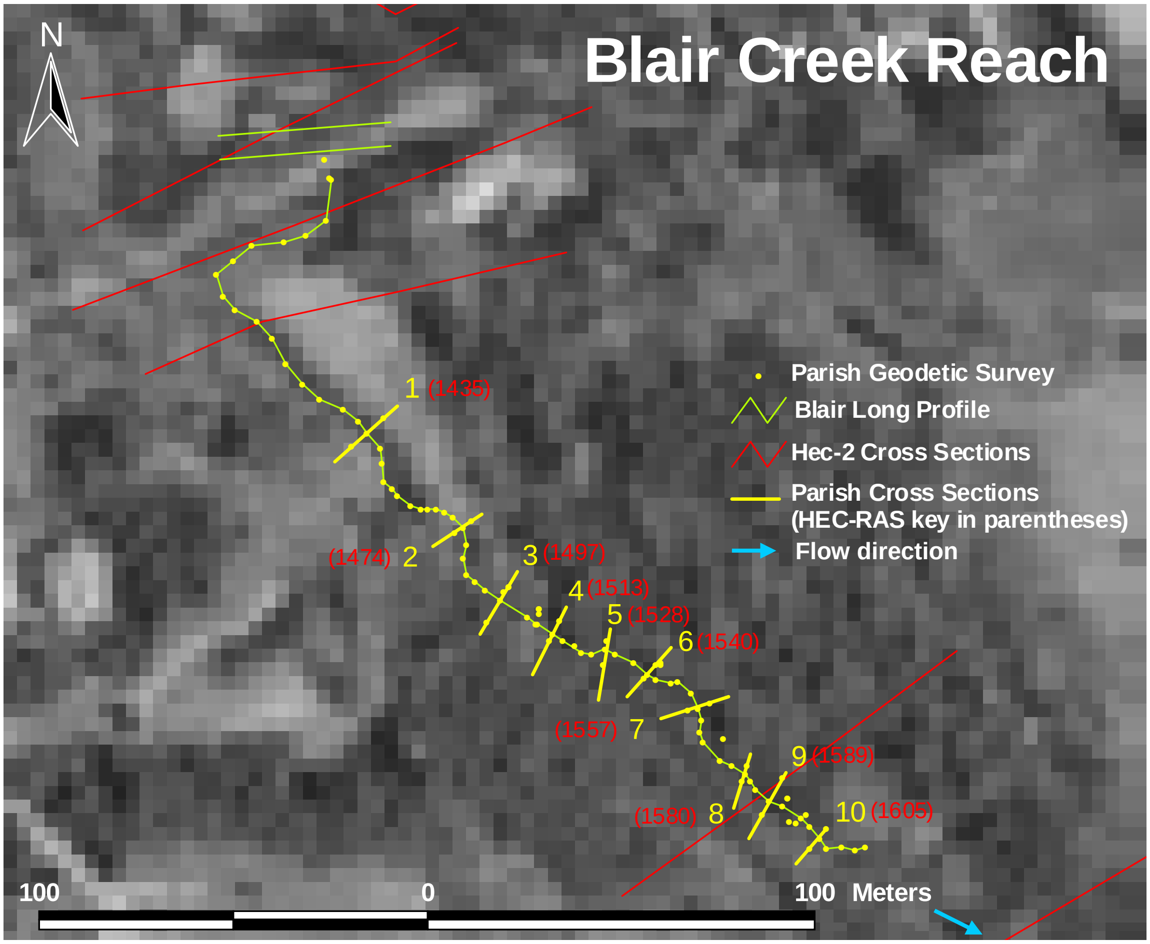


Figure 5.8 Blair Creek long profile and cross sections locations

5.6.3 Case Study

The monitoring of watershed conditions has only been occurring for a short time; the period of record is too short to carry out any streamflow analysis. To extend the available streamflow information, the Guelph All-Weather Sequential Events Runoff (GAWSER) model created by a consultant (Stantec) for the Blair Creek Servicing Study, was obtained. The simulation period for the model was extended from 1960–1999 to 1960–2003, to allow comparison against observed streamflow information obtained since the installation of the stream gauge. The model was used to simulate pre-development and post-development flows. The 'pre-impact condition' would simulate the current conditions over the years from 1960 to 2003. The projected urbanization condition would use the same watershed data, but with the percentage of impervious surfaces increased to 45%, to simulate a "post-impact condition", spanning the years between 2004 and 2047. The post-impact condition included mitigation measures. The simulated information was organized to analyse the results with the IHA software and investigate how instream flow methods might apply to the Blair Creek Watershed.

The details of the two simulation conditions are as follows:

Pre-impact condition: existing condition of less than 1% impervious surfaces.

- Modeled in GAWSER with current climatic conditions and existing land cover characteristics.

Post-Impact Condition: estimated condition of approximately 45% impervious surfaces to simulate a more urbanized landscape.

- Issues with run-off and infiltration
- Use IHA software to analyze changes in specific hydrologic and hydraulic parameters. Changes were also compared to geomorphic thresholds to assess potential impacts from a geomorphic perspective.

5.7 Whitemans Creek Pilot Reach

Whitemans Creek is a tributary of the Grand River located in the lower, southwestern portion of the Grand River Watershed. The creek outlets to the Grand River just north of the City of Brantford. It is similar to the Nith River in that the northern portion of its watershed is till plain and the southern portion is sand plain.

Over the period from 1961 through 1992 there were three Water Survey of Canada (WSC) gauges operated in this watershed. Two gauges, the Kenny Creek and Horner Creek gauges, were dropped in 1991. The Whitemans Creek near Mount Vernon gauge continues to operate and provides a period of record from 1961 through 2003. This gauge is located at the upstream end of the study reach; records at this gauge have been affected by agricultural water takings. This is an Ontario Low Water Response indicator gauge and is also a long-term PWQM site.

The Whitemans Creek pilot reach was chosen due to the continuing drought issues this region faces nearly every year. This Creek is subject to heavy irrigation demand on both groundwater and surfacewater. The burden of large extractions from both groundwater and surfacewater for irrigation is a concern for the Whitemans Creek watershed. Investigation of this reach provides an example of establishing instream flow techniques in an area where heavy demand exists and cumulative effects are an issue. Instream flow targets are required for this stream given the heavy demand for water during the irrigation season.

The Whitemans Creek pilot reach was the focus of some aquatic biota sampling between 1987 and 1996 by the MNR and the GRCA. The coldwater fishery in Whitemans Creek enabled some mark and recapture studies to be done previously for different objectives. This information was used in the current study to try to correlate low-flows to fish populations. Further information and results can be found in Chapter 8.

A master’s thesis was completed in this reach by Mark Hartley in 1999. Information from this master’s thesis was used as a starting point with respect to hydraulic modeling and geomorphic analysis.

5.7.1 Description of Physical Attributes

The Whitemans Creek watershed is predominantly used for agriculture, with small hamlets of dispersed rural populations. The Norfolk Sand Plain is a dominant feature, having well-drained soils contributing to the high permeability of the land, and low runoff capabilities. The shallow unconfined aquifer is relatively well connected to surfacewater and contributes baseflows to the Creek, which is especially significant during low-flow periods. Agricultural crops in the watershed such as tobacco, potatoes and sod require multiple irrigation applications during the growing season that contribute to the high demands for water during the dry periods of the year.

This Creek is a high quality groundwater-fed coldwater stream through its lower reaches, which supports brown trout and rainbow trout populations and is considered a pristine watercourse. This stream actually gets colder as it moves downstream through the Norfolk Sand Plain from Burford to the confluence with the Grand River. Upstream, the creek supports northern pike and smallmouth bass.

5.7.2 Field Program

The locational overview of the study site can be seen in Figure 5.9, and a more detailed view of the cross section locations is shown in Figure 5.10.

The fieldwork consisted initially of relating the cross sections from the Hartley master's thesis to a common survey datum and using this information to construct a detailed HEC-RAS hydraulic model to estimate hydraulic relationships. M.M. Dillon consulting engineers were contracted to carry out an invert survey and relate cross sections collected from the previous thesis work to a common datum. This field component was completed in the summer and fall of 2003. After analyzing the results of this work, it became apparent that additional cross section information was required, along with substrate information to facilitate calculation of geomorphic thresholds.

Parish Geomorphic was contracted to collect additional information in late August 2004 to compliment work completed by M.M. Dillon. A detail HEC-RAS model was then developed and calibrated. Results from the detailed hydraulic modelling were used by Parish to develop geomorphic thresholds for this reach.

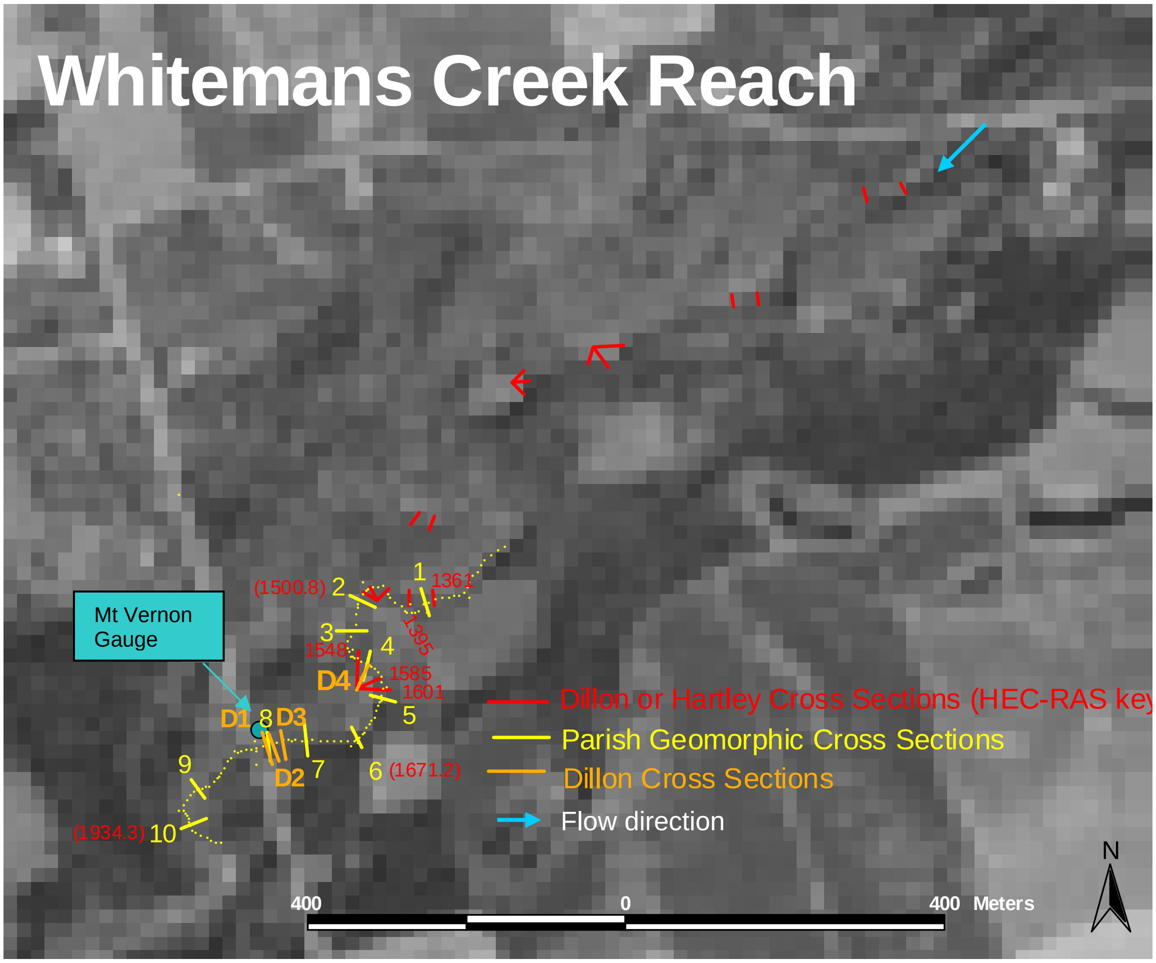


Figure 5.9 Overview Whitemans Creek cross section locations

5.7.3 Case Study

The case study for the Whitemans Creek reach consisted of two components. The first component followed a similar approach to other reaches. Flow, hydraulic, geomorphic and desktop instream flow indices were developed. Flow information was analysed with the IHA software and compared to upstream water takings.

The second component of the case study consisted of analyzing the MNR biomass data available for this reach and assessing correlations between biomass and flows. This was carried out to investigate the possibility of using biomass information to help infer instream flow requirements.

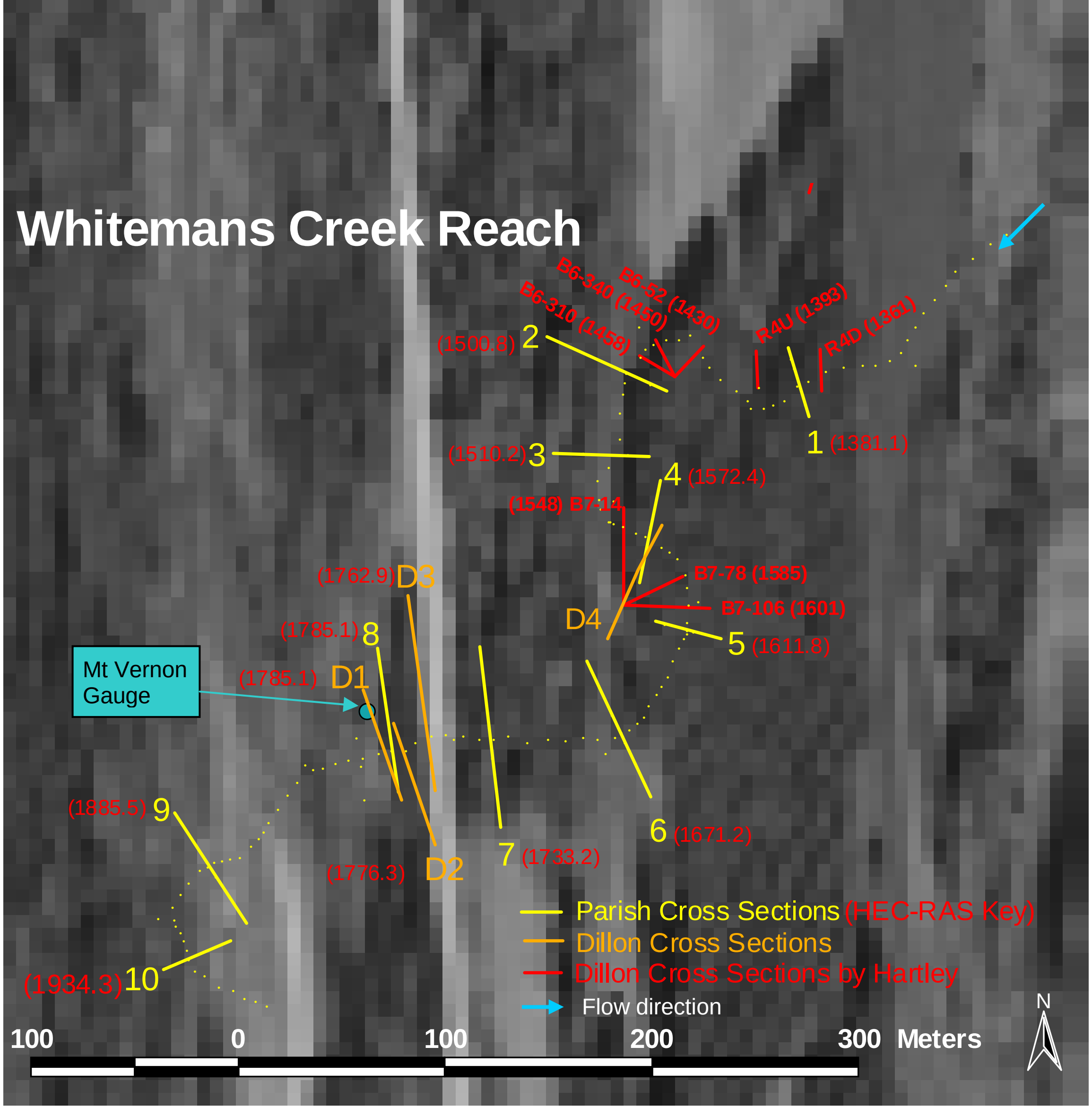


Figure 5.10 Whitemans Creek detailed cross section view

5.8 Mill Creek Pilot Reach

The Mill Creek pilot reach subwatershed is located on the eastern side of the Grand River Watershed between the Paris and Galt moraines, between the Speed River subwatershed and the lower central portion of the Grand River. The creek itself is located in an outwash spillway between the moraines. Mill Creek is a tributary to the Grand River on the eastern side, and one of the small stream sites of the study.

A stream gauge has been operated by the GRCA since 1990 on this watercourse. This is an Ontario Low Water Response indicator gauge. An additional upstream gauge was installed in 2002 in this watershed.

Mill Creek has been influenced by human activities since the 1800's with agriculture, industry and urban development being the primary uses. Aggregate development has increased pressure in the last 50 years, converting forested and agricultural land. Currently, the watershed land use is diverse with agriculture, rural residential and open spaces in the headwaters, large highways (Highway 401 and the Hanlon Expressway) intersecting the watershed, and forested wetlands near the mouth of the creek.

Mill Creek was chosen as one of the study reaches due to the large takings of water from aggregate extraction posing issues for the instream flow requirements of the creek. Also, a subwatershed study was completed for Mill Creek in 1996 by CH2M Gore & Storrie *et al*. (1996) with instream flow requirements as one of the objectives. This study is a follow-up to assess other instream flow methods.

5.8.1 Physical Attributes of the Mill Creek Pilot Reach

The Mill Creek subwatershed study was completed to characterize the human and environmental systems that interact and how to better manage the subwatershed. The information below is in part taken from the subwatershed study.

Mill Creek is a groundwater-fed, coldwater stream that is located in the spillway between the Paris and Galt moraines. The main channel of this stream is incised in the glacial spillway channel. The creek is a coldwater stream that supports brown trout populations. Brook trout continue to inhabit the tributaries.

The topography of the Mill Creek subwatershed is gently rolling and the soils are predominantly medium to course in texture due to the nature of the till plains geology, and are relatively well drained. However, there are poorly drained regions of hummocky topography in the lower lying areas of the subwatershed that coincide with the Large Class 1 wetlands. It was estimated that approximately 60% of Mill Creek's total length flows through peaty, heavily forested wetlands, and thus the subwatershed is relatively adept at flood peak attenuation (CH2M Gore & Storrie, 1996).

5.8.2 Field Program

Geomorphic fieldwork was completed by *Parish Geomorphic* field crews in December of 2003. The reach that was surveyed is seen in Figure 5.11. A more detailed view of the cross section locations for this reach is seen in Figure 5.12. The cross sections collected by *Parish Geomorphic* along with the substrate information were used to estimate geomorphic thresholds for this reach.

The cross sectional information collected by *Parish Geomorphic* was used to construct a detailed HEC-RAS model to estimate hydraulic relationships in this reach. Upon calibration of the HEC-RAS model, it was discovered that additional cross section information was required. Additional surveyed cross sections were obtained by GRCA staff downstream of the study reach to facilitate calibration of the HEC-RAS model to water level information collected by the Parish survey.

Several spot flow measurements were collected in this reach to relate flows collected by the GRCA-operated Side Road 10 stream gauge, located downstream, to the study reach. Water temperature information was also collected in this reach.

This reach also serves as a pilot reach to investigate the application of stable isotope analysis. Mike Power of the University of Waterloo collected isotope and benthic samples for analysis and testing of the stable isotope method.

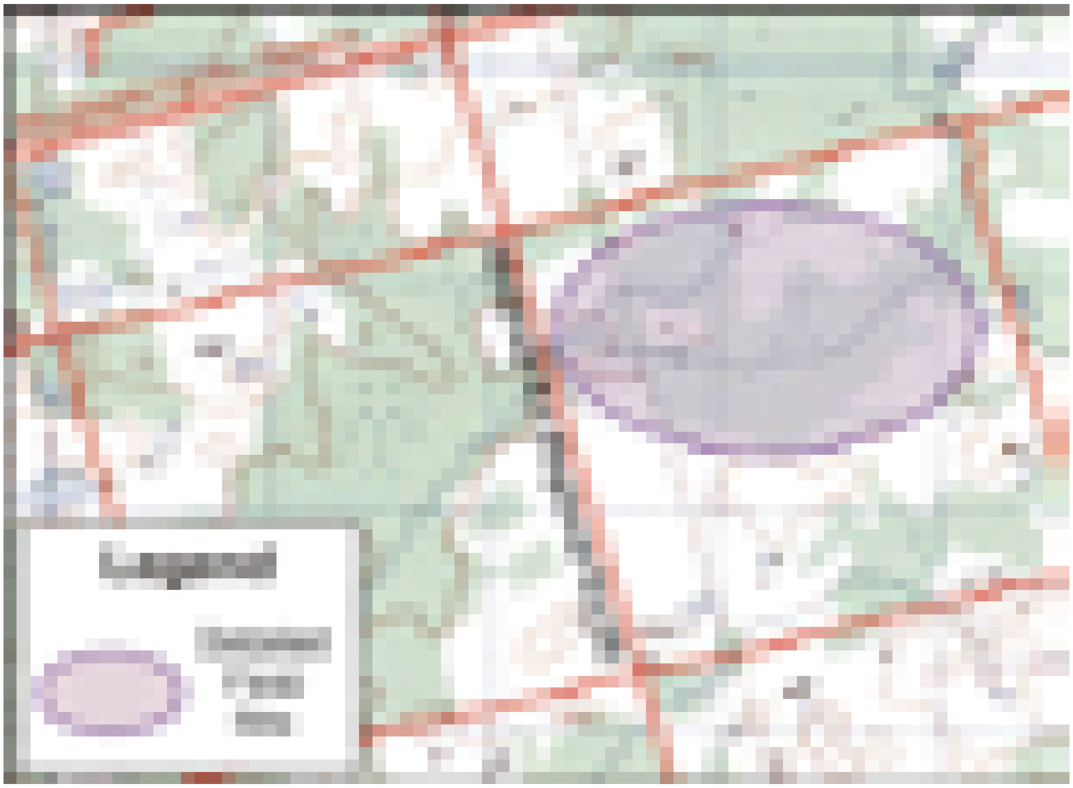


Figure 5.11 Detailed geomorphic field location on Mill Creek

5.8.3 Case Study

The case study for this reach focused on two investigations. First, the flow, hydraulic and geomorphic indices were calculated and compared, similar to the other reaches. The IHA software was used to analyse the potential impacts of takings on hydrologic and hydraulic parameters relative to indices calculated for this reach.

The second focus of the case study was the potential for erosion in this reach. John Parish of *Parish Geomorphic* noted (2004, pers. comm.) that the stream through the study reach is an E type channel according to the Rosgen classification. This implies the channel bank is stabilized by local vegetation. If the root zone of the local vegetation were dried out due to lowering of the normal stream level by takings, the vegetation may die off, triggering a channel adjustment. The discussion in Appendix C further investigates the sensitivities of this type of channel.

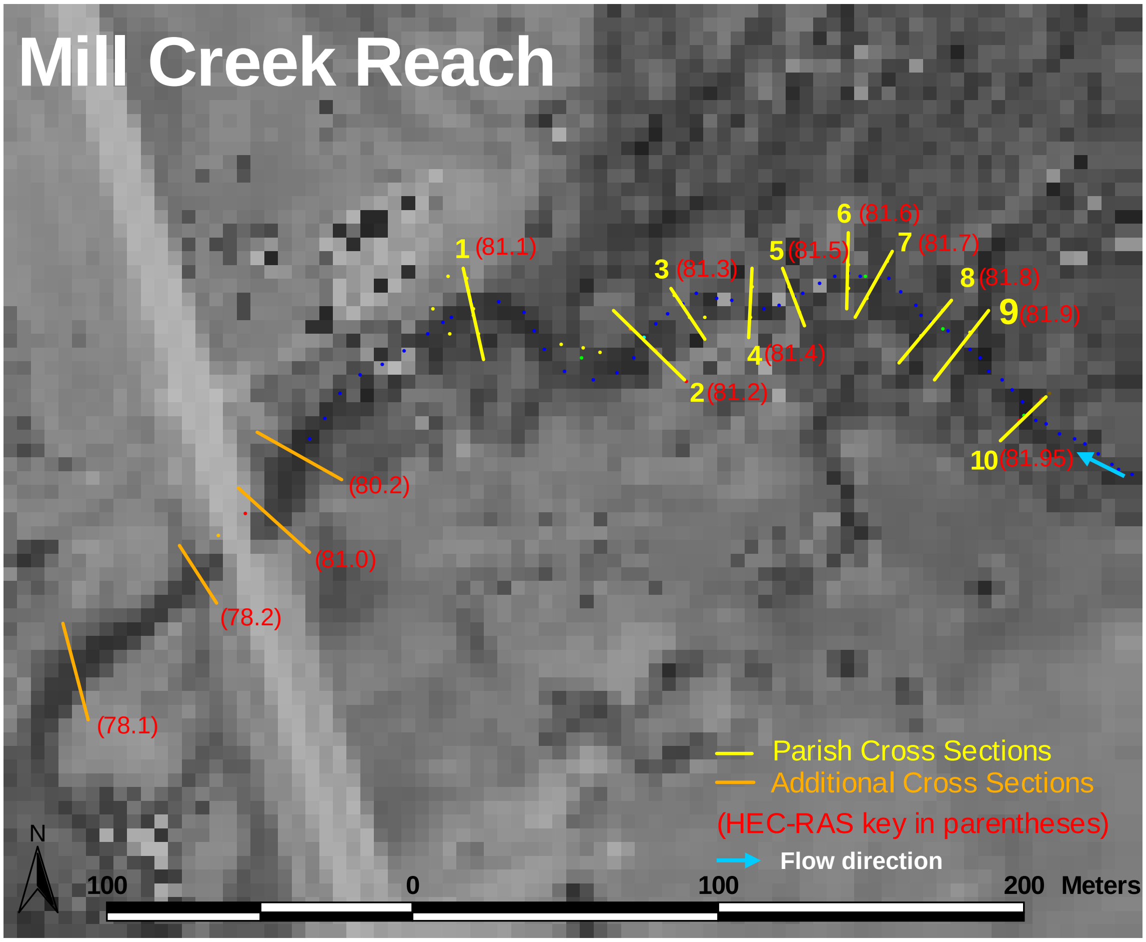


Figure 5.12 Mill Creek pilot reach cross sections and geodetic survey

5.9 Carroll Creek

Carroll Creek is a smaller tributary of the Grand River, which flows into the Grand River just south of the Town of Elora. This watercourse drains a portion of the Alma moraine to the main Grand River. It is a coldwater stream and a good example of a headwater catchment. The drainage area is approximately 45 km^2.

A streamflow gauge has been operated in this watershed since 1996 by the GRCA. An extensive biophysical study was completed by the University of Guelph and the Ministry of Natural Resrouces (MNR) to investigate the benefits of riparian buffers to watercourse health. As part of this study, extensive hydraulic surveys were completed over the lower reaches of the watercourse. The extensive amount of information compiled as part of the MNR study is uncommon; in excess of 160 cross sections were collected. These cross sections were typically collected in discrete reaches as illustrated by Figure 5.13. Although the cross sections were not referenced to a common datum, an invert survey was completed over a portion of the reach and was used to relate cross sections to a common datum.

5.9.1 Field Program

The field program consisted of collecting information to relate cross sections to a common datum and compiling field information collected in 1996 to facilitate a geomorphic analysis by *Parish Geomorphic* in this reach.

An exceptional amount of effort was expended to organize the cross section information into a HEC-RAS model. First, the cross sectional information had to be extracted from a database used to store the information for this project, and adapted to a typical two-dimensional (x,y) cross section format. Then, the cross sections had to be related to a common datum and the distance between cross sections had to be measured. Once this work was completed the cross sections were organized into a HEC-RAS model.

The other difficulty encountered in this reach was the stability of the rating curve at the gauge station. During the workup of the streamflow data, it was discovered that the rating curve is subject to backwater associated with aquatic plant growth, which results in an unstable rating curve. Thus, the streamflow data had to be interpreted and adjusted to provide streamflow estimates for this reach.

5.9.2 Case Study

The case study in this reach focused on examining the variation in hydraulic indices along the reach. A major coldwater tributary joins the main Carroll Creek channel immediately downstream of Middlebrook Road. The detailed reach information was used to investigate how hydraulic indices varied with drainage area along the creek. Analysis similar to the work completed in other reaches, including an analysis of flow, hydraulic and geomorphic indices was also completed.

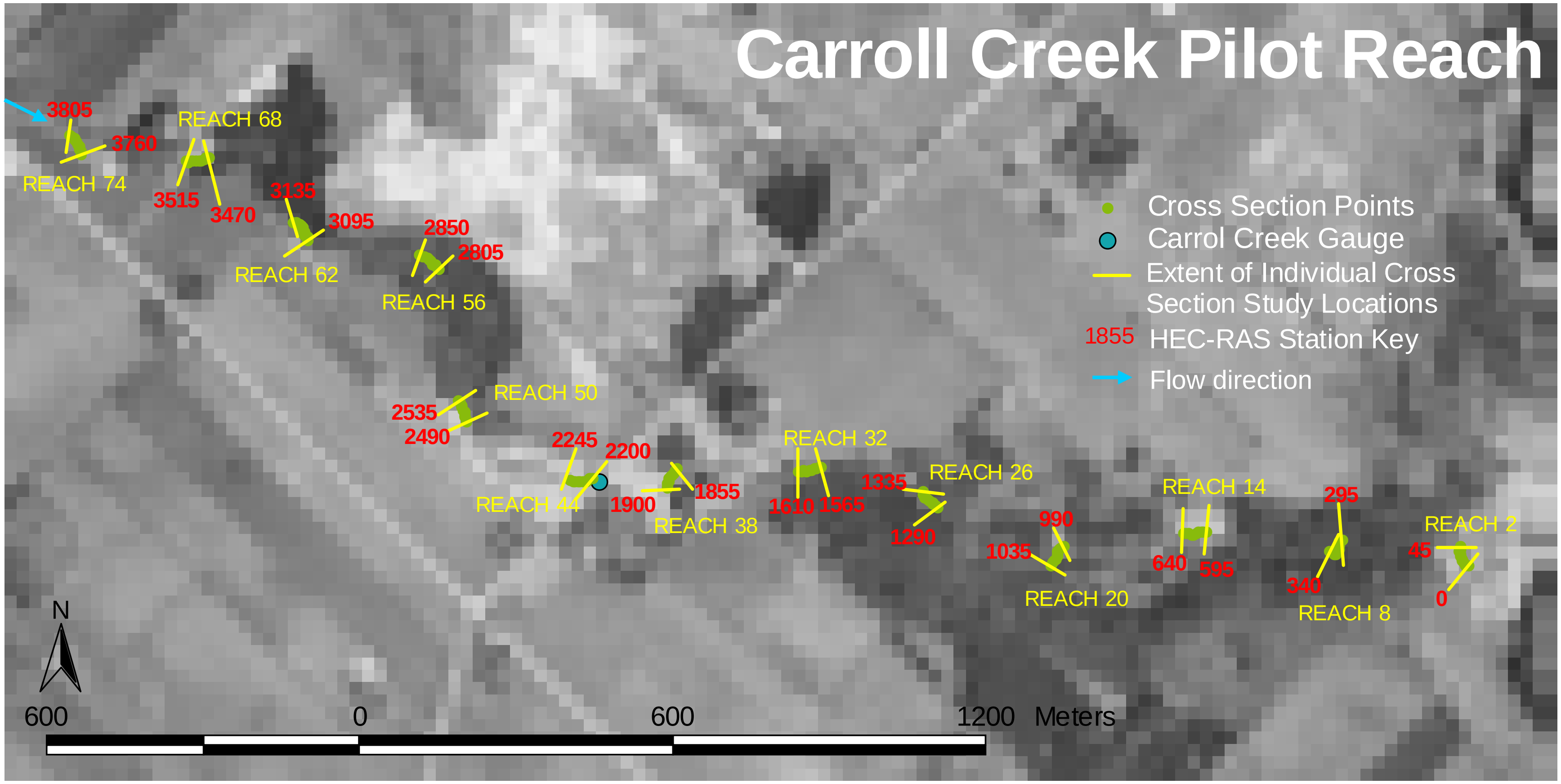


Figure 5.13 Location map of Carroll Creek cross sections

6.0 WATER USE AND WATER TAKINGS

6.1 Permits to Take Water

Water takings in Ontario are regulated by the Ontario MOE with the PTTW program. Permits for both surfacewater and groundwater are required for takings over 50,000L/day ($50m^3$/day). This chapter outlines the process taken to characterize the water taking permits in the pilot reaches. A step-by-step method similar to this process can be employed by other watershed managers to aid in the scoping of their water taking issues. Then the water takings for each pilot reach are described based on the PTTWs in its subwatershed.

6.2 Characterizing the Water Takings

Understanding the permits and subsequently the water takings includes knowing the source, location and amount of the takings. Several steps were used to characterize the water taking permits in the Grand River watershed. The steps taken to characterize the PTTWs can be applied to any study to scope out water takings and potential cumulative impacts. The steps are as follows:

1. Obtain PTTW information from the MOE
2. Characterize the permits on a Watershed Basis
    a. Spatially locate the permits in the watershed; generate maps
    b. Categorize the permits by source of supply (i.e. surfacewater or groundwater)
    c. Calculate the amount of water taking by volume and depth. Depth calculated by dividing the volume by a specific catchment area.
3. Determine whether water taking will impact the source of supply

Each step is outlined below, with examples from the Grand River watershed.

6.2.1 Obtaining PTTW Information

The MOE administers the PTTW program and grants permits for all large water users including takings for commercial, municipal, agricultural, industrial, recreational and other uses. Permits, historically, may have been granted in regions experiencing water shortages creating the potential for overtaking. Permits for water takings are granted on a maximum taking criteria, and as of yet there is little ecological basis behind the granting or restricting of permits, or the amounts of the permits. There is also no metering to determine whether the permitted amount is actually being used; metering is only required when the water taking is very large. Compliance is an issue in some subwatersheds of the Grand River Watershed; Whitemans Creek being one area with potential compliance issues.

The PTTW information can be obtained from the MOE on a permit basis. The information includes: the source of the supply (surface or groundwater); the general and specific use; the holder of the permit; the amount of the water taking; and the time frame for the permit. This information is useful in the next step of characterizing the permits.

6.2.2 Characterizing the Permits on a Watershed Basis

The location of the permits, in UTM coordinates, is included in the MOE database, which allows the permits to be spatially referenced on a map. The location of the permit pinpoints the subwatershed where the water taking will occur, which can then be compared to the availability of supply for that subwatershed. It is useful to separate the surfacewater and groundwater components of the permits to get a sense of the water taking pressure on each source across the watershed.

Whether a taking is a groundwater or surfacewater taking is not always clear cut. For example, a dug pond in a sand plain area may be a groundwater taking since that is the source of supply. Another example is a shallow groundwater taking adjacent to a stream, which may draw a portion or all of its supply from the surfacewater in the stream. These are important considerations when characterizing the source of the supply and potential impacts associated with a taking. Clearly, surfacewater and groundwater takings may have different effects on the watercourses in the subwatershed.

The locations of permitted water takings for the Grand River watershed were illustrated by the creation of a map. Figure 6.1 shows the locations of the permits, and is categorized into surfacewater or groundwater as the source of supply. To visually assess the water taking pressure, graduated symbols were used to represent the volume of the water taking per day on this map.

An additional way to visualize the water takings is to divide them into subwatersheds, to see the areal impact of the water taking. As shown in Figure 6.2, the watershed was divided into subwatersheds and a select few permits were mapped to show the volumetric taking, spread over the source subwatershed. Figure 6.2 does not show all the PTTW takings for the entire watershed; the municipal and agricultural takings were omitted. However, the depth of the water taking can be seen across the subwatershed, to show the severity of the water removal from either the surfacewater or groundwater source. Summing all permitted amounts from the same catchment also shows the aggregate effects of the water takings on a subwatershed scale. There are limitations to this approach. First, the catchment area may not coincide with the recharge area supplying water. For example, a deep bedrock taking may receive recharge from an area much larger than the catchment. Another issue is buried valleys that may divert water into or out of a catchment. These limitations should be kept in mind. This approach to mapping water takings can be further refined by dividing the takings into deep groundwater and shallow groundwater takings.

Ultimately, Permits to Take Water should be linked to a source aquifer or stream. If linked to a source aquifer, the discharge locations of the source aquifer should be identified to link the impact of the taking to the natural environment. The majority of water that infiltrates into the ground discharges at some point either locally, regionally, or in the case of southern Ontario, to the Great Lakes. The information base necessary to link potential impact location to a PTTW is not available in most areas, although this may now be possible in selected areas like the Oak Ridges Moraine.

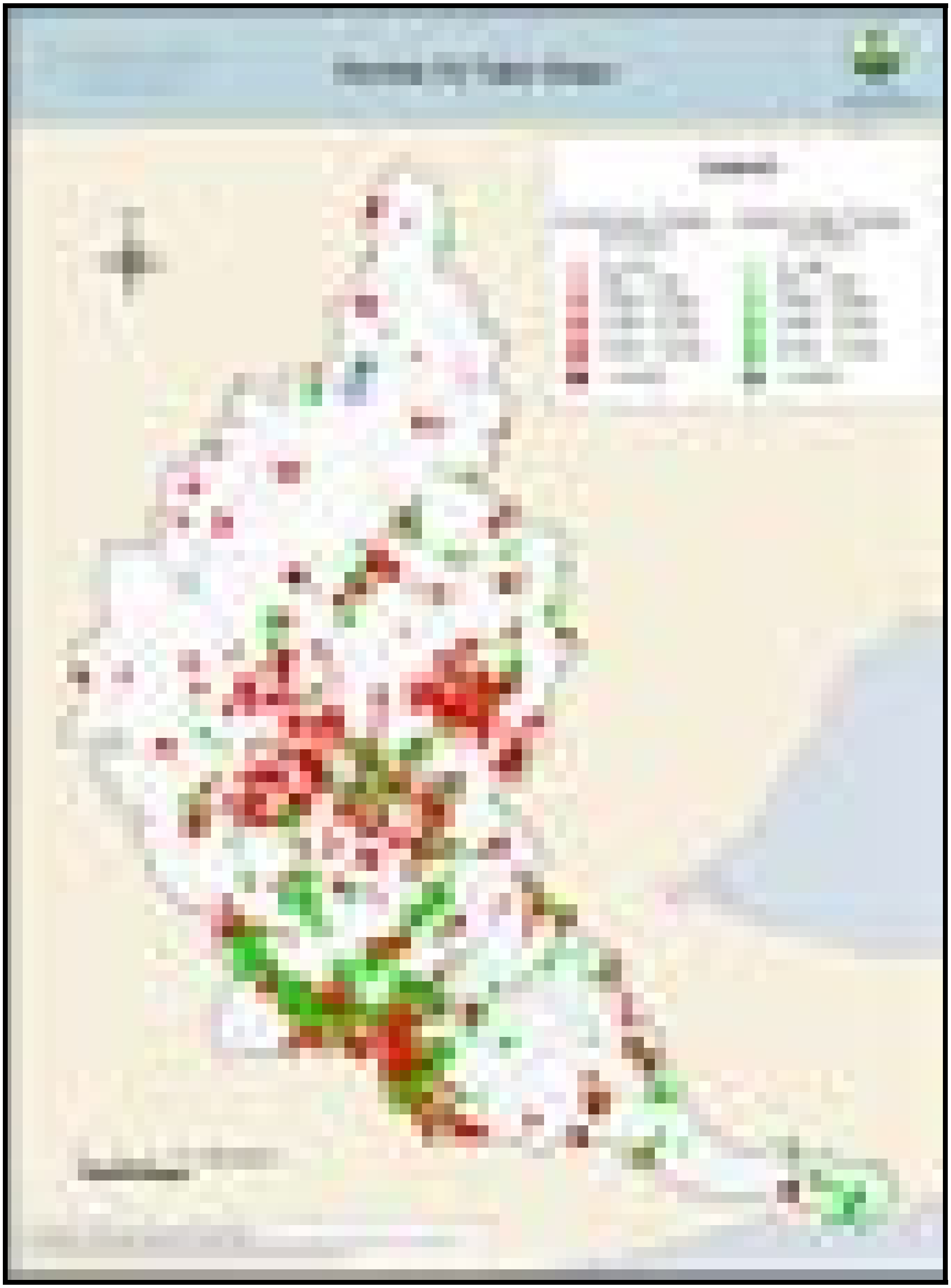


Figure 6.1 Locations, source and amounts of PTTWs across the Grand River Watershed

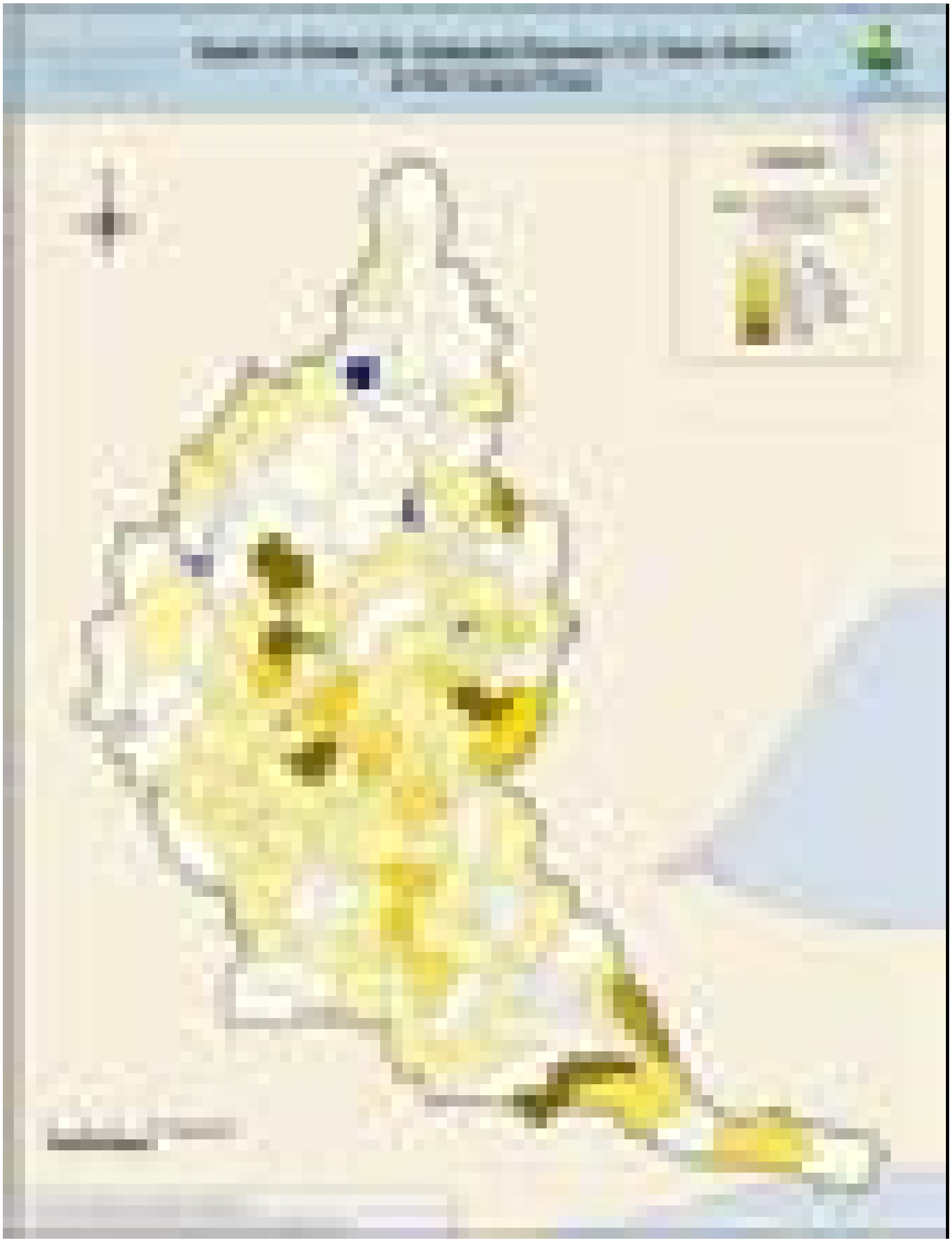


Figure 6.2 Depth of water taking for selected Permits to Take Water

6.2.3 Analyzing the Impact of the Water Taking Permit

Reviewing the location maps of the PTTW information will likely show regions of higher usage. These concern areas may pose a problem with respect to balancing water demand and supply. For instance, for the Grand River watershed, it can be seen in Figure 6.1 that there are small concentrations of permits near large urban areas, in some cases extracting from the same source. This may pose a concern for the ecological water requirements of these areas, especially if the surfacewater users are taking their maximum permitted amount at the same time. These are areas where more detailed scoping should be completed, a task that is often done by local municipalities. Large municipal takings are subject to environmental assessments which look in detail at potential impacts associated with large takings. As the requirements of the natural environment are better understood, they can be built into the environmental assessment process.

An important consideration is the temporal aspect of the water takings. Often, many of the water takings will have a seasonal component, especially if the taking is for agricultural use or for golf course irrigation. These uses will be heavy in the summer but very minimal in the winter months. A consideration of the temporal aspects are key to understanding when the concern of overtaking could occur, since life cycle requirements (see Chapter 4) have differing needs over the course of a year.

With respect to ecological flow requirements, surfacewater takings will undoubtedly have a strong influence on the flows in streams and rivers. However, groundwater, particularly the baseflow contribution from shallow groundwater aquifers, also can have important influences on flow in a river. Distinction between shallow and deep groundwater wells is useful in determining the influence of groundwater takings on the surfacewater flows. Deep groundwater takings from confined aquifers likely have little influence on the flows on the surface above, while shallow groundwater aquifers may provide some flows. In areas such as the Whitemans Creek watershed with the Norfolk Sand Plain, the shallow unconfined aquifer is so well-connected to the surfacewater, that any water takings from groundwater can be assumed to have an impact on the surfacewater levels. In other words, the groundwater that was taken would have discharged to the creeks locally and contributed to the baseflows, if it had been left in the natural environment. When calculating the naturalized flow regime, there is often a lag associated with water takings from a groundwater source.

The key importance when considering the water taking permits is the relative amount of demand compared to the supply at any given time and place. Once the aggregate amount of all the permits is calculated, it must be compared to the water supply in that subwatershed. The water supply could be considered the inputs to the system, namely the precipitation that falls onto that subwatershed, and water takings could be compared as a percentage of the inputs to the system. On a subwatershed scale, the water use compared to the supply can be categorized into 3 tiers, to determine the priority for examination. The first tier has the water supply exceeding the takings, or the water takings are less than a certain percentage of the supply. Thus, overuse is not occurring at the current time. Subwatersheds in the first tier are of low concern for examining ecological flow requirements at this time. Monitoring of new permits in the first tier region should still continue and local impacts associated with a taking must be considered. The second tier is when the water takings are equal to the supply, or are approaching the limit of the availability of the water resource (the takings are between the lowest and highest allowable percentages). More detailed scoping to determine the actual amount of the water takings (also known as the adjusted takings) should be completed in this situation. The third tier occurs when the water taking permits equal or exceed the supply (takings are over a certain percentage of the supply), meaning that overuse of the water resources is apparent. No more permits should be allowed in this area or a local water supply plan is needed to determine how to equitably share the water resource to avoid impacts. Detailed scoping is necessary to determine the adjusted water taking amounts and a study on the ecological flow requirements of this reach should be completed. The third tier is a high priority for examining the impacts of water abstraction on the aquatic ecosystem.

The next section will characterize the PTTWs from the pilot reaches of this study. The water taking permits from surfacewater and groundwater sources in each of the study reaches are separated to better characterize the impacts. Each table lists the general and specific purpose, and the maximum allowed taking for the permits. The last column shows the percentage of the total permits considered for the reach that permits for various purposes comprise. The maximum permitted amount is shown as the only recorded volume on the permit, but it is uncertain whether the actual amount of water taken is less than, equal to or above this amount, as metering is not required. Adjusted values will be noted, which are more accurate estimates of the volume taken, either from metering by the water user or other records made during the permit.

6.3 Grand River at Blair

The Grand River at Blair reach includes all water taking permits upstream of this location in the watershed. Water takings are predominantly from groundwater sources, due to the municipal groundwater extraction.

6.3.1 Surfacewater Permitted Takings for the Grand River at Blair Reach

Table 6.1 incorporates all permits registered in the watershed above the Grand River at Blair reach. The surfacewater sources have generally been permitted to industrial uses that occur along the Grand River and its tributaries in the upper middle and upper Grand subwatersheds.

The majority of the surfacewater takings upstream of the Blair reach are industrial (81.16%), with minor uses coming from golf course irrigation (7.40%), aggregate washing (5.33%) and agricultural water use (4.89%). The catchment basin of the Blair reach may have both intensive industrial zoning as well as agricultural lands.

Table 6.1 Surfacewater takings upstream of the Grand River at Blair Reach

General Purpose	Specific Purpose	Taking (m^3/s)	Percentage of Taking
Agricultural	Other Agricultural	0.093	4.89
Commercial	Golf Course Irrigation	0.141	7.40
	Other Commercial	0.007	0.34
Dewatering	Construction	0.011	0.55
Industrial	Aggregate Washing	0.102	5.33
	Manufacturing	0.006	0.33
	Other Industrial	1.548	81.16
Total		**1.908**	100.00

Other than industrial uses, the major water takings are all seasonal. This will concentrate these water takings into the summer months when the flows are naturally lower in the river. Aggregate washing is a seasonal summer event, generally occurring between May and October. Often the permitted amount is not fully used, as some aggregate washers employ a water recycling practice to reuse the water they have extracted from the stream. Thus, it is possible that the actual taking for aggregate washing could be lower than the value in Table 6.1. This would also apply to other areas of the watershed.

6.3.2 Groundwater Permitted Takings for the Grand River at Blair Reach

The groundwater wells in the northern Grand subwatersheds are more extensive than the surfacewater takings, as previously mentioned. The groundwater permits are greater in number and cover a larger geographic region than the surfacewater takings, which are more confined to a narrow band around the watercourses. Groundwater in these regions is found under the till plains which generally have low infiltration rates but have the ability to recharge large volumes over a large area. Table 6.2 shows the groundwater permits for the Grand River watershed above Blair.

Aquaculture is an unusually large user of groundwater in this region. Municipal water takings are predominantly by the Regional Municipality of Waterloo, with select few by townships and villages such as Centre Wellington, Drayton and Grand Valley. Municipal water takings comprise 39% (61 of 156) of the permitted takings in this area.

Table 6.2 Groundwater takings upstream of the Grand River at Blair Reach

General Purpose	Specific Purpose	Taking (m^3/s)	Percentage of Taking
Agricultural	Nursery	0.004	0.11
	Other Agricultural	0.037	1.02
	Sod Farm	0.003	0.09
Commercial	Aquaculture	0.500	13.96
	Bottled Water	0.007	0.19
	Golf Course Irrigation	0.015	0.41
	Other Commercial	0.018	0.50
	Snowmaking	0.033	0.91
Dewatering	Construction	0.040	1.11
	Other Dewatering	0.126	3.52
	Pits and Quarries	0.075	2.09
Industrial	Aggregate Washing	0.142	3.96
	Food Processing	0.054	1.51
	Manufacturing	0.043	1.20
	Other Industrial	0.002	0.07
Institutional	Other Institutional	0.002	0.05
Recreational	Wetlands	0.005	0.14
Remediation	Groundwater	0.206	5.75
Water Supply	Campgrounds	0.017	0.46
	Communal	0.051	1.43
	Municipal	2.113	58.97
	Other Water Supply	0.091	2.53
Total		**3.583**	100.00

6.4 Grand River Exceptional Waters Reach

The subwatershed of the Exceptional Waters Reach for the PTTW assessment is much larger than the smaller tributaries that are included in this pilot study. All the permits that are located above the reach were taken into consideration. As the subwatershed of the Exceptional Waters Reach is lower in the Grand River watershed, the catchment area as well as the area under consideration for permits, is much larger than any of the other study reaches. This area covers the major basins above the reach including all the upper and middle Grand basins, and tributaries of the Nith River, Whitemans Creek, Speed River and Conestogo basins. Total surfacewater and groundwater permitted takings are approximately the same volume, and permits are for similar uses.

6.4.1 Surfacewater Permitted Takings for the Exceptional Waters Reach

The Exceptional Waters Reach covers all the permits discussed previously for the Grand at Blair reach, as well as a few additional basins. Some of these basins will be more specifically highlighted in the next few sections as they are included as some of the other small study reaches. Table 6.3 shows all surfacewater permits upstream of the Exceptional Waters Reach of the Grand River.

Generally, for the area upstream of this reach, municipal, agricultural and industrial are the largest permitted takings. Agricultural uses will predominate in the summer months of July and August, with irrigation requirements peaking during the growing season and drier months of the year. Other seasonal water uses include golf course irrigation and aggregate washing which comprise 7% of the total year-long takings, but about 24% of the seasonal water takings in this area.

Table 6.3 Surfacewater takings upstream of the Exceptional Waters Reach

General Purpose	Specific Purpose	Taking (m^3/s)	Percentage of Taking	Total % for General Purpose
Agricultural	Field and Pasture Crops	0.065	0.70	22.21
	Fruit Orchards	0.005	0.05	
	Market Gardens / Flowers	0.058	0.63	
	Nursery	0.008	0.09	
	Other Agricultural	1.496	16.19	
	Sod Farm	0.006	0.07	
	Tobacco	0.414	4.48	
Commercial	Aquaculture	0.016	0.17	3.35
	Golf Course Irrigation	0.279	3.02	
	Other Commercial	0.015	0.16	
Construction	Other Construction	0.070	0.76	1.87
	Road Building	0.103	1.11	
Dewatering	Construction	0.011	0.11	0.24
	Other Dewatering	0.012	0.13	
Industrial	Aggregate Washing	0.355	3.84	21.76
	Manufacturing	0.023	0.24	
	Other Industrial	1.633	17.68	
Miscellaneous	Wildlife Conservation	0.095	1.03	1.03
Recreational	Other Recreational	0.144	1.56	1.56
Remediation	Groundwater	0.002	0.02	1.44
	Other Remediation	0.131	1.42	
Water Supply	Municipal	4.300	46.55	46.55
Total		**9.238**	100.00	100.00

6.4.2 Groundwater Permitted Takings for the Exceptional Waters Reach

The water takings from the Exceptional Waters Reach of the Grand River are difficult to determine, as there is no defined subwatershed basin for this reach. Thus, it is assumed that groundwater takings (Table 6.4) within 1 km of the reach are diverted from the Exceptional Waters Reach.

Commercial water bottling occurs in the Nith, Upper and Upper Middle Grand basins, which is a consumptive use that removes water permanently from the subbasin. Dewatering is a process in construction that removes water that occurs on construction sites when digging has reached the groundwater table. Pumping or dewatering is necessary to remove the water so that construction can continue, and often the water is treated and discharged. Discharge could be back to the adjacent land or to the sanitary sewer system.

Table 6.4 Groundwater takings upstream of the Exceptional Waters Reach

General Purpose	Specific Purpose	Taking (m^3/s)	Percentage of Taking	Total % for General Purpose
Agricultural	Field and Pasture Crops	0.025	0.27	15.21
	Market Gardens / Flowers	0.069	0.74	
	Nursery	0.004	0.04	
	Other Agricultural	0.972	10.43	
	Sod Farm	0.003	0.03	
	Tobacco	0.344	3.699	
Commercial	Aquaculture	0.807	8.65	10.50
	Bottled Water	0.047	0.51	
	Golf Course Irrigation	0.095	1.02	
	Other Commercial	0.030	0.32	
Dewatering	Construction	0.160	1.71	1.92
	Other Dewatering	0.019	0.21	
Industrial	Aggregate Washing	0.620	6.65	12.41
	Food Processing	0.094	1.01	
	Manufacturing	0.020	1.10	
	Other Dewatering	0.329	3.53	
	Other Industrial	0.011	0.12	
Miscellaneous	Other Miscellaneous	0.242	2.59	2.59
Recreational	Other Recreational	0.002	0.02	0.07
	Wetlands	0.005	0.05	
Remediation	Groundwater	0.097	1.04	2.04
Water Supply	Campgrounds	0.030	0.32	56.25
	Communal	0.038	0.41	
	Municipal	5.028	53.92	
	Other Water Supply	0.149	1.60	
Total		**9.325**	100.00	100.00

6.5 Nith River at Canning

The landuse in the subwatershed of the Nith River above Canning is generally agricultural and thus agricultural uses account for a majority of the water takings in this area.

6.5.1 Surfacewater Permitted Takings for Nith River at Canning

Surfacewater takings (see Table 6.5) are predominantly for agricultural irrigation. Tobacco is grown in the area, which requires several irrigation applications during the summer months. Other agricultural uses (36.9%) are most likely irrigation as well, which is categorized as a seasonal water use. Much of the taking in this subwatershed is seasonal (85.59%), including all agricultural takings and golf course irrigation. Other recreational activities that required a permit could also have a seasonal component, but the seasonal characteristics of these activities are unknown.

Table 6.5 Surfacewater takings upstream of the Nith River at Canning Reach

General Purpose	Specific Purpose	Taking (m^3/s)	Percentage of Taking
Agricultural	Field and Pasture Crops	0.017	5.19
	Market Gardens / Flowers	0.054	16.17
	Other Agricultural	0.124	36.90
	Tobacco	0.086	25.41
Commercial	Aquaculture	0.008	2.25
	Golf Course Irrigation	0.006	1.90
	Other Commercial	0.009	2.56
Recreational	Other Recreational	0.032	9.59
Total		**0.34**	100.00

6.5.2 Groundwater Permitted Takings for Nith River at Canning

Groundwater takings for the Nith River subwatershed (Table 6.6) are much larger than the surfacewater takings. Agriculture still accounts for a substantial portion of the takings, but municipalities are the major water users upstream of this reach. Oxford County and the Regional Municipality of Waterloo have the largest municipal takings. Municipal takings just outside of Kitchener include the New Hamburg water supply. It is important to note that several of the municipal supplies west of Kitchener supply municipal water to the City of Kitchener, Waterloo and Cambridge. Treated effluent from these communities is returned to the Grand River, not to the Nith River.

Table 6.6 Groundwater permitted takings upstream of the Nith River Reach

General Purpose	Specific Purpose	Taking (m^3/s)	Percentage of Taking	Total % for General Purpose
Agricultural	Field and Pasture Crops	0.024	1.69	5.82
	Market Gardens / Flowers	0.006	0.44	
	Other Agricultural	0.022	1.55	
	Tobacco	0.031	2.15	
Commercial	Aquaculture	0.015	1.07	3.21
	Bottled Water	0.015	1.05	
	Golf Course Irrigation	0.012	0.87	
	Other Commercial	0.003	0.22	
Industrial	Aggregate Washing	0.240	16.85	19.31
	Food Processing	0.023	1.62	
	Other Dewatering	0.011	0.76	
	Other Industrial	0.001	0.09	
Water Supply	Communal	0.003	0.22	71.66
	Municipal	0.991	69.68	
	Other Water Supply	0.025	1.76	
	Total	**1.422**	100.00	100.00

The Nith subwatershed has a water bottling company extracting with several permits. Seasonal water takings are also quite extensive for the groundwater takings of the Nith River subwatershed, comprising 23.5% of all the water takings, or 0.34m^3/s.

6.6 Eramosa River

The Eramosa River currently has a limited number of permitted water takings, but has a considerable taking for municipal water supplies for the city of Guelph.

6.6.1 Surfacewater Permitted Takings for the Eramosa River Reach

The Eramosa River reach has a variety of water taking permits that include agriculture, commercial and recreational, as see in Table 6.7. Recreational takings typically associated with Ducks Unlimited ponds or on stream reservoirs operated by the CA or private individuals were removed from consideration. Filling of on stream ponds are short duration takings and Ducks Unlimited ponds are typically one time takings. The largest direct water taking in this watershed is the City of Guelph's Arkell surfacewater taking. It has a unique temporal aspect to its water taking permit and hence was not included in Table 6.4 or in the PTTW database. The municipal water taking in this reach is a substantial portion of the water use, when considering the maximum permitted taking. The municipal permit changes the maximum permitted taking at different times of the year, based on streamflow. For instance, the maximum permitted amount occurs between April 15th and May 31st, when streamflows are expected to be higher from spring melt and precipitation. As can be seen in Table 6.8, the differing amounts (the average actual recorded taking, or the averaged, maximum or minimum permitted amount) result in a variety of percentages for the total permitted takings in the Eramosa River subwatershed.

Table 6.7 Surfacewater permitted takings upstream of the Eramosa Reach

General Purpose	Specific Purpose	Taking (m^3/s)	Percentage of Takings
Agricultural	Fruit Orchards	0.002	1.06
	Other Agricultural	0.014	7.85
Commercial	Golf Course Irrigation	0.054	30.17
Recreational	Other Recreational	0.109	60.92
Total		**0.178**	100.00

Conditions attached to the City of Guelph's Arkell surfacewater taking are described below. This PTTW is very well designed, as it already reflects the variability of the surfacewater supply and has established cut-off limits based on streamflows. For instance, once streamflows recede to below 0.42 (m^3/s) no further takings are permitted. The history of this taking was discussed with City of Guelph staff. This taking is limited by infrastructure capacity, the pump has been purposefully sized to take less than the minimum taking prescribed in the PTTW. The infrastructure capacity allows a taking of 100 (L/s); this value was used to construct a naturalized flow series.

The following conditions are attached to the Arkell surfacewater taking. This particular PTTW could be used as a model to illustrate how instream flow requirements might be incorporated into a PTTW. The conditions respect the variability of the surfacewater supply with season and also recognize the downstream water quality implications associated with the taking.

Provided that dissolved oxygen levels in the Speed River at Wellington Road No. 32 are greater than 6 (mg/l) for 80 percent of the time over any 24 hour period and greater than 5 mg/l at the lowest point during the same 24 hour period, and provided that 30 cfs (0.85 m^3/s) streamflow is maintained past the Guelph STP and also provided that 15 cfs (0.42 m^3/s) streamflow is maintained in the Eramosa River past the Federal streamflow gauging location 02GA029, the City of Guelph may pump water from the Eramosa River for aquifer recharge at Arkell Springs up to the following rates:

April 15 to May 31 - 7 million Imperial gallons in a day (0.368 m^3/s)
June 1 to June 30 - 5 million Imperial gallons in a day (0.261 m^3/s)
July 1 to July 15 - 4 million Imperial gallons in a day (0.211 m^3/s)
July 16 to Aug. 31 - 3 million Imperial gallons in a day (0.158 m^3/s)
Sept. 1 to Nov. 15 - 2 million Imperial gallons in a day (0.105 m^3/s)

In the summer months, the potential City of Guelph water taking can be over 67% (0.368 m^3/s) of the total water takings from surfacewater in the reach (as seen in Table 6.8) based on the temporal values given in the description of the permit above. Actual water takings during the months of April to November, however, are generally at or below the 0.1 m^3/s on a given day, which is approximately 36% of the total permitted water taking amount for the watershed, provided streamflows are in excess of 0.42 (m^3/s).

Table 6.8 Surfacewater takings adjusted for municipal use in Eramosa River Reach

General Purpose	Specific Purpose	Taking (m^3/s)	%	Taking (m^3/s)	%	Taking (m^3/s)	%	Taking (m^3/s)	%
Agricultural	Fruit Orchards	0.002	1.89	0.002	0.86	0.002	0.51	0.002	1.80
	Other - Agricultural	0.014	5.03	0.014	3.51	0.014	2.56	0.014	4.94
Commercial	Golf Course Irrigation	0.054	19.33	0.054	13.48	0.054	9.85	0.054	18.99
Recreational	Other - Recreational	0.109	39.04	0.109	27.22	0.109	19.89	0.109	38.35
Water Supply	Municipal	0.100	35.91	0.221	55.33	0.368	67.34	0.105	37.04
Total		**0.278**	100.00	**0.399**	100.00	**0.546**	100.00	**0.283**	100.00
NOTES:		approx. recorded taking		averaged PTTW amt		maximum PTTW amt		minimum PTTW amt	

6.6.2 Groundwater Permitted Takings for the Eramosa River Reach

Groundwater takings from the Eramosa Reach mainly comprise takings for the municipal supply for the City of Guelph. Studies of the groundwater system in this area suggest that there is limited connection locally between the deep bedrock groundwater supplies and the surfacewater supply.

Table 6.9 Groundwater permitted takings upstream of the Eramosa River Reach

General Purpose	Specific Purpose	Taking (m^3/s)	Percent of Taking
Agriculture	Other Agriculture	0.015	1.92
Commercial	Golf Course Irrigation	0.038	4.84
	Aquaculture	0.159	20.15
Water Supply	Municipal	0.577	73.10
Total		**0.790**	100%

6.7 Blair Creek

The Blair Creek subwatershed still has only a few water takings, all from groundwater sources. There are no surfacewater takings from this subwatershed.

6.7.1 Groundwater Permitted Takings for Blair Creek

Currently, the groundwater takings upstream of the Blair Reach are small, but relative to the flows in the creek, the seasonal water uses may be considerable. Irrigation for golf courses is the major purpose of the takings, which will occur from June to August generally. Agricultural uses are also seasonal and if they are for irrigation, will coincide with the driest times of the year when natural precipitation is inadequate for growing crops. Table 6.10 has the values for the water taking permits from groundwater in the Blair Creek subwatershed region. The takings indicated in Table 6.10 are of the same order of magnitude as the normal baseflow in this watercourse.

Table 6.10 Groundwater permitted takings upstream of the Blair Creek Reach

General Purpose	Specific Purpose	Taking (m^3/s)	Percent of Taking
Agriculture	Other Agriculture	0.002	1.22
Commercial	Golf Course Irrigation	0.170	98.78
Total		**0.173**	100.00

6.8 Whitemans Creek

The Whitemans Creek watershed is predominantly agricultural in nature. This watershed is small in geographical area, and has a large concentration of water taking permits. The shallow sand aquifer is an important source for takings. Water takings from the creek and its tributaries are a smaller, but still significant portion of the total permits in the subwatershed. Due to the heavy reliance on these sources for irrigation, drought and low-flows are of particular concern in this watershed.

6.8.1 Surfacewater Permitted Takings for Whitemans Creek

Most of the water takings in the Whitemans Creek watershed are for seasonal, summer water uses. The Whitemans Creek watershed is intensively agricultural in nature and thus agriculture is the major water user in this catchment. Tobacco is a particular crop of focus in this region, as it has high water consumption patterns. In addition to being grown on the well-drained, sandy soils of the area, the specific temporal water requirements of tobacco result in heavy irrigation in the summer months. Surfacewater takings (see Table 6.11) totalling 1.49 m^3/s are in the same order of magnitude as the mean summer flow of 1.7 m^3/s. Instances have been observed when the instantaneous flow at the Mount Vernon gauge has fallen to 0.3 m^3/s.

Table 6.11 Surfacewater takings upstream of Mt. Vernon Reach on Whitemans Creek

General Purpose	Specific Purpose	Taking (m^3/s)	Percentage of Taking
Agricultural	Market Gardens / Flowers	0.004	0.25
	Nursery	0.008	0.53
	Other Agricultural	1.111	74.38
	Tobacco	0.253	16.97
Commercial	Aquaculture	0.008	0.53
Construction	Other Construction	0.013	0.88
	Road Building	0.002	0.11
Miscellaneous	Wildlife Conservation	0.095	6.34
Recreational	Other Recreational	0.000	0.00
Total		**1.49**	100.00

Other agricultural crops including potatoes, ginseng and sod are among the irrigated crops in the region that have specific water requirements, governed by the climatic patterns of moisture input to the watershed. Potatoes for instance, require ‘topping up’ of their water requirements by irrigation late in the season. This additional water is required to get a plump and full potato shape with little evidence of water stress, which returns a higher value on the market. Sod also has late summer water requirements to ensure a thick and full canopy just before harvest. Nursery and garden flowers, as well as the increasingly popular vegetable crops in the region have high water consumption patterns throughout their growing seasons, to produce higher quality products. Some of the other agricultural water uses may include livestock watering, which are maintained throughout the year, but crop watering or irrigation will primarily be in the months of July and August.

6.8.2 Groundwater Permitted Takings for Whitemans Creek

Groundwater takings are fairly substantial in the Whitemans Creek subwatershed (Table 6.12) due to the shallow sand aquifer of the Norfolk Sand Plain. Groundwater is easy to extract and wells do not have to be very deep. Agricultural irrigation is a huge portion of the takings, for crops such as tobacco, vegetables and sod.

Table 6.12 Groundwater takings upstream of Whitemans Creek

General Purpose	Specific Purpose	Takings (m^3/s)	Percent of Taking
Agriculture	Field and Pasture Crops	0.063	2.97
	Market Garden/ Flowers	0.023	1.10
	Nursery	0.008	0.39
	Other Agricultural	1.590	74.91
	Tobacco	0.355	16.71
Commercial	Aquaculture	0.011	0.50
	Golf Course Irrigation	0.021	0.99
	Other Commercial	0.005	0.26
Dewatering	Other Dewatering	0.019	0.90
Industrial	Food Processing	0.001	0.03
Miscellaneous	Other Miscellaneous	0.020	0.97
Water Supply	Municipal	0.006	0.27
Total		**2.123**	100.00

The combined surfacewater and groundwater takings, approximately 3.6 m^3/s, exceed the summer mean flow of 1.7 m^3/s and approach the mean annual flow of 4.3 m^3/s. The volume of takings in comparison to streamflow statistics at the Mount Vernon gauge confirms that the Whitemans Creek watershed is an area of concern and that there is potential and instances of over use of the resource.

6.9 Mill Creek

The Mill Creek subwatershed has only groundwater taking permits. The surfacewater takings have been short-term permits.

6.9.1 Surfacewater Permitted Takings for Mill Creek

The Mill Creek basin has only two categories of surfacewater takings, which are for dewatering purposes and recreational uses in a park. The dewatering operation was a short-term permit. The other permit has also expired, but Table 6.13 shows the volume of water takings that have been permitted in the Mill Creek watershed.

Table 6.13 Surfacewater takings upstream of Mill Creek Reach

General Purpose	Specific Purpose	Taking (m^3/s)	End of Permit
Dewatering	Other - Dewatering	0.012	12/2001
Recreational	Other - Recreational	0.002	03/2004
Total		**0.013**	

6.9.2 Groundwater Permitted Takings for Mill Creek

Aggregate washing is by far the largest use of permitted water taken for this subwatershed as seen in Table 6.14. However, it is possible that water recycling is employed by the aggregate washers and the permitted takings may not be reflective of the actual water takings that occur for this purpose. Municipal water takings include the Regional Municipality of Waterloo and a camp in the watershed. A small, agricultural water taking is used for a nursery.

Table 6.14 Groundwater permitted takings upstream of Mill Creek

General Purpose	Specific Purpose	Taking (m^3/s)	Percent of Taking
Agriculture	Other Agriculture	0.003	0.47
Commercial	Bottled Water	0.030	4.50
	Golf Course Irrigation	0.024	3.50
Industrial	Aggregate Washing	0.428	63.57
	Manufacturing	0.077	11.38
Water Supply	Campgrounds	0.012	1.77
	Municipal	0.095	14.08
	Other Water Supply	0.005	0.73
Total		**0.173**	100.00

The total permitted water uses in the watershed are approximately 20% of the summer mean flow at the Side Road 10 stream gauge, neglecting the municipal water taking that occurs downstream of the stream gauge. Therefore, water taking currently is not as significant in this watershed as in other pilot reaches.

6.10 Carroll Creek

The Carroll Creek subwatershed is a small watershed with very little activity. Only one water taking, from a surfacewater source for agricultural irrigation purposes, has a permit. The taking is small, only 0.0006 m^3/s, which comprises only a small percentage of the flow in the creek. There are no groundwater takings from Carroll Creek other than rural domestic takings.

6.11 PTTW Concerns

The PTTW program, under the authority of the Ontario Water Resources Act (1961), is intended to allocate groundwater and surfacewater in the province. Each PTTW stipulates a limit that the permitted user can take, based on an application to the MOE. The PTTW program promotes water as a public resource that cannot be diminished in either quality or quantity by any user in a way that would harm another user.

The PTTW database is beneficial to identify the maximum allowable takings for each permit for any watershed or subwatershed in the province and permits may have temporal limits such as a daily maximum allowable taking. The PTTW database may also be used to identify the purpose and expiry date of a permit.

Unfortunately, the maximum allowable limit is not an accurate assessment of the actual takings that typically occur. Follow-up after a permit has been granted is seldom done, unless the permitted amount is very high; actual water takings need not be metered and assessed. Municipalities, which typically record their takings, are an exception. However, the actual takings of municipalities are not currently included in the PTTW database., Also, review of compliance with permits is lacking.

It was found by the ECO (2001) that permit application decisions did not appear to consider the availability of water in the watershed or the quantity allocated to a water use sector. A review of the PTTW program was completed by Kreutzwiser *et al.* (2004), who cited an Ontario Federation of Agriculture assessment of the PTTW, saying that permit applicants tended to overestimate water needs. With respect to water use information, this paper (Kreuztwiser *et al*., 2004) states that:

> "…in their current form, PTTW program data should not be used to determine how much water is being taken or to analyze water taking trends to determine future water availability. Additionally, the PTTW database does not currently represent an accurate amount of water takings in the Province and it cannot be relied upon by municipalities, conservation authorities and the general public"

This statement was a reiteration of many other studies that have been done concerning the PTTW program, in both academic and governmental research. Actual water takings are not represented in the PTTW database, and when the application overestimates the use, the information is inadequate for the assessment of water budgets and potential conflicts between human and ecosystem needs.

Another issue that is very crucial to the assessment of potential impacts is the temporal aspect of the water takings. Seasonal summer water takings are of particular concern to aquatic ecosystems, as they often coincide with the natural decrease in moisture availability due to less precipitation, higher temperatures and increased evapotranspiration. The temporal aspect of the permits for agriculture and aggregate washing in much of the Grand River watershed is a key issue when characterizing the demands on the water source. The timing of certain takings such as aggregate washing, agriculture and golf course irrigation have to be extrapolated based on variables of climate, water availability, pumping ability, permit allowance, soil moisture and numerous other factors. Essentially, it is not an easy process for either the water taker or the water manager trying to determine the amount of water being taken. It could be assumed that these takings occur between the months of May to October, though irrigation can often be assumed to occur in a narrower time frame (July and August) in a year of normal precipitation and streamflow.

The MOE is currently acting on some of the deficiencies in the PTTW database; steps have been taken to improve water taking data. For instance, by 2008, all permit holders will be required to collect and record data on water volumes taken daily and report annually to the MOE. Additional limitations were found during the course of this study, when applying PTTW information to assess cumulative impacts on the natural environment. A key learning from the present study is the need to link takings to a specific source and the natural discharge points of that source. For example, a taking may be from an intermediate aquifer which may have many discharge points into different subwatersheds. In order to assess the impacts of a taking or cumulative takings from a discrete or common source, the extent of that source needs to be quantified along with the its recharge and discharge points.

Suggestions for a watershed-wide strategy are described in further detail in Chapter 9.

7.0 EVALUATION OF INSTREAM FLOW ASSESSMENT TECHNIQUES

This chapter describes the analysis completed as part of the Grand River Pilot Project to estimate instream flow requirements and assess how existing permitted takings accommodate these requirements. The literature review in Chapter 4 identified several flow, hydraulic and geomorphic based methods; a selected number of these methods were applied to estimate instream flow thresholds from historical streamflow data and hydraulic analysis. In this chapter, a short description of each of the techniques is given, as well as some data generated from the selected pilot reaches. A case study approach is used to estimate instream flow requirements on an individual reach basis. These case studies will form the basis for a recommended watershed strategy for the application of instream flow techniques.

7.1 Flow Based Assessment of Instream Flow Requirements

The flow assessment was approached with two objectives in mind. The first and primary objective was to organize the data needed to apply instream flow techniques. This data included flow statistics including monthly and annual mean flows, running average flows, 7Q flows, flow duration and high flows. The secondary objective was to present flow data in different manners to allow various disciplines to interact and glean an understanding of the data.

The primary sources of daily streamflow data are the Environment Canada Hydat CD for stations operated by Environment Canada and the GRCA streamflow archive for stations operated by the GRCA. The GRCA streamflow stations are operated to a different standard than Environment Canada. Flow data for GRCA operated stations is not corrected for backwater due to ice or aquatic vegetation effects. Differing standards must be kept in mind when analyzing flow data.

Prior to carrying out a flow based assessment, it is essential to have the streamflow information organized in a database. Having this information organized in a database facilitates arranging the information to support the requirements of the various instream flow methods. The GRCA data is organized in an MS-Access database. Other databases exist; one that is gaining use amongst CA’s is the HEC-DSSVUE (US Army Corps of Engineers, July 2003) database, which is designed to organize time series data on a basin basis. This database is freely available from the US Army Corps of Engineers. Table 7.1 summarizes several instream flow techniques and the data required to apply each technique.

Table 7.1 Data requirements for instream flow techniques

Instream Flow Method	**Required Flow Data**
Tennant Method	Mean Annual Flow
Tessmann Method	Mean Monthly Flows
Flow Duration Method	Ranked Time Series (Composite and Seasonal)
Geomorphic Methods	Time series daily and instantaneous extremes
Low-flow Statistical Methods	7-day, 15-day running average flow series
IHA / RVA Methods	Daily Time series based on water year
Characterization	**Required Flow Data**
Annual flow plots	Time series daily flows
Percentile flow plots	Time series flows by Julian day by year
Maximum flow occurrences	Maximum monthly flow and Annual instantaneous flow

7.1.1 Monthly and Annual Mean Flows

A table of monthly mean flows, for each study reach, was generated to provide sufficient information to apply the Tennant and Tessmann instream flow techniques. The tables summarize the monthly mean flows for the period of record by year and by month. The table also includes the annual average flow and highlights the monthly minimum, maximum and 10th percentile values for each month. The highlighted flows help draw attention to low-flow and high flow periods in the flow record. Table 7.2 is an example of one of these tables and illustrates the mean monthly flows for the Eramosa River above Guelph. Note the dry period in the latter half of 1998 and extending into 1999. Information for other reaches is included in Appendix B.

Table 7.2 Eramosa River Above Guelph mean monthly streamflow

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1962			6.20	4.48	1.52	1.15	0.55	0.54	0.61	1.57	2.39	1.57	**2.06**
1963	1.08	0.93	4.59	2.74	2.34	0.87	0.82	0.62	0.52	0.50	0.63	0.51	**1.35**
1964	1.22	0.78	2.79	3.62	2.09	1.19	1.26	1.44	0.62	0.63	0.72	1.69	**1.50**
1965	2.12	4.58	2.95	10.47	2.59	0.65	0.85	0.75	0.82	2.04	2.54	3.62	**2.83**
1966	2.35	2.82	5.23	3.41	2.19	1.46	0.52	0.52	0.42	0.50	1.39	2.54	**1.95**
1967	2.07	2.15	3.16	8.57	2.58	3.26	2.94	1.08	0.84	1.93	2.25	3.31	**2.84**
1968	1.70	4.30	7.15	3.73	2.26	1.32	1.02	2.85	2.15	1.69	2.78	2.75	**2.81**
1969	2.64	2.99	5.48	8.40	3.88	1.58	0.87	0.79	0.41	0.66	1.75	0.99	**2.54**
1970	0.82	0.97	1.36	6.49	2.49	0.96	1.14	0.85	1.21	1.48	2.20	3.06	**1.92**
1971	1.64	1.95	2.81	7.95	1.99	2.00	1.48	1.62	1.06	0.81	1.06	2.47	**2.24**
1972	1.65	1.48	2.18	12.00	3.29	2.32	1.71	0.79	0.79	1.92	2.18	2.59	**2.74**
1973	3.04	2.91	10.72	5.21	3.65	1.92	0.84	0.84	0.50	0.97	2.45	1.79	**2.90**
1974	2.56	2.56	7.56	6.47	6.44	2.32	1.06	0.76	0.64	0.78	1.72	1.17	**2.84**
1975	1.49	2.09	4.84	7.36	2.91	1.67	0.71	0.86	1.18	1.06	1.54	1.93	**2.30**
1976	1.37	3.75	11.06	6.63	4.74	1.99	1.61	1.46	1.75	1.83	1.47	1.24	**3.24**
1977	0.65	0.66	7.90	4.76	1.62	1.06	0.88	1.27	2.24	3.41	3.46	4.16	**2.67**
1978	2.66	1.85	3.08	11.27	4.32	1.53	0.72	0.70	1.71	1.43	1.66	1.74	**2.72**
1979	1.94	1.43	7.92	8.63	4.19	1.81	1.25	1.49	1.66	1.36	2.52	3.64	**3.15**
1980	2.12	1.10	5.34	5.94	3.08	1.95	1.67	0.95	1.03	1.44	1.28	1.89	**2.32**
1981	0.94	5.44	2.74	2.99	1.86	1.20	1.66	1.51	2.16	2.98	2.80	1.75	**2.34**
1982	1.24	1.11	3.24	10.93	2.63	3.56	1.61	1.18	1.58	1.49	3.38	5.60	**3.13**
1983	3.04	3.54	3.86	4.98	5.35	2.15	0.90	1.21	1.22	1.24	1.51	1.98	**2.58**
1984	1.11	4.89	4.49	6.08	3.05	1.95	0.91	0.64	1.23	1.00	1.93	2.41	**2.48**
1985	1.82	3.53	9.13	10.69	2.43	1.63	1.55	1.45	2.40	1.90	6.09	3.60	**3.85**
1986	2.45	1.99	6.03	3.98	2.82	2.08	3.05	3.21	9.06	6.93	3.42	3.47	**4.04**
1987	2.56	1.38	5.43	7.00	1.83	1.09	1.17	0.75	0.71	1.09	1.47	2.43	**2.24**
1988	1.83	2.19	4.35	3.86	1.91	0.62	0.51	0.53	0.71	1.14	2.00	1.49	**1.76**
1989	1.83	1.34	3.56	3.14	2.35	2.70	0.60	0.48	0.39	0.65	1.65	0.64	**1.61**
1990	1.64	2.79	6.05	2.88	2.71	1.22	0.87	0.88	0.62	2.31	2.66	4.13	**2.40**
1991	3.50	2.87	7.08	7.60	2.98	1.24	1.29	1.14	0.52	0.88	0.93	1.94	**2.66**
1992	1.68	1.49	2.35	5.69	3.35	1.49	1.68	2.53	2.95	3.20	7.10	3.90	**3.12**
1993	6.32	1.93	3.39	7.47	2.46	2.68	1.28	0.79	0.88	1.20	1.44	1.53	**2.62**
1994	0.74	1.58	3.64	5.96	3.53	1.26	0.67	0.48	0.41	0.58	1.00	1.02	**1.74**
1995	4.34	1.15	4.05	3.17	2.63	1.53	0.86	1.43	0.38	1.03	3.37	2.17	**2.18**
1996	4.03	3.99	3.93	8.29	5.83	4.08	1.59	1.06	2.96	2.73	2.57	4.40	**3.79**
1997	4.72	6.93	7.51	6.59	4.24	1.60	0.84	0.75	0.71	0.76	1.29	0.97	**3.08**
1998	2.76	1.80	5.56	3.30	1.64	1.15	0.70	0.44	0.27	0.48	0.61	0.87	**1.63**
1999	1.54	1.91	2.14	2.29	0.85	0.81	0.56	0.32	0.48	0.84	1.95	1.41	**1.26**
2000	1.05	2.26	2.49	2.77	3.53	3.85	2.06	2.26	0.93	0.76	1.25	1.23	**2.04**
2001	1.03	6.20	3.18	6.14	2.09	1.56	0.81	0.43	0.44	1.34	1.47	2.47	**2.26**
2002	1.64	3.02	3.79	5.09	3.80	2.08	0.85	0.54	0.56	0.75	1.09	0.90	**2.01**
Maximum	**6.32**	**6.93**	**11.06**	**12.00**	**6.44**	**4.08**	**3.05**	**3.21**	**9.06**	**6.93**	**7.10**	**5.60**	**4.04**
Average	**2.12**	**2.57**	**4.89**	**6.07**	**2.98**	**1.77**	**1.17**	**1.08**	**1.26**	**1.49**	**2.12**	**2.27**	**2.48**
Minimum	**0.65**	**0.66**	**1.36**	**2.29**	**0.85**	**0.62**	**0.51**	**0.32**	**0.27**	**0.48**	**0.61**	**0.51**	**1.26**
Lower 10 Percentile	**1.02**	**1.08**	**2.49**	**2.99**	**1.83**	**0.96**	**0.60**	**0.48**	**0.41**	**0.63**	**1.00**	**0.97**	**1.63**

7.1.2 Running Average Flows

Single day minimum flows are not considered as a variety of conditions may affect flows or measurements and unduly influence low flow statistics. Running average flows are intended to sort out anomalies of single-day flows that could bias the data. Running average flows (7-day, 15-day and 30-day) were calculated and tabulated similarly to the mean monthly flows. Example results are presented by Tables 7.3 and 7.4 for the

Eramosa River above Guelph. This data was also plotted to visualize changes in flow as seen in Figure 7.1. Other averaging periods beyond 30-days were also used, since the longer averaging periods aid in the interpretation of the information. For example, drought periods are evident when the range of running average flows experience lows in the same year, such as during 1998 and 1999.

Table 7.3 Minimum 7-day average flows for Eramosa River Above Guelph

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Jan-Apr	May-Sep	Oct-Dec
(m^3/s)																	Sum of occurences by season		
Maximum	3.62	2.19	6.42	5.47	3.54	2.43	1.32	1.21	3.33	3.99	2.79	3.15	1.07	2.19	1.07	2.50	Jan-Apr	May-Sep	Oct-Dec
Average	1.28	1.31	1.89	2.99	1.78	1.07	0.69	0.57	0.71	0.90	1.14	1.40	0.49	1.11	0.50	0.84	1	37	3
Minimum	0.13	0.45	0.39	1.27	0.61	0.38	0.17	0.18	0.11	0.31	0.36	0.36	0.11	0.13	0.11	0.31			
Lower 10 Percentile	0.57	0.77	0.83	1.51	1.20	0.62	0.39	0.30	0.30	0.36	0.57	0.61	0.27	0.54	0.27	0.36			

Table 7.4 Eramosa River Above Guelph annual minimum running average flows

Year	7-day	15-day	30-day	60-day	90-day	120-day	150-day	180-day	210-day	240-day	270-day	300-day	330-day	360-day
(m^3/s)														
Maximum	1.07	1.11	1.56	2.08	2.23	2.47	2.84	2.86	2.66	2.60	2.56	2.50	2.88	3.01
Average	0.49	0.55	0.65	0.79	0.90	0.98	1.04	1.09	1.16	1.29	1.50	1.67	1.85	2.02
Minimum	0.11	0.18	0.25	0.31	0.38	0.41	0.48	0.51	0.56	0.63	0.70	0.84	0.96	1.06
Lower 10 Percentile	0.27	0.33	0.37	0.42	0.48	0.52	0.61	0.68	0.71	0.88	0.97	1.13	1.24	1.46

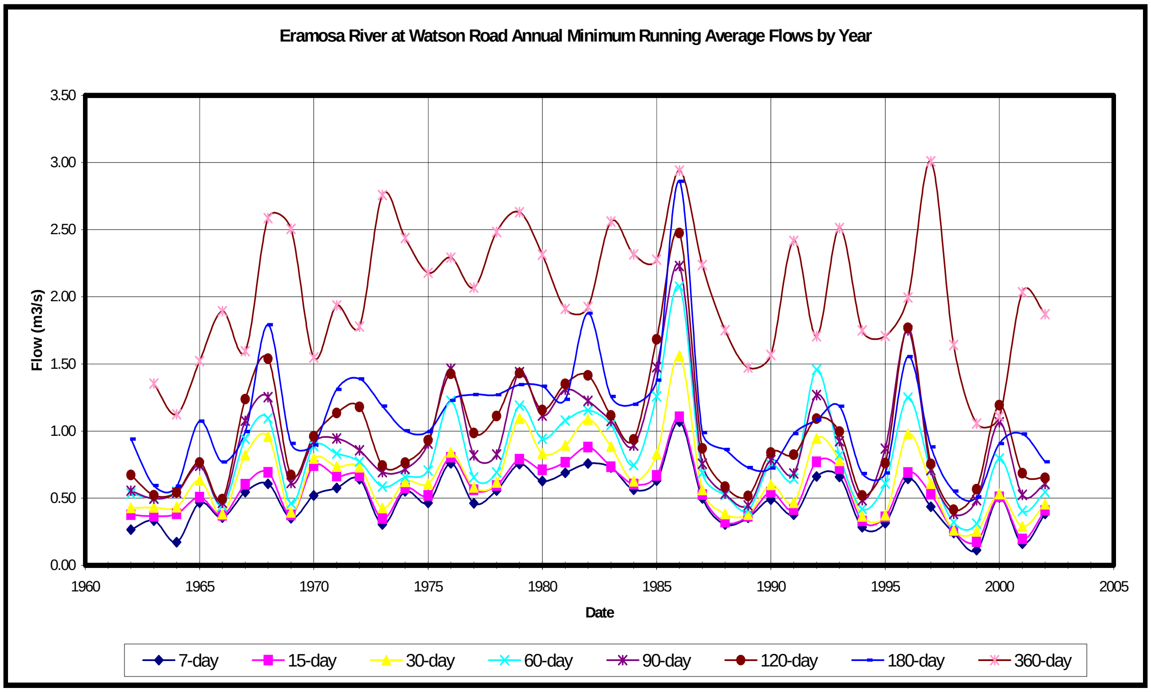


Figure 7.1 Annual minimum running average flows for Eramosa River Above Guelph

7.1.3 Seven Q Flow Statistics

The 7-day flow minimums were used to calculate low-flow statistics for the gauges in the study reaches. Flow statistics calculated include 7Q2, 7Q5, 7Q20, 7Q50 and 7Q100. These statistics were calculated for both annual and summer periods of the year. Generally, very little difference was found between the annual and summer periods, therefore the annual statistics were selected for use.

Low-flow statistics such as the 7Q series are often used in the design of sewage treatment plants and they represent extreme low-flow conditions. They are generated in this study for comparison purposes but are not recommended to establish instream flow requirements. These statistics are expected to be well below the flow necessary to sustain a healthy ecological system. For reaches with a short period of record it was not practical to calculate 7Q statistics. Therefore 7Q statistics were only calculated for reaches with long periods of record.

A range of statistical distributions was used to fit the 7-day low-flow data in order to calculate the 7Q statistics. Plots of each distribution were examined for goodness of fit and the distribution with the best fit was selected to calculate the low-flow statistics.

A statistical package is included with the publication Hydrologic Applications by Kite (1991). This package was used to calculate 7Q series statistics. Table 7.5 displays the 7Q statistics for the Eramosa River above Guelph. At this site, the Type III External Distribution Method of Moments provided the best goodness of fit for the low-flow data.

Table 7.5 Eramosa River Above Guelph annual 7Q flow statistics: 1948-2002

Low-flow Statistics Statistical Method	**Annual Return Period 7-day Flow (m^3/s)**					
	2	**5**	**10**	**20**	**50**	**100**
Two Parameter Log Normal Method of Moments	0.457	0.330	0.278	0.242	0.207	0.186
Two Parameter Log Normal Maximum Likelihood	0.457	0.330	0.278	0.242	0.207	0.186
Three Parameter Log Normal Method of Moments	0.482	0.324	0.247	0.186	0.120	0.077
Type III External Distribution Method of Moments	0.481	0.324	0.248	0.188	0.123	0.081
Type III External Distribution Method of Smallest Observed Drought	0.482	0.319	0.244	0.190	0.139	0.111
Type III External Distribution Method of Maximum Likelihood	0.488	0.320	0.239	0.178	0.118	0.084
Pearson Type III External Distribution Method of Moments	0.479	0.323	0.249	0.192	0.130	0.092
Pearson Type III External Distribution Method of Maximum Likelihood	0.481	0.325	0.251	0.192	0.129	0.089
Pearson Type III External Distribution Method of Moments (indirect)	0.489	0.318	0.240	0.184	0.131	0.102
Maximum	0.489	0.330	0.278	0.242	0.207	0.186
Average	0.477	0.324	0.253	0.199	0.145	0.112
Minimum	0.457	0.318	0.239	0.178	0.118	0.077

7.1.4 Flow Duration

Flow duration statistics (Table 7.6) show the percentage of time that a flow is met or exceeded in an interval of time. Thus, a 10% flow is generally a very high flow, that only occurs (or is exceeded) 10% of the time and a 75% flow is a low-flow that is equalled or exceeded by 75% of the flows during that time period.

Flow duration curves were generated for stream gauges in the study reaches. Both annual composite and seasonal flow duration curves were constructed. The flow duration curves allowed the various frequency statistics to be extracted, such as 50% flow or 60% flow, for both composite total flow and seasonal total flow.

Baseflow duration curves and statistics (see Table 7.7) were also generated for comparison purposes. They were constructed using the BFLOW separation technique. A description of baseflow separation techniques can be found in the technical brief by Bellamy (2003).

Table 7.6 Total flow duration statistics for study sites

	Canning		Brantford		Brantford-Whiteman's		Eramosa		Mill Creek		Whiteman's		Doon	
	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer
10%	23.5	8.7	120.0	50.0	110.7	45.7	5.3	2.5	1.9	1.00	9.8	3.5	89.8	33.1
20%	12.9	5.7	72.4	36.5	66.5	34.1	3.4	1.6	1.4	0.78	5.7	2.3	53.9	23.9
30%	9.0	4.5	52.6	30.7	48.5	28.7	2.5	1.3	1.1	0.66	4.0	1.8	36.9	17.3
40%	6.8	3.8	41.9	27.4	38.9	25.7	1.9	1.1	0.89	0.55	3.0	1.5	28.2	15.2
50%	5.4	3.3	35.0	25.0	32.4	23.6	1.5	0.93	0.80	0.49	2.3	1.2	22.4	14.0
60%	4.4	2.9	29.6	22.9	27.5	21.8	1.2	0.79	0.70	0.46	1.8	1.1	17.2	12.9
70%	3.6	2.6	25.3	21.3	23.8	20.3	1.0	0.69	0.59	0.35	1.4	0.88	14.6	12.2
80%	2.9	2.3	22.1	19.7	20.9	18.9	0.80	0.57	0.49	0.25	1.1	0.74	12.7	11.1
90%	2.4	2.0	19.0	18.0	18.1	17.1	0.60	0.43	0.30	0.19	0.78	0.57	11.0	9.8
100%	1.4	1.3	10.9	12.4	9.9	11.1	0.18	0.14	0.14	0.14	0.22	0.17	4.5	6.1

Table 7.7 Baseflow duration statistics for study sites

	Canning		Brantford		Brantford-Whiteman's		Eramosa		Mill Creek		Whiteman's		Doon	
	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer
10%	8.9	4.7	52.0	28.7	47.6	26.7	2.6	1.2	1.00	0.64	4.2	1.8	38.4	22.3
20%	6.7	3.7	40.2	25.1	37.0	23.6	1.9	1.0	0.85	0.52	3.1	1.4	28.5	14.8
30%	5.4	3.2	33.6	22.9	30.9	21.7	1.5	0.83	0.76	0.49	2.4	1.2	22.7	13.3
40%	4.6	2.9	29.0	21.9	26.7	20.6	1.2	0.71	0.67	0.44	2.0	1.0	17.8	12.2
50%	3.9	2.6	25.6	20.6	23.6	19.4	1.1	0.64	0.60	0.35	1.6	0.88	14.7	11.6
60%	3.3	2.4	22.7	19.3	21.3	18.4	0.87	0.57	0.52	0.27	1.3	0.76	13.0	11.2
70%	2.8	2.2	20.6	18.4	19.4	17.6	0.70	0.50	0.46	0.21	1.1	0.66	11.8	10.6
80%	2.4	1.9	18.6	17.3	17.7	16.4	0.58	0.41	0.34	0.17	0.80	0.54	10.9	9.8
90%	2.0	1.7	16.5	15.6	15.4	14.6	0.42	0.31	0.20	0.16	0.59	0.40	9.3	8.3
100%	1.1	0.8	9.6	10.6	8.2	9.2	0.12	0.09	0.09	0.13	0.15	0.12	4.2	5.9

Flow duration statistics are compared to other streamflow statistics and to estimates from instream flow techniques that are discussed later in this chapter.

7.1.5 High Flow Statistics

High flows also play a very important role with respect to maintaining ecosystem quality. They are necessary for flushing, sediment movement and the introduction of nutrients from the floodplains into the river. High flows were characterized for each of the gauges in the study reaches. A hierarchy of high flows was investigated that included annual instantaneous maximums, annual daily maximum flows and monthly daily maximum flows.

The analysis of maximum flows is important to understand the frequency of out-of-bank and bankfull flow events. Out-of-bank and bankfull flow events are important to the geomorphology of the system and to the health of riparian floodplains. They shape the channel and connect the aquatic community to critical life history habitat through inundating floodplains. Research has found that large, frequent hydrological perturbations, such as floods, are critical for maintaining biodiversity, productivity and biological populations in aquatic stream environments in the long-term (Power et al., 1995).

The bankfull discharge for the Eramosa above Guelph gauge was referenced from the Database of Morphologic Characteristics of Watercourse in Southern Ontario, produced for the Ministry of Natural Resources by Bill Annable in 1996. The bankfull discharge estimated by Annable (1996) was later updated by *Parish Geomorphic* as part of their geomorphic investigation of the Eramosa reach. The bankfull discharge estimates were used to illustrate the frequency and magnitude of out-of-bank flows. Figure 7.2 illustrates the comparison of bankfull flow to the monthly maximum flows for the period of record at the Eramosa above Guelph gauge.

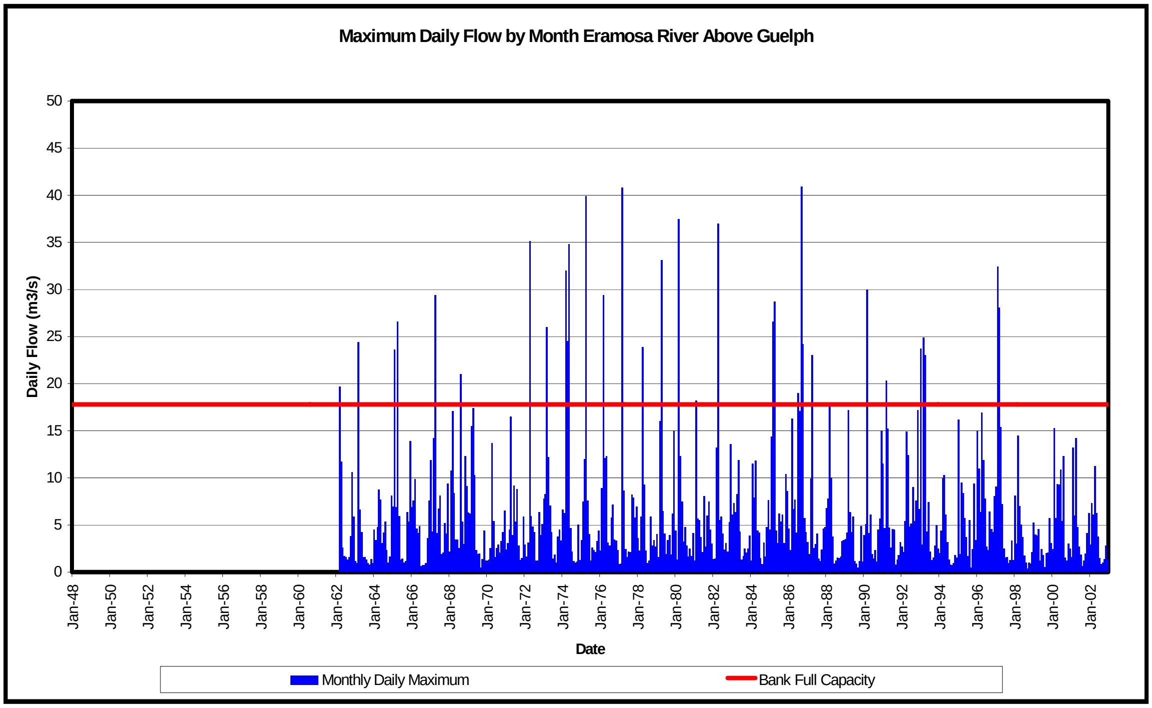


Figure 7.2 Maximum daily flows by month for the Eramosa River Above Guelph

High flow statistics were calculated using Environment Canada's Consolidated Frequency Analysis Program, Version 3 (CFA3). The Three Parameter Log Normal Distribution was found to provide the best fit for gauges in the Grand River Watershed. High flow statistics were only calculated where sufficient streamflow records existed to reasonably apply CFA3.

7.1.6 *Indicators of Hydrologic Alteration*

IHA is a software program created by the Nature Conservancy which was developed to calculate hydrologic regime characteristics. It provides a tool to analyze changes in the characteristics over time, by interpreting daily data such as streamflow. Daily flow data needs to be organized monthly by water year to facilitate the application of the IHA software. The water year begins on October 1st of the previous calendar year and ends on September 30th of the following year. Further information about the IHA software may be found at http://www.freshwaters.org/tools/, and descriptions of this approach can also be obtained through papers by Richter *et al*. (1996, 1997, and 1998).

The IHA software is designed to generate statistics for 33 ecologically relevant hydrologic parameters that can be used to describe the natural flow regime. The 33 parameters are organized into 5 groups and are intended to provide specific measures of the flow regime that can be used to describe and analyze potential impacts. The IHA groups are listed in Table 7.8 and summarized below.

Table 7.8 Description of *Indicators of Hydrologic Alteration* parameter groups

Group	Description	Number of Parameters
1	Magnitude of monthly water conditions	12
2	Magnitude and duration of annual extremes	12
3	Timing of annual extremes	2
4	Frequency and duration of high and low pulses	4
5	Rate and frequency of change in conditions	3

Group 1 parameters measure the monthly magnitude; essentially these 12 parameters include the monthly mean flows (one for each month of the year). These parameters provide a measure of the general consistency of flow.

Group 2 parameters measure maximum and minimum flows for 1-day, 3-day, 7-day, 30-day and 90-day periods. These parameters are intended to provide a measure of the magnitude and duration of extreme flows. Group 2 parameters also report the number of zero flow days (days with no flow) and a baseflow parameter. The baseflow calculated by the IHA software is based on the 7-day annual minimum flow divided by the annual mean.

Group 3 parameters report the Julian date on which the maximum and minimum 1-day flows occur in a water year. This measure is important to analyze the variability of the time of annual extremes and how they might be altered by changes such as water takings.

Group 4 parameters report the frequency and duration of high and low-flow pulses. This measure is intended to analyze the persistence of high and low-flows. High flow pulses may be used to infer out-of-bank flows that carry nutrients to floodplain vegetation. Low-flow pulses may be used to infer low flow or drought conditions and the persistence of these conditions. The IHA software uses the 75th and 25th flow percentiles to partition high and low-flow pulses. Percentiles used to partition flows need to be refined for local stream conditions based on hydraulic analysis.

Group 5 parameters report the rate of rise and fall of flow for a given location and the number of reversals between rising and falling conditions. The rate of rise and fall and the frequency of reversals can be used to assess how rapidly habitat extent is being varied and whether these changes are being increased with a given taking strategy.

The output from the IHA software is useful to characterize the flow regime. Summaries of annual statistics were produced for each of the stream gauges in the study reaches. Annual summaries are a standard product from the IHA software, in both tabular and graphical format. The monthly data begins with the first month of the water year (October) and gives annual statistics based on the water year and not the Julian year. Minimum and maximum daily flows are provided, as well as the dates of the extreme occurrences. Zero days are the number of day that there was no flow at this reach, which generally does not occur in the Grand River watershed. Further explanation of the parameters can be found in the IHA user's manual or in Richter *et al*. (1996).

A standardized process for assessing hydrologic impacts is included within the IHA software. The RVA Method is another analysis frame in which to assess change in a structured manner. This method of determining hydrologic alteration is based on the premise that streamflow has a natural range of variability. The RVA software would plot and determine whether an activity, such as a water taking, would alter the streamflow outside this normal variability. Significant alteration would occur if the streamflow regime is altered more than one standard deviation from the natural variability, which may have ecological consequences. The degree of alteration of the flow regime that can be tolerated by a stream ecosystem needs to be confirmed for local conditions.

The IHA software provides a framework to analyze and diagnose potential impacts. It is an effective diagnostic tool that can be used to analyze streamflow or other time series data. The case studies completed as part of this report provides examples of how the IHA software can be applied to analyze water impacts associated with water takings.

Further information and outputs for the other pilot reaches can be found in Appendix G.

7.1.7 Tennant and Tessmann Instream Flow Techniques

The Tennant method (Tennant, 1976) is a streamflow based, desktop method used to estimate instream flow requirements. It assumes aquatic habitat conditions are similar for streams carrying the same proportion of mean annual flow. Instream flow estimates from the Tennant method are based on a percentage of the annual streamflow at a given location. Tennant (1976) related percentage mean annual streamflow to aquatic habitat conditions. Table 7.9 presents this relationship, and as can been seen from this table the Tennant method uses a two season approach based on mean annual flow (Q_{MA}).

Table 7.9 Habitat conditions for the Tennant instream flow method

***Aquatic-Habitat Condition for Small Streams**	**Percentage of Q_{MA}, April – September %**	**Percentage of Q_{MA}, October – March %**
Flushing Flow	200	200
Optimum Range	60 – 100	60-100
Outstanding	60	40
Excellent	50	30
Good	40	20
Fair	30	10
Poor	10	10
Severe Degradation	<10	<10
Q_{MA} – Mean Annual Flow *Aquatic habitat relationship needs to be confirmed for Ontario		

[Adapted from Tennant, 1976]

Tessmann (1980) modified the Tennant method from a two-season flow method to a monthly-based approach. Table 7.10, from the Prairie Provinces Water Board 1999 Study, summarizes the criteria for application of the Tessmann method.

Table 7.10 Tessmann instream flow method conditions

Situation	**Minimum Monthly Flow %**
1. IF $Q_{MM} < 40\% \, Q_{MA}$	USE: Q_{MM}
2. IF $Q_{MM} > 40\% \, Q_{MA}$ & $40\% \, Q_{MM} < 40\% \, Q_{MA}$	USE: $40\% \, Q_{MA}$
3. IF $40\% \, Q_{MM} > 40\% \, Q_{MA}$	USE: $40\% \, Q_{MM}$
Tessmann specified a 14-day period of 200% Q_{MA} during the month of highest runoff for flushing purposes. Q_{MA}- mean annual flow, Q_{MM}- mean monthly flow	

[Source: Prairie Provinces Water Board 1999, from Tessmann 1980]

The Tessmann method describe in the above assumes a Tennant April to September good condition and an October to March outstanding condition. For the purpose of this study the Tessmann method was further modified by using the Tennant criteria for other conditions to produce a Tessmann Optimum, outstanding, excellent, good, fair, poor and degraded condition.

An MS-Excel spreadsheet was set up to calculate the Tennant and Tessmann instream flow requirements for gauges in the study reaches. In addition to calculating instream flow requirements, the spreadsheet was set up to calculate the Ontario Low Water Response Plan (OLWRP) flow indices (OMNR *et al.*, 2003), for the given stream gauge stations. These indices were calculated for comparison purposes, and can be seen in Table 7.11. The OLWRP flow indices are a 3-tier indicator of low-flows, characterized by a percentage of both long-term average precipitation and streamflow. Higher tier levels indicate a more severe negative departure from the long term precipitation and streamflow values.

Table 7.11 Ontario Low Water Response Plan Flow Indices

Condition	**Indicator**	
	Precipitation	Streamflow
Level I	< 80% of average (3 month and 18 month, average precipitation)	**Spring:** - monthly flow <100% lowest average summer month flow **Other times:** - monthly flow <70% of lowest average summer month flow
Level II	< 60% of average (1 month, 3 month and 18 month, average precipitation) Week with less than 7.6 mm of rainfall	**Spring:** - monthly flow <70% lowest average summer month flow **Other times:** - monthly flow 50% of lowest average summer month flow
Level III	< 40% of average (1 month, 3 month and 18 month, average precipitation)	**Spring:** - monthly flow <50% average summer month flow **Other times:** - monthly flow <30% of lowest average summer month flow

[Source: Ontario Ministry of Natural Resources *et al*., 2003]

Beyond comparison purposes, including the OLWRP streamflow indices serves two purposes. First, comparing these indices to different levels of aquatic habitat condition predicted by the Tennant and Tessmann methods provides a check of the indices against potential environmental impact. This may provide additional justification for these indices. Second, Annear *et al.* (2002) discusses communications as one important component of an instream flow program. The OLWRP could serve as a communication component for a Provincial Instream Flow Program.

All of the parameters from the Tennant, Tessmann, and OLWRP are graphically displayed to compare values to one another and to the annual streamflows. Figure 7.3 is an example of the parameters that were calculated for the Eramosa Above Guelph reach, with the data provided in Table 7.12. Indices presented in Table 7.12 were calculated for other pilot reaches and are presented in Appendix F.

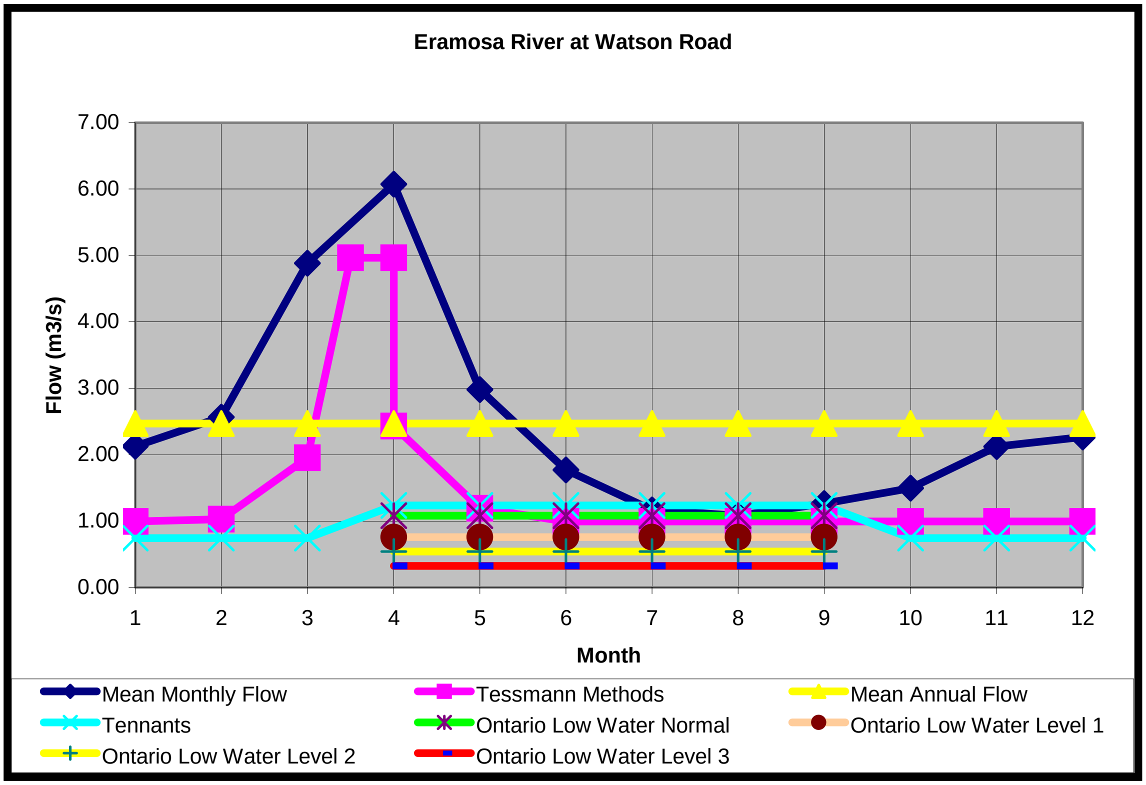


Figure 7.3 Comparison of Tennant and Tessmann methods for the Eramosa Above Guelph

Table 7.12 Comparison of Tennant and Tessmann thresholds and OLWRP indices for the Eramosa River Above Guelph

Month	Mean Monthly Flow (m^3/s)	TENNANTS Method Results (m^3/s)	**Tessmann Method Flows**				**Ontario Low Water Response Thresholds**			
			Excellent (m^3/s)	Fair (m^3/s)	Poor (m^3/s)	Degraded (m^3/s)	Normal Minimum Summer	Level 1	Level 2	Level 3
1	**2.12**	0.74	0.99	0.74	0.50	0.25		1.08	0.75	0.54
2	**2.57**	0.74	1.03	0.77	0.51	0.26		1.08	0.75	0.54
3	**4.89**	0.74	1.95	1.47	0.98	0.49		1.08	0.75	0.54
3.5			4.96	4.96	4.96	4.96		1.08	0.75	0.54
4	**6.07**	1.24	2.43	1.82	1.12	0.61	1.08	0.75	0.54	0.32
5	**2.98**	1.24	1.19	0.89	0.60	0.30	1.08	0.75	0.54	0.32
6	**1.77**	1.24	0.99	0.74	0.50	0.25	1.08	0.75	0.54	0.32
7	**1.17**	1.24	0.99	0.74	0.50	0.25	1.08	0.75	0.54	0.32
8	**1.08**	1.24	0.99	0.74	0.50	0.25	1.08	0.75	0.54	0.32
9	**1.26**	1.24	0.99	0.74	0.50	0.25	1.08	0.75	0.54	0.32
10	**1.49**	0.74	0.99	0.74	0.50	0.25		1.08	0.75	0.54
11	**2.12**	0.74	0.99	0.74	0.50	0.25		1.08	0.75	0.54
12	**2.27**	0.74	0.99	0.74	0.50	0.25		1.08	0.75	0.54
Annual	**2.48**									

7.2 Hydraulic Investigations and Analysis

The hydraulic investigations in each study reach are intended to complement the flow-based investigations. Hydraulic investigations were carried out to fulfill four primary objectives:

1. To allow the construction of detailed hydraulic models to calculate a range of hydraulic versus flow relationships;
2. To define connectivity and bankfull flow thresholds to complement the flow analysis;
3. To support the geomorphologic investigations in each study reach with the end goal of defining geomorphic thresholds; and
4. To investigate the ability of detailed hydraulic models as a means of establishing instream flow requirements in the absence of long-term flow information.

7.2.1 Hydraulic Modelling and Calibration: HEC-RAS

Hydraulic investigations in this study relied upon models produced and maintained by the US Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC). The models HEC-2 and the updated version HEC-RAS, were selected, as they are familiar to water resource professionals and commonly used models.

Existing HEC-2 and HEC-RAS models, if they existed in pilot reaches, were used as a starting point to build more detailed hydraulic models. HEC-2 and HEC-RAS compute flow, velocity, channel depth and other hydraulic parameters in rivers based on cross sections. The primary calculation in HEC-RAS is based on the solution of the one-dimensional energy equation. Energy losses are estimated using friction calculations (Manning's equation) and contraction/expansion calculations. HEC-RAS can be run under steady flow (one flow), or unsteady flows (hydrograph). For the purposes of this study, only steady flow simulations were used. Examples of the output screens for the HEC-RAS model can be seen in Figure 7.4. Detailed information on HEC-RAS, which is freely available, can be found on their website, including the user manual at the following website: http://www.hec.usace.army.mil/software/hec-ras/hecras-hecras.html.

Hydraulic models (e.g. HEC-RAS, previously HEC-2) are commonly used to estimate the water surface elevation during flood flows. These models perform backwater calculations and consider the impacts of culverts/bridges, channel geometry, and roughness of the channel on the water surface for a particular flow. In addition to elevation of the water surface, hydraulic models can output such information as flow area, top width, water depth, velocity, Froude number, and wetted perimeter, to name a few (see Table 7.13).

It was reasoned that a hydraulic model could be employed to estimate changes in various hydraulic parameters due to changes in flow. Investigation of the hydraulic parameters could provide insight into how aquatic habitat or health varies with flow, allowing the determination of inflection points in the hydraulic characteristics, which may be useful in estimating instream flow requirements.

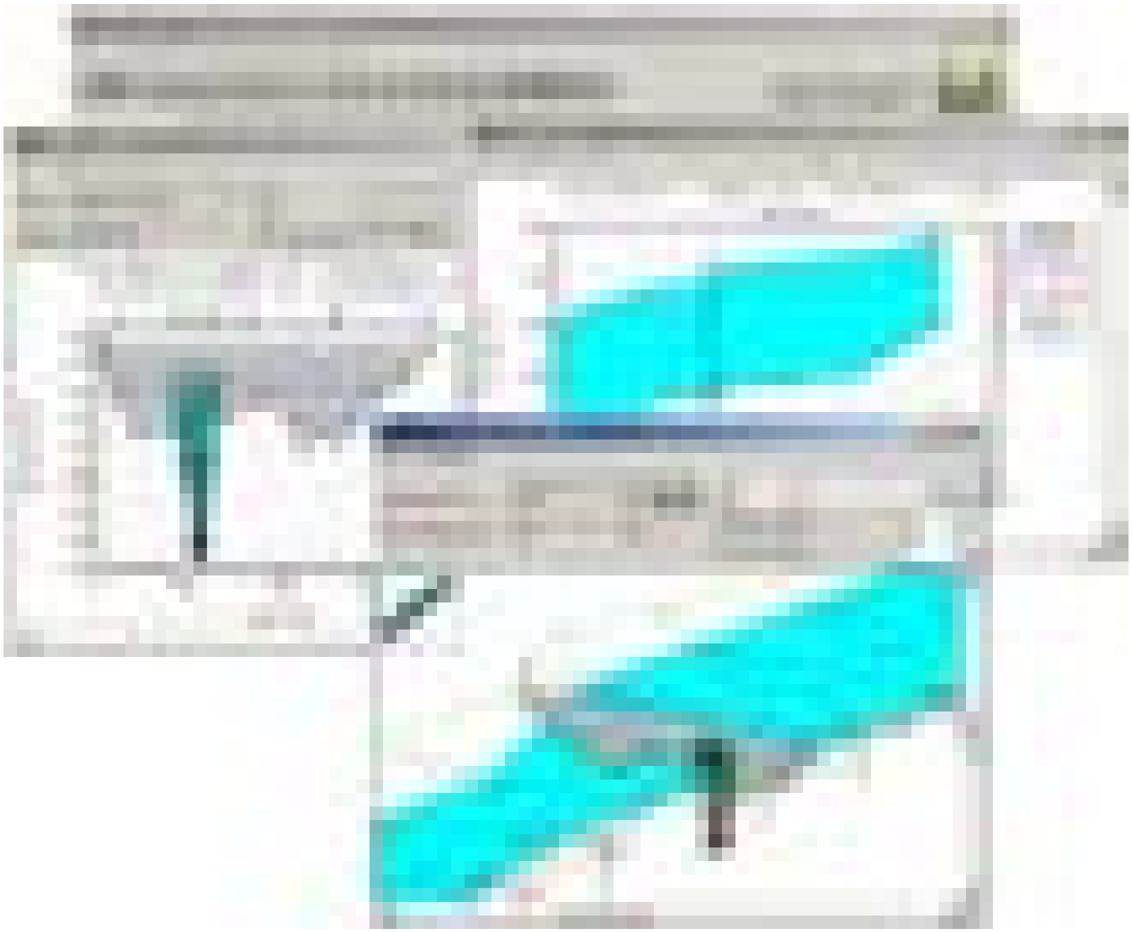


Figure 7.4 Illustration of the HEC-RAS screen output
[Source: USACE, 2004)

Table 7.13 Summary of hydraulic parameters used to interpret hydraulic results

Hydraulic Parameter	Definition	Significance
Flow Depth (m)	Maximum depth of water in cross section	Could be used to determine at which flow, channel connectivity is lost. Personal communication with Jack Imhof (2004) suggests 20 cm of depth needed for connectivity in the Eramosa River Study Reach
Flow Area (m^2)	Area of cross section that conveys flow	Signifies the space available to aquatic life at various flows
Wetted Perimeter (m)	Perimeter of cross section that conveys flow	Determines the amount of submerged channel substrate available
Flow Velocity (m/s)	Velocity of flow in main channel	May be used to assess the limitation for species migration. Movement of specific species is limited at specific velocity thresholds
Froude Number	Criterion of the type of flow present. As Froude number approaches 0, the flow is more tranquil and slower. As it approaches 1, flow is characterized by shallow and fast motion	Identifies pools versus riffles. May be used to identify at which flow riffles are overcome by a pool, or vice versa
Topwidth (m)	Top width of cross section that conveys flow	Useful parameter to identify changes in hydraulic characteristics, can often be used to identify persistent hydraulic conditions
Width to Depth Ratio	Dimensionless ratio calculated by dividing channel width by maximum depth at a given flow	Used in geomorphic calculations and to infer large changes in the hydraulic regime, for example flow becomes confined to the thalweg

7.2.2 Conceptualization of a Low-flow Hydraulic Model

Scale plays a very important role when considering the detail necessary to construct hydraulic models with the ability to model the full range from low to high flows. Existing HEC-2 or HEC-RAS models were available for many of the pilot reaches; however these models were typically constructed with the objective of floodplain mapping. While sufficient to model floodplains, the HEC-2 and HEC-RAS models lacked the detail needed to model low-flow hydraulics.

To properly capture the low-flow hydraulics of a reach, the model cross sections must include riffles and other controls that affect low-flow hydraulics. A conceptual representation of a low-flow reach is presented in plan view by Figure 7.5 and in longitudinal profile by Figure 7.6. These figures illustrate that a low-flow reach could be conceptualized to have three primary elements: pools, runs and riffles. Riffles form control sections that back water up into runs and pools, and are typically the most sensitive to changes in flows. The hydraulics of riffles change more dramatically in response to changes in flow than the corresponding hydraulics of pools and runs. Beyond the construction of detailed hydraulic models in each pilot reach, detailed hydraulic cross sections were also necessary to calculate geomorphologic thresholds.

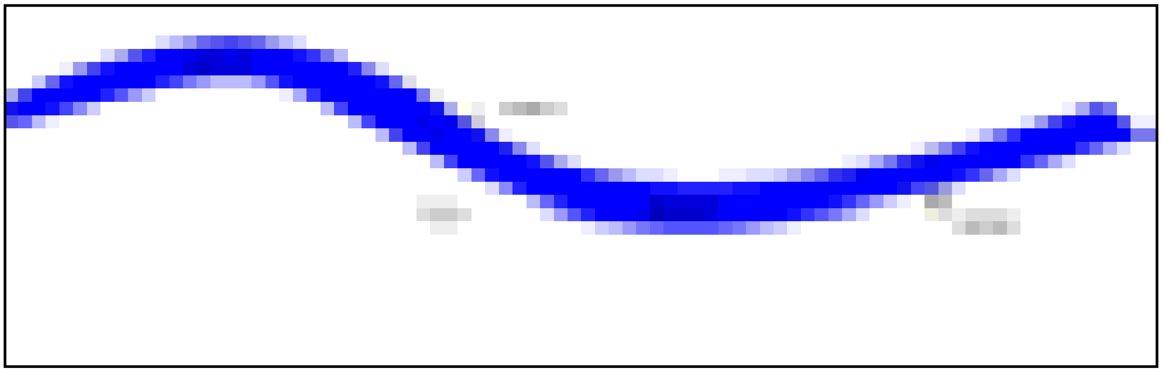


Figure 7.5 Conceptual plan view of a low-flow reach

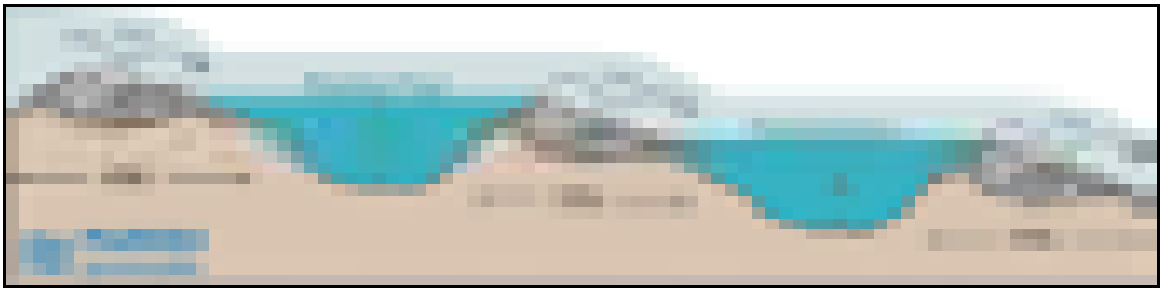


Figure 7.6 Conceptual longitudinal profile of a low-flow reach
[Source: *Parish Geomorphic*, 2004]

The sources for the detailed hydraulic model information are listed in Table 7.14. The level of detail of the hydraulic surveys varies depending on the size of the stream being investigated. The geomorphic surveys completed by *Parish Geomorphic* for this study ranged from 250 m to 5000 metres in length with 10 to 15 cross sections surveyed in each reach. A summary of reach information is provided in Table 7.15. In addition to surveying cross sections, the invert and water surface profiles were surveyed in all but the Grand River Blair reach where only the invert was surveyed. These surveys proved very important to the calibration of the hydraulics model, discussed later in this chapter, as it allowed a check of how well the hydraulic model recreated the surveyed water surface profile. Figures 7.7 to 7.9 provide illustrations of the cross section locations, longitudinal survey and a conceptual cross section view, from the *Parish Geomorphic* report.

Table 7.14 Summary of Hydraulic Model Source Information

Reach	Existing HEC Model	Source of Detail Cross Sections	Geomorphic Survey (Year)	Substrate Characterization (Year)
Grand River Blair	Yes	Partial EA	Yes (2004)	Yes (2004)
Grand River Exceptional Waters	Yes	Exceptional Water Study and 2003 Survey	Yes (2003)	Yes (2004)
Nith River Canning	Yes Old	EC Detail DEM	Yes (2004)	Yes (2004)
Whitemans Creek	Partial	Master Thesis, Geomorphic Survey	Yes (2003)	Yes (2004)
Blair Creek	Yes	Geomorphic Survey	Yes (2003)	Yes (2003)
Mill Creek	Yes	Geomorphic Survey	Yes (2003)	Yes (2003)
Eramosa River	Yes	Geomorphic Survey	Yes (2003)	Yes (2003)
Carroll Creek	No	MNR Habitat Study	Yes (1996)	Yes (1996)

Table 7.15 Summary of Hydraulic Model Reach Information

Reach	Reach Length (m)	Number of Reaches	Number of Cross Sections	Average X-Section Spacing (m)	Average Width of X-Section (m)
Grand River Blair	5000	1	15	330	185
Grand River Exceptional Waters	10,656	1	100	106	160
Nith River Canning	745	1	25	30	28
Whitemans Creek	780	1	10	7.8	15
Blair Creek	170	1	10	17	5
Mill Creek	219.7	1	10	22	8
Eramosa River	379.5	1	10	38	20
Carroll Creek	3805	13	130	29	4.5

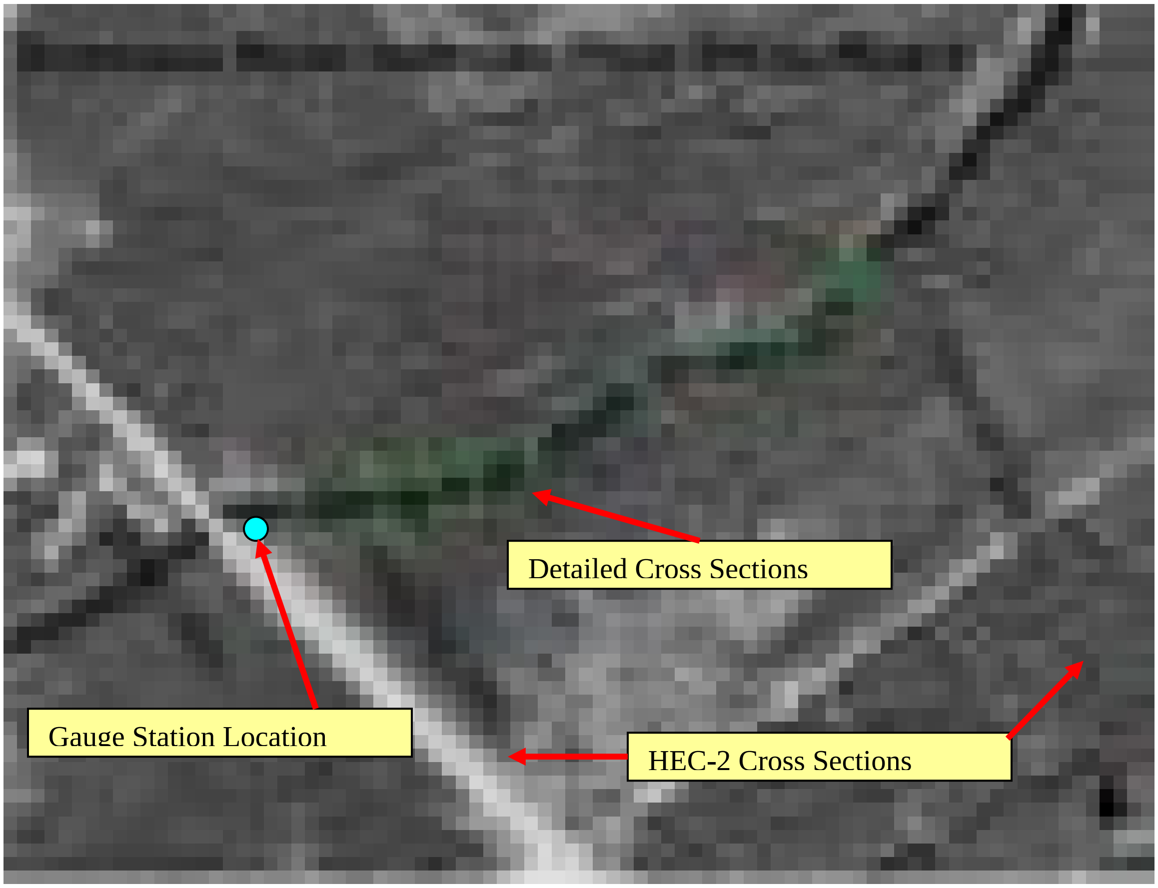


Figure 7.7 Location of Eramosa River pilot reach detailed cross sections

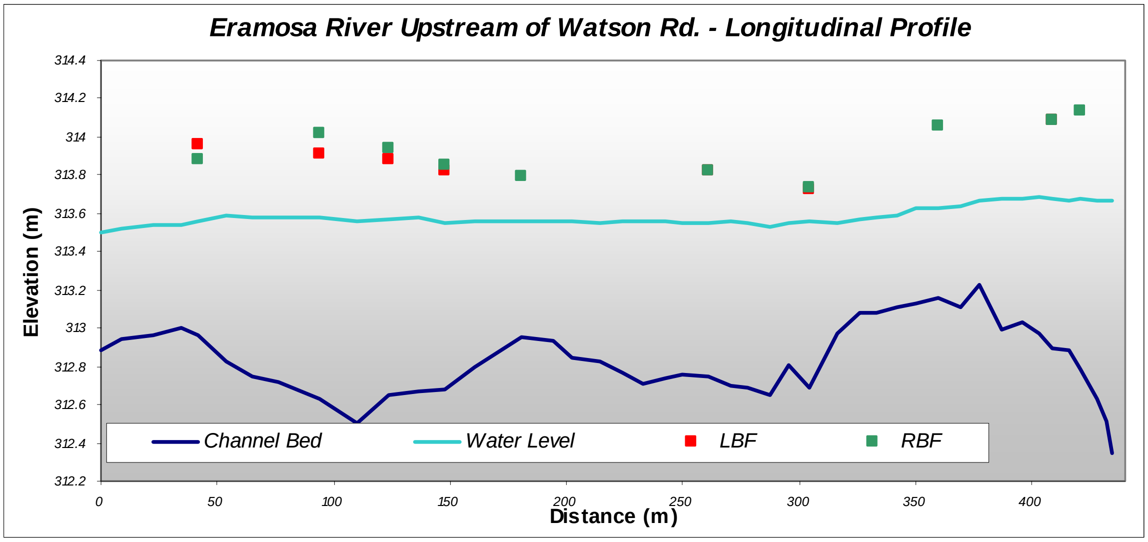


Figure 7.8 Typical longitudinal profile from geomorphic survey

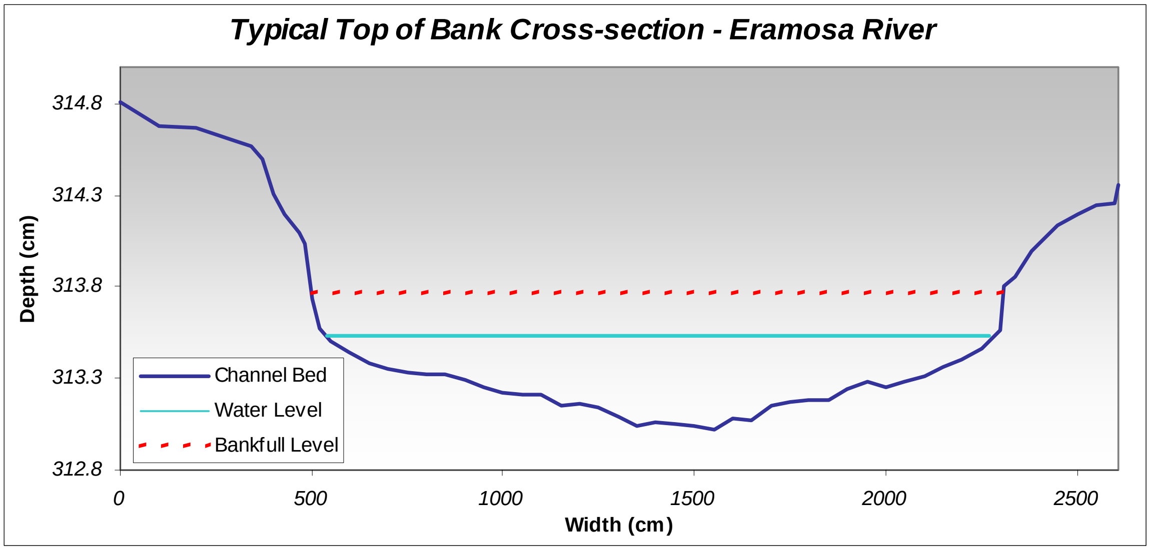


Figure 7.9 Typical cross section from a geomorphic survey

During the course of completing this study, it became apparent that properly capturing riffle hydraulics can be a challenge. Riffles can often be diagonal or curvilinear in shape during low-flows and slowly inundated as flows increase. To properly capture hydraulics of riffles, multiple cross sections should be considered with three as the minimum. The three critical locations of these cross sections are: following the riffle crest, one upstream and one downstream of the riffle crest. Capturing these three cross sections allows the hydraulic changes associated with a riffle to be represented with a hydraulic model. During low-flows, the control is the crest of the riffle; as flows increase the control becomes the channel cross section represented by the sections upstream and downstream of the riffle. The use of three cross sections is an important insight learned from this study and should be incorporated in a field protocol for the construction of lowflow hydraulic models.

7.2.3 Hydraulic Model Development for Eramosa Reach

The critical underpinning of any hydraulics model is the channel geometry. Given that the study is primarily focused on low-flows, very detailed geometry is needed to accurately represent the pool/riffle sequence in the system. Previously, most hydraulic models were used to generate regional floodlines. Channel geometry was usually assumed to be a trapezoidal channel, while more attention was paid to the floodplain geometry. Given that this study was primarily concerned with low-flows, more detailed surveying was needed for the in channel geometry.

Where detailed channel geometry was available from previous studies, this data was incorporated into a hydraulic model for the study area. For areas that did not have such historical data, *Parish Geomorphic* completed detailed evenly spaced surveys over approximately 300 metres, collecting channel invert elevations, water surface elevations and at least 10 bankfull cross sectional profiles. The surveyed cross sections were then used to augment current hydraulic models.

Shown below in Figure 7.10 are the channel inverts with computed water surface for the study area at Eramosa River above Guelph reach. Five different water surfaces are presented, for flows ranging from 0.1 m^3/s to 0.5 m^3/s.

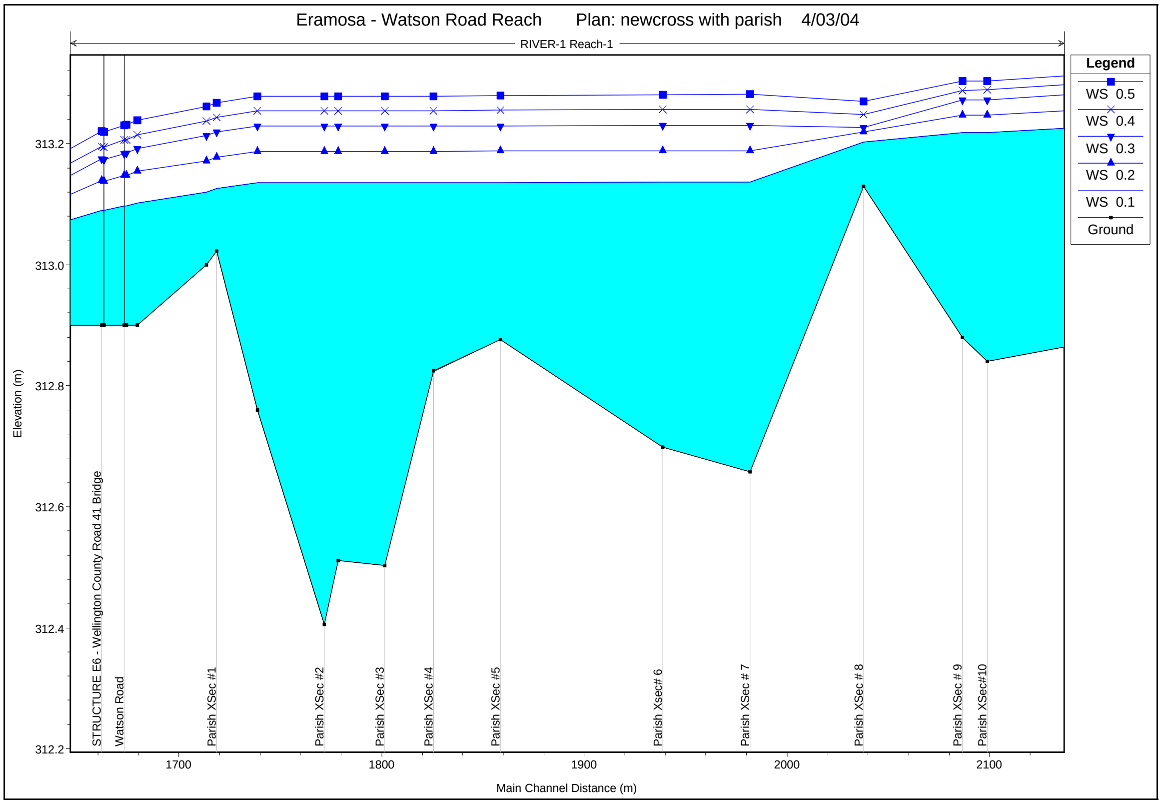


Figure 7.10 HEC-RAS flow profiles for the Eramosa River Above Guelph reach

7.2.4 Hydraulic Model Calibration for the Eramosa Reach

A model must be calibrated to observed conditions to provide confidence in its estimates. For the WSC stream gauge in the Eramosa pilot reach, the flow to stage relationship (also known as a rating curve) was checked against the HEC-RAS model. Comparing the HEC-RAS generated rating curve to the WSC rating curve for the gauge yields the graph in Figure 7.11.

As can be seen in Figure 7.11, the difference between the simulated and observed rating curves is very close to zero through much of the rating curve. Simulated and observed curves begin to diverge at the lower end, although the difference in water surface elevation is very small, approximately 3 – 4 cm. The differences are more clearly seen in Figure 7.12.

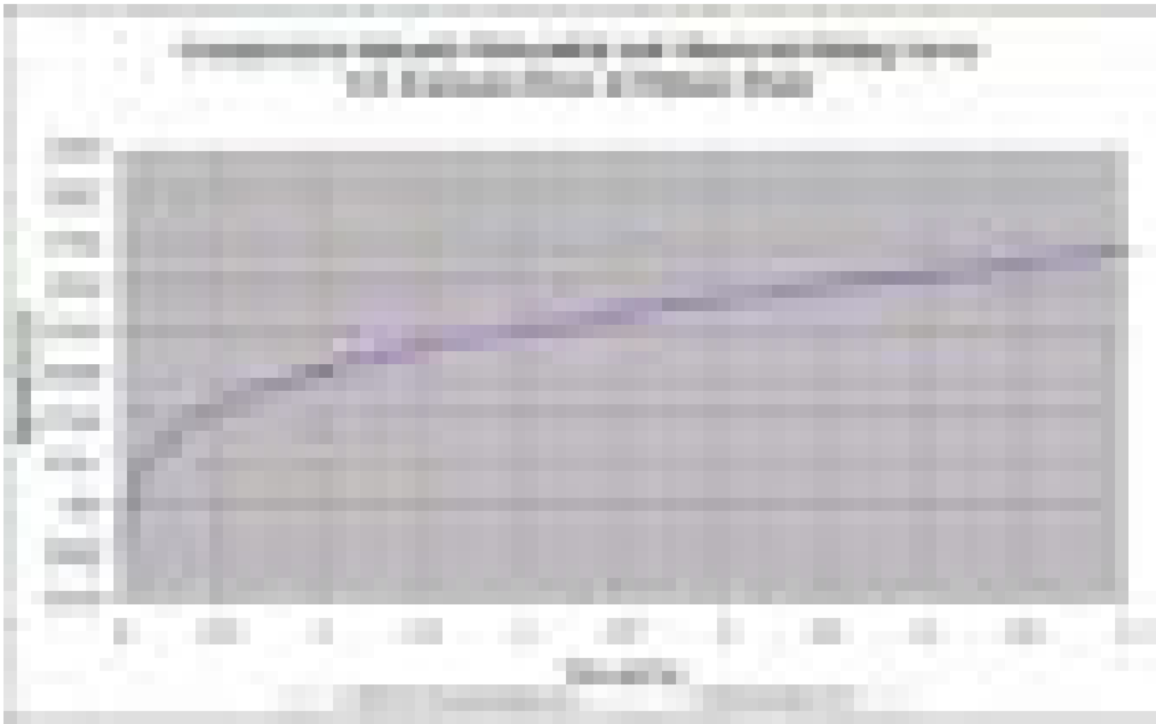


Figure 7.11 Comparison of simulated and observed rating curves for the Eramosa Above Guelph gauge

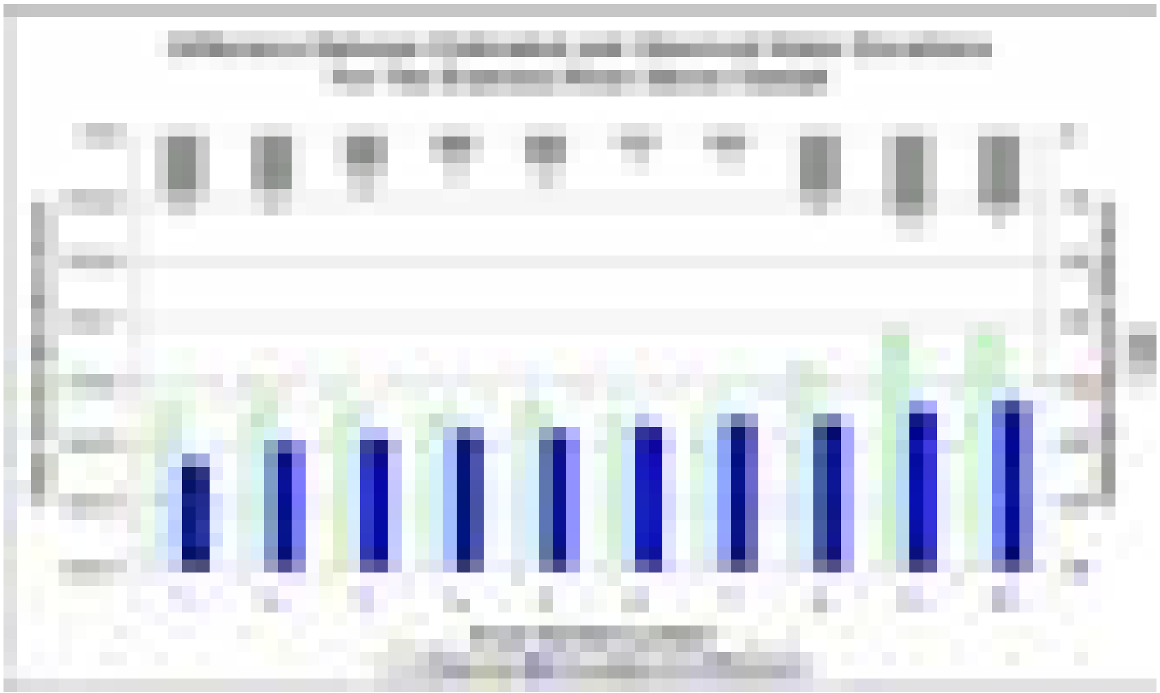


Figure 7.12 Comparison of simulated and observed water profile for the Eramosa Above Guelph pilot reach

Not all locations will be able to rely on a WSC maintained rating curve for calibration purposes. In the absence of an observed rating curve, water surface elevations can be surveyed during the initial survey. If a flow measurement is made at the same time, the modeller then has one point on a rating curve, and can use this for calibration. Furthermore, having one water surface elevation at all cross sections allows the modeller to determine how well the model is representing actual conditions at all points within the study reach.

In terms of calibration, the most widely modified variable is commonly the Manning's coefficient. However, before extensive work is done with this variable, some time should be devoted to determining whether all significant channel characteristics have been picked up in the initial survey work. Given the scale of work that is being undertaken at this level, it is critical that the entire pool/riffle sequence is incorporated into the hydraulic model. What could seem like a fairly insignificant riffle could cause significant backwater effect during low-flows. For this reason, it is crucial that the survey crew understand the reasoning for the survey work and recognize important channel features. In planning this sort of work, provision should be included for a second field survey to obtain further information, if model calibration is not satisfactory.

Once the model has been reasonably calibrated, a number of hydraulic variables can be generated. Table 7.16 presents a sampling of variables available to the modeller from HEC-RAS. While only two profiles (flows) are shown with the results of the Eramosa pilot reach, up to 2000 profiles can be run and output using the HEC-RAS model.

Further analysis can now be done on how the various hydraulic parameters vary with flow, and how they may impact aquatic habitat or health.

Table 7.16 Sample output of HEC-RAS model for the Eramosa pilot reach

River Station	Profile (m^3/s)	Q Total (m^3/s)	Min Ch El (m)	Max Chl Dpth (m)	W.P. Total (m)	W.S. Elev (m)	Vel Chnl (m/s)	Flow Area (m^2)	Top Width (m)	Froude # Chl
Parish Sec#10	0.4	0.4	312.84	0.45	16.78	313.29	0.08	5.29	16.49	0.04
Parish Sec#10	0.5	0.5	312.84	0.46	16.92	313.30	0.09	5.55	16.62	0.05
Parish Sec#9	0.4	0.4	312.88	0.41	18.20	313.29	0.08	4.89	17.72	0.05
Parish Sec#9	0.5	0.5	312.88	0.42	18.41	313.30	0.10	5.17	17.91	0.06
Parish Sec#8	0.4	0.4	313.13	0.12	9.05	313.25	0.77	0.52	8.97	1.03
Parish Sec#8	0.5	0.5	313.13	0.14	11.86	313.27	0.68	0.74	11.76	0.86
Parish Sec#7	0.4	0.4	312.66	0.60	16.13	313.26	0.06	6.36	15.9	0.03
Parish Sec#7	0.5	0.5	312.66	0.62	16.31	313.28	0.07	6.76	16.07	0.04
Parish Sec#6	0.4	0.4	312.7	0.56	20.41	313.26	0.05	7.36	19.73	0.03
Parish Sec#6	0.5	0.5	312.7	0.58	20.56	313.28	0.06	7.86	19.86	0.03
Parish Sec#5	0.4	0.4	312.88	0.38	22.27	313.26	0.07	5.90	22.09	0.04
Parish Sec#5	0.5	0.5	312.88	0.40	22.55	313.28	0.08	6.44	22.36	0.05
Parish Sec#4	0.4	0.4	312.82	0.43	21.66	313.25	0.06	6.63	21.03	0.03
Parish Sec#4	0.5	0.5	312.82	0.46	22.03	313.28	0.07	7.14	21.36	0.04
Parish Sec#3	0.4	0.4	312.5	0.75	20.80	313.25	0.04	11.09	20.53	0.02
Parish Sec#3	0.5	0.5	312.5	0.78	20.99	313.28	0.04	11.59	20.17	0.02
106124	0.4	0.4	312.51	0.74	18.67	313.25	0.04	10.38	18.53	0.02
106124	0.5	0.5	312.51	0.77	18.91	313.28	0.05	10.84	18.75	0.02
Parish Sec#2	0.4	0.4	312.41	0.85	20.13	313.25	0.04	10.39	19.01	0.02
Parish Sec#2	0.5	0.5	312.41	0.87	20.53	313.28	0.05	10.86	19.40	0.02
106084	0.4	0.4	312.76	0.49	17.62	313.25	0.07	5.92	17.56	0.04
106084	0.5	0.5	312.76	0.52	19.05	313.28	0.08	6.37	18.98	0.04
Parish Sec#1	0.4	0.4	313.02	0.22	9.47	313.24	0.37	1.07	9.45	0.36
Parish Sec#1	0.5	0.5	313.02	0.24	10.51	313.28	0.38	1.30	10.48	0.35
106059	0.4	0.4	313	0.24	11.79	313.24	0.28	1.43	11.76	0.26
106059	0.5	0.5	313	0.26	12.28	313.28	0.29	1.72	12.24	0.25
106025	0.4	0.4	312.9	0.32	10.20	313.22	0.22	1.78	10.18	0.17
106025	0.5	0.5	312.9	0.34	10.57	313.24	0.25	2.04	10.54	0.18
106024	0.4	0.4	312.9	0.31	9.40	313.21	0.35	1.14	9.37	0.32
106024	0.5	0.5	312.9	0.33	10.59	313.23	0.36	1.38	10.56	0.32
106019		Bridge								

TERMS:
Q Total – Total Flow
Min Chan El (m) – Minimum Channel Elevation
Mas Chl Dpth – Maximum Channel Depth
W.P. Total – Wetted Perimeter Total
W.S. Elev – Water Surface Elevation
Vel Chnl – Channel Velocity
Froude # Chnl – Froude Number

7.2.5 Hydraulic Model for Nith River at Canning Reach

Less traditional methods were also examined in this study. Environment Canada had previously completed detailed bathymetric surveys to map the surface of the river bottom of the Nith River at Canning. The surveyed points were combined with ground surface elevation points and used to construct a seamless DEM for the area, shown by Figure 7.13.

ARCView was used to generate cross sections from this DEM, which were incorporated into a hydraulic model. An existing hydraulic model provided information on the two bridge structures within the reach. Figure 7.14 is a three dimensional wire mesh schematic of the study area for the Nith River at Canning reach.

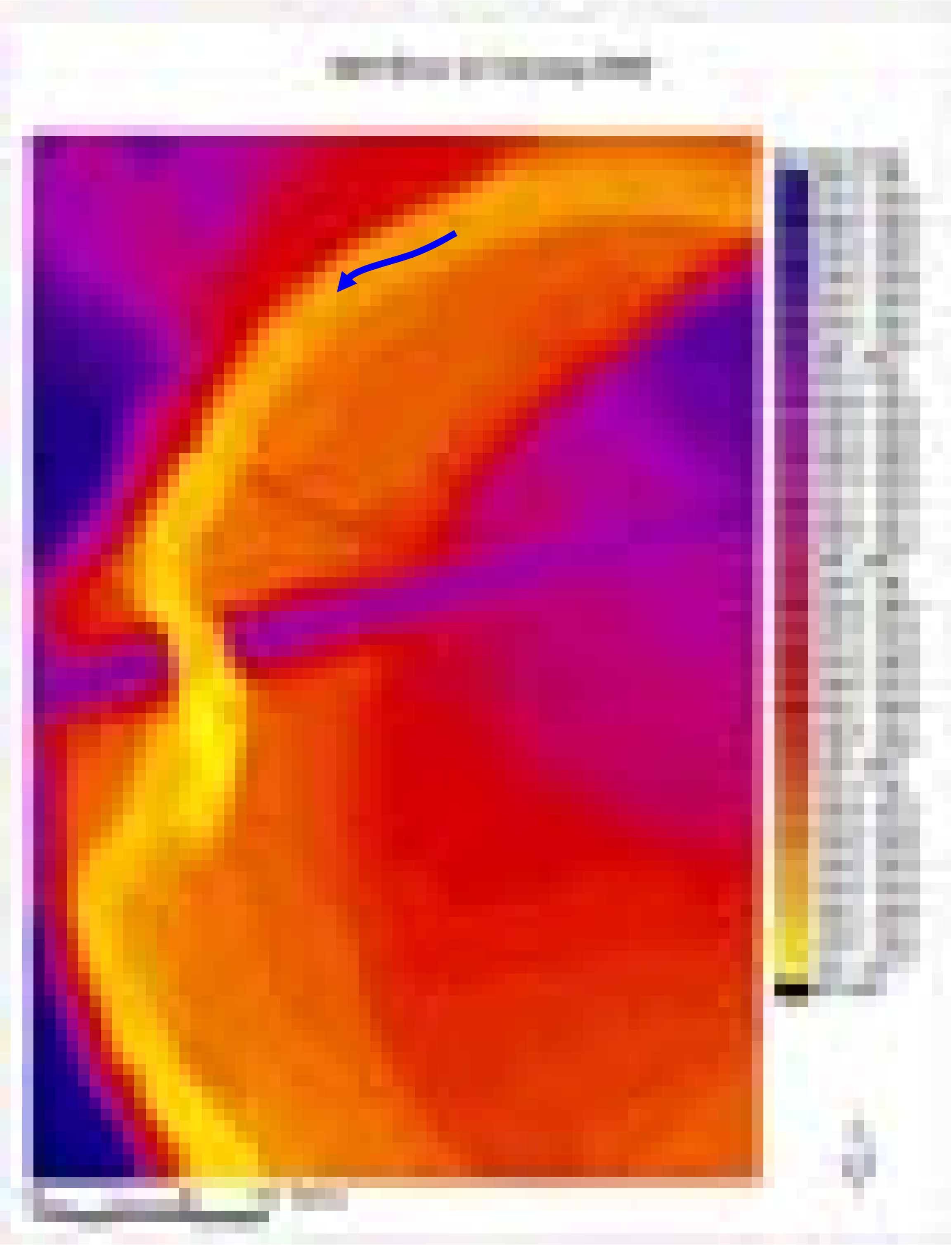


Figure 7.13 Digital Elevation Model Nith River Canning Study Reach

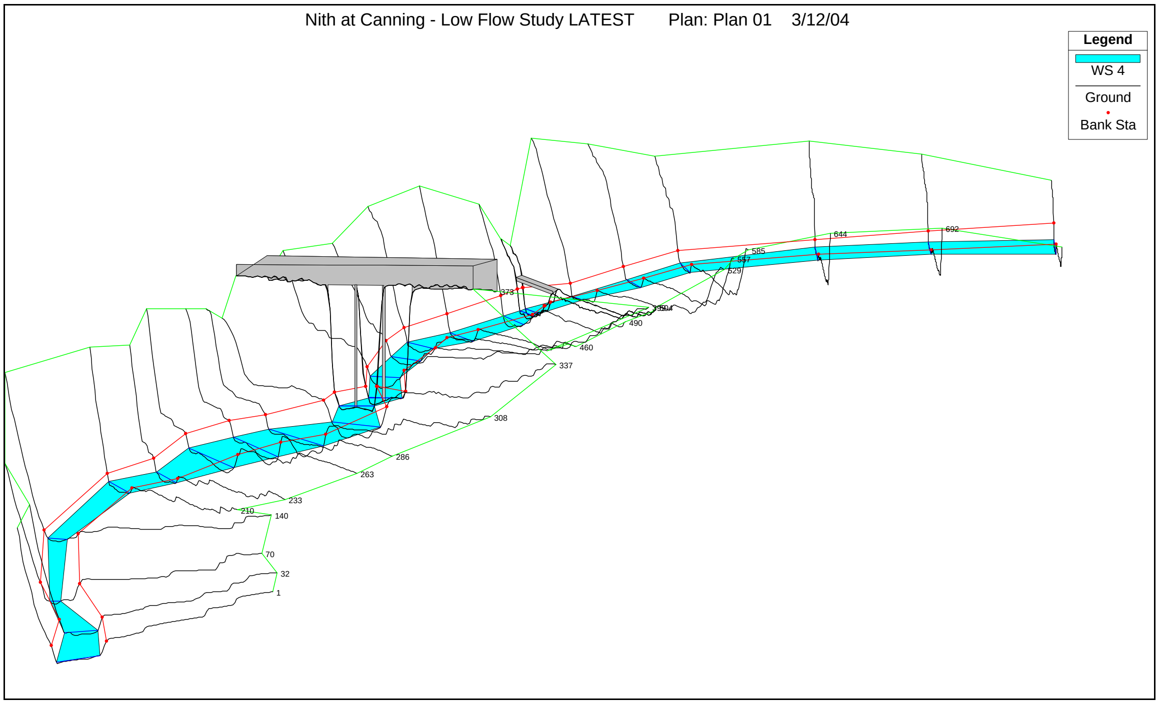


Figure 7.14 Three Dimensional Wire Mesh Nith River Canning Study Reach

Like the Eramosa River study site, calibration was carried out using a WSC maintained rating curve. When calibrating, one must keep in mind that any representation of actual conditions can have errors; a WSC rating curve is no different. Rating curves are generated by gathering a number of manual flow measurements, with associated water surface elevations. Where there have been no measurements for a specified flow, extrapolation is used to expand the stage-discharge relationship (e.g. for extremely low or extremely high flows). This has the possibility of introducing error into the rating curve, which must be considered when using a rating curve for calibration purposes.

The Figures 7.15a and 7.15b illustrate such error. The lower end of the simulated and observed rating curves seems to match quite closely for the Canning gauge. The curves begin to diverge after approximately 200 m^3/s. It was thought that the model was missing a floodplain characteristic that becomes significant at high flows. During the spring freshet in March of 2004, the Nith River was experiencing the highest observed flows since the early 1980's. Seeing an opportunity to make a flow measurement at a seldom seen flow, WSC gauged the Nith River at Canning. The results of that gauging are included on Figure 7.15a. The gauged point, while not agreeing with the WSC gauge-rating curve, falls directly on the HEC-RAS generated curve. This would suggest that the upper end of the simulated rating curve is more accurate than the WSC rating curve. Likewise, with the lower end of the rating curve, shown Figure 7.15b, there would not have been considerable opportunity to gauge the lower end of the curve below 4.0 m^3/s, with the average summer flow at this station being 4.7 m^3/s.

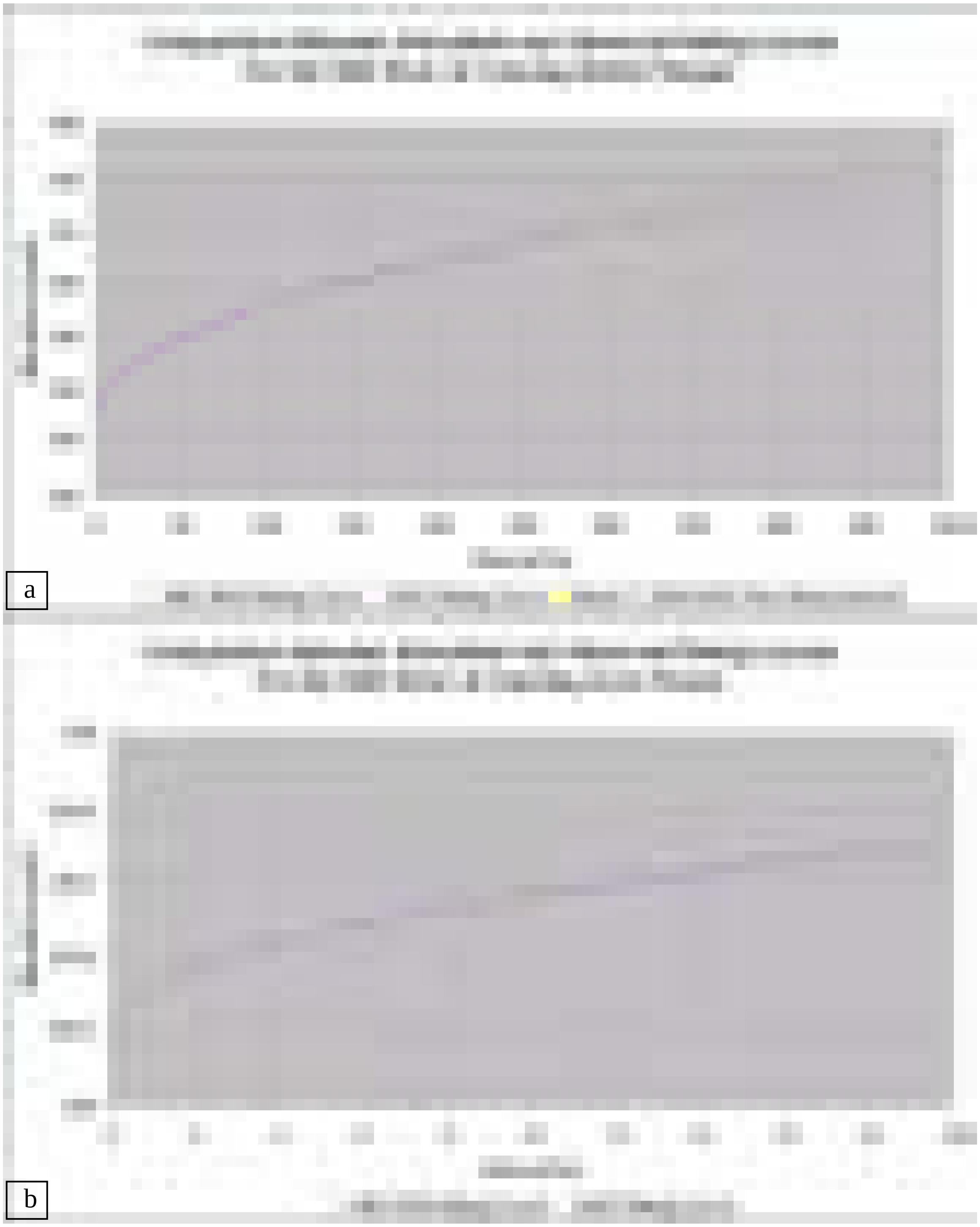


Figure 7.15 Comparison of the observed and simulated rating curve for the Nith River at Canning Reach

Deviation of the lower flow portion of the hydraulic model may be the result of channel features not captured in the digital elevation model that impose hydraulic effects during extreme low-flows. Further field investigation would be needed to confirm the hydraulic model during extreme low-flows. However, the graphs in Figure 7.15 demonstrate the utility a detailed hydraulics model can play in estimating the hydraulic response to different flow conditions. In 2004, a geomorphic survey was completed in the Canning reach. The survey cross sections collected by *Parish Geomorphic* were used to further refine the hydraulic model for this reach.

7.2.6 Hydraulics Modeling Summary

Detailed hydraulic models were created for each pilot reach. Each model was calibrated with available information. Once calibrated, water surface profiles were simulated for a range of flows with HEC-RAS. The output from HEC-RAS was imported into Ms-Excel spreadsheets and standard charts were created to graphically present flow versus various hydraulic parameters for cross sections in each study reach. Hydraulic inflection points were extracted from these charts and organized for comparison against other indices.

Output from the hydraulic models is presented in Appendix D, for all the study reaches. This appendix includes calibration results, charts of channel cross sections and flow versus hydraulic parameter charts.

Results presented for the Exceptional Waters reach illustrate the diminishing returns of additional cross sections. The Exceptional Water reach had over 100 cross sections surveyed within the reach. When results of flow versus selected hydraulic parameters are presented, it is apparent that the high density of cross sections provided very little additional information. This work illustrates that there is a point when adding additional cross sections doesn’t necessarily add additional value or knowledge to the study. A finite number of carefully selected cross section sites can yield the same level of information as blanketing an area with cross sections. It is important when constructing low-flow hydraulic models to capture low-flow controls, as discussed previously (at the end of Section 7.3.2), particularly in the riffle sections.

It became apparent when completing the hydraulic modeling that channel shape plays an important role in the sensitivity of a reach to water taking. An analysis of channel shape is included in Appendix C. The analysis of channel shape is intended to communicate how channel shape affects hydraulic parameters such as wetted perimeter. This may assist water managers when completing initial qualitative assessments of how different reaches may respond to water takings.

The use of hydraulic models in this study demonstrates that detailed low-flow hydraulic models can be constructed with carefully collected cross sections and calibrated to observed water level information. Once calibrated, these models can be used to identify hydraulic inflection points where large changes in hydraulic habitat may occur with a small change in flow. Hydraulic modeling is one option that can be considered in an overall watershed strategy, where limited flow records exist and instream flow requirements need to be established. The overall watershed strategy is further discussed in Chapter 9.

7.3 Geomorphologic Investigation and Analysis

Several factors affect the health of streams. Streamflow and water quality are often recognized as key factors that affect the health of a stream, but the stream’s ability to convey sediment is also important. Dave Rosgen, in his book Applied River Morphology (1996), identifies the stream's ability to convey sediment as being equally important to its ability to convey flow.

A stream's form evolves to come into equilibrium with the flow and sediment regime. Flow abstraction or water taking has the potential to affect a stream's ability to convey sediment. This could upset the flow and sediment equilibrium resulting in erosion or sedimentation. This could also have significant impact to hydraulic habitat that is used by the aquatic community. The purpose of investigating geomorphic thresholds is to understand the flow and sediment transport relationship to avoid impacting the delicate balance between streamflow and sediment transport.

7.3.1 Geomorphologic Thresholds

Parish Geomorphic was contracted as part of the Grand River Instream Flow Pilot study to carry out geomorphic investigations on the selected streams. The intent of these investigations was to identify potential geomorphic thresholds that could be used to assess the impacts of water takings from streams. This section includes excerpts from the *Parish Geomorphic* case study, using the Eramosa Above Guelph reach as an example. Selected excerpts from the *Parish Geomorphic* Report are included in Appendix E, while the detailed investigations by *Parish Geomorphic* are included under separate cover.

The investigation by *Parish Geomorphic* identified four geomorphic thresholds for consideration. These include:

Bed Mobilizing D_{50} Flow
Bankfull Flow
Flushing Flow
Residual Pool Threshold Flow

The bed mobilizing flow is the flow at which the median, or D_{50}, bed material becomes mobilized. This reflects the flow at which a significant portion of the bed material is mobilized which is important to habitat maintenance and creation. This magnitude of flow would be expected to scour pools and riffles, replenishing or creating new habitat through substrate mobilization.

The bankfull flow threshold is the threshold that identifies when out-of-bank flow is expected to occur. Out-of-bank flows are important to the replenishment of nutrient and sediment to the riparian floodplain. Depending on the characteristics of the riparian floodplain, out-of-bank flows may be very important to shallow groundwater recharge.

The flushing flow threshold is conceptually defined as the frequent flows that flush fine sediments from the coarse matrix that comprises a riffle. This flow sweeps accumulated fine sediments from the riffles reducing the potential suffocation of aquatic life present in these areas. Figure 7.16 from the *Parish Geomorphic* report illustrates this concept.

Figure 7.16 Conceptual illustration of fine materials removed by a flushing flow [Source: *Parish Geomorphic*, 2004]

The residual pool threshold flow is the flow at which pools become isolated. This threshold was quantified by identifying the residual pool depth. This residual pool depth is defined as the difference in depth between a pool and the downstream riffle crest. As noted by *Parish Geomorphic*, this flow may be well below the flow needed to maintain connectivity between pools. Figure 7.6 (Section 7.2.2) illustrates the concept of residual pools.

7.3.2 Geomorphologic Thresholds for the Eramosa River Above Guelph

The Eramosa River Above Guelph study reach is discussed in this section; similar geomorphic investigations were completed in other study reaches. A 400-metre reach of the Eramosa River upstream of the Watson Road Bridge was investigated. The Environment Canada “Eramosa Above Guelph” stream gauge is located at the downstream end of this reach. Ten detailed cross sections were surveyed throughout the study reach and a modified Wolman pebble count was used to characterize the substrate. See the full *Parish Geomorphic* report for details. Detailed cross sections from this reach were used to construct the detailed HEC-RAS hydraulic model.

Table 7.17 summarizes the results of the *Parish Geomorphic* case study of the Eramosa reach. Of interest in these results are the limited occurrences of out-of-bank and bed mobilizing flow events. The Eramosa River is a very damped system; high flows are moderated by the presence of disconnected drainage areas (internally drained areas that store water). The *Parish Geomorphic* results reflect this characteristic. The residual pool threshold seems to agree well with connectivity requirements suggested by the detailed hydraulic model constructed for this reach.

Table 7.17 Geomorphic thresholds and exceedances for Eramosa River above Guelph

Statistic or Threshold	Residual Pool Threshold	Flushing Pool Threshold	Bankfull Flow Threshold	Bed Mobilizing Flow Threshold
Threshold (m^3/s)	0.44	5.38	15.5	21.8
Days Threshold Exceeded	14,243	1440	132	61
% Time Threshold Exceeded (%)	95.6	9.67	0.89	0.41

[Source: *Parish Geomorphic*, 2004]

7.3.3 Geomorphic Threshold Summary

All four geomorphic parameters were calculated for each study reach and are summarized in Appendix E. When considering the geomorphic parameters, it should be kept in mind that each reach has unique fluvial characteristics. For example, the Eramosa reach has a large D_{50} value, therefore is less fluvially active than the Blair Creek reach, which has a much smaller D_{50} value.

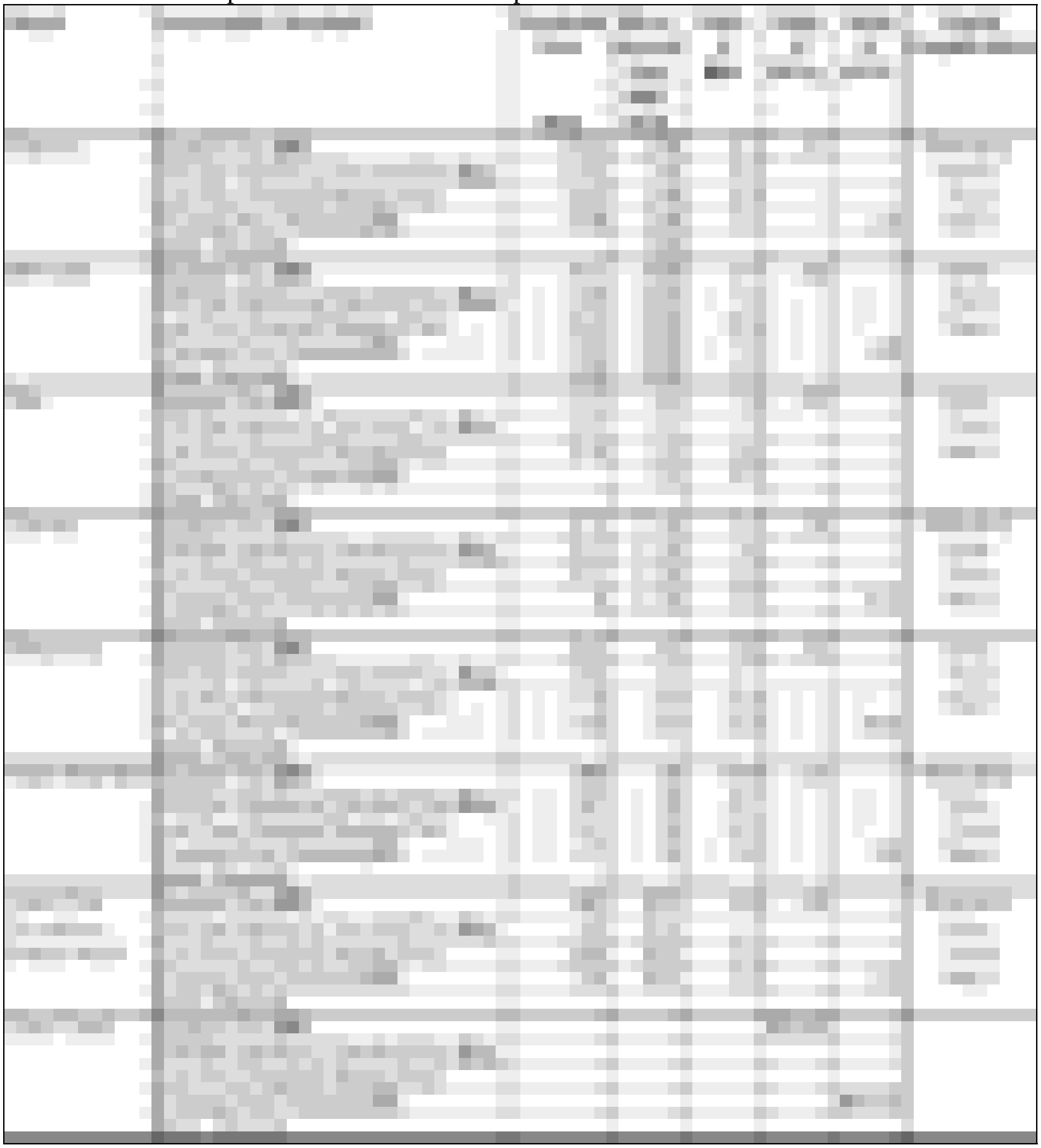
Another measure of fluvial activity is the comparison of the geomorphic bed mobilizing flow to the bankfull flow. This would produce a dimensionless value that could be used to infer fluvial activity of different reaches. The following classification will be used to describe fluvial activity:

Bankfull/D_{50} < 1	Tendency to being moderately inactive fluvial reach
Bankfull/D_{50} > 1 and < 3.5	Moderately active fluvial reach
Bankfull/D_{50} > 3.5	Active fluvial reach

The four thresholds were adjusted depending on the fluvial characteristics of each reach. Additional bed mobilizing parameters were calculated for the Blair Creek reach, which is more fluvially active due to its substrate composition.

A summary of the geomorphic thresholds for each reach is presented by Table 7.18.

Table 7.18 Geomorphic thresholds for the 8 pilot reaches



7.4 Results of Hydraulic and Geomorphic Comparisons

After completing the flow, hydraulic and geomorphic analyses, attention was focused on interpreting the results, with three main objectives. The first objective was to complete a direct comparison of the thresholds, flow statistics and hydraulic results to determine if commonalities exist that could support key thresholds. The second objective was to assess the ability of hydraulic based methods to predict thresholds in the absence of long-term flow records. The third objective was to investigate how the indices might be used to implement instream flow requirements.

Efforts were made during this study to integrate field data collection to satisfy geomorphic and hydraulic modelling objectives. In addition, flow analysis was integrated with geomorphic analysis to check the geomorphic thresholds; this integration is illustrated by Figure 7.17, using the Eramosa River Above Guelph results.

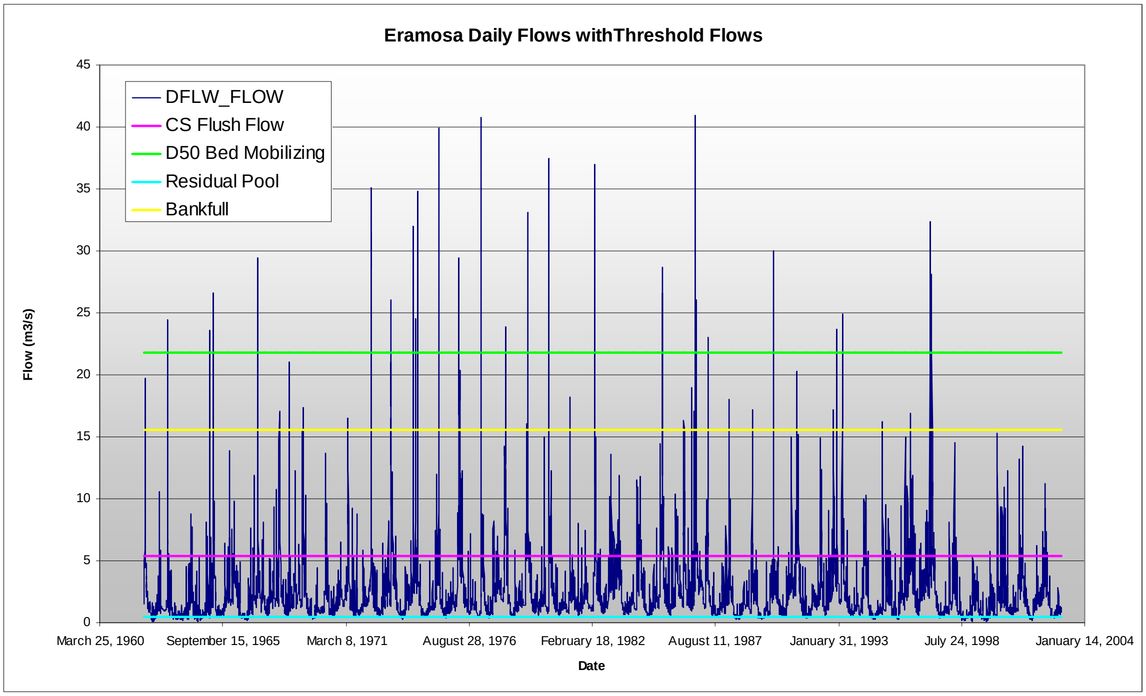


Figure 7.17 Overlay of geomorphic thresholds with Eramosa daily flow series
[Source: *Parish Geomorphic*, 2004]

The results seem to confirm that there is a good correlation between hydraulic inflection points and flow statistics and thresholds, which is important with respect to estimating and implementing instream flow thresholds in ungauged reaches.

7.4.1 Comparison of Threshold, Flow Statistics and Hydraulic Results

In order to interpret the range of flow, hydraulic and geomorphic information, posters were created for the Eramosa River reach to allow quick visualization and cross comparison of such information as flow and hydraulic parameters. The posters were also used to visualize the information summarized by the IHA software and were an attempt to communicate information to different disciplines to facilitate discussion. The Eramosa reach was used as a test case to develop methods of analyzing and interpreting information, which were than applied to other reaches.

Three posters were created in total (see Appendix I, back cover sleeve). The first poster presents the daily flow series for the period of record. A chart is created for each year; all charts used a common scale to facilitate comparison between years. This first poster is used to illustrate the variability, magnitude and timing of high and low-flows. It illustrates that some years have little or no spring runoff and that the timing of spring runoff is variable. It also illustrates the variability of the supply; the stream used to support takings is dynamic therefore the taking strategy may also have to be dynamic.

The second poster in Appendix I presents several tables and charts. Running average flow tables are presented along with the 7Q flow statistics. It presents the results of flow based IFN techniques for comparison against the flow regime and other methods. Annual percentile plots of total flow and baseflow are presented to illustrate the dynamic nature of the flow regime. Ranked duration curves of percentile flows are also presented to help summarize the flow regime. Decadal plots of total flow and baseflow are presented to illustrate annual variation of the flow regime from one year to the next. This poster also presents the high flow statistics and flow series. The overall intent of the poster is to illustrate the dynamic nature of the flow regime and the compressed variability during the low-flow season.

The third poster presents daily flow series for each reach with the 25th and 75th percentile limits identified. These are the percentile limits used by the IHA software. The standard summary table from the IHA software output is presented along with the results from the hydraulic and geomorphic analyses.

The posters help illustrate the variability of the flow regime and graphically illustrate the meaning of some of the statistics summarized by the IHA software. Posters could not be created for all reaches in this study, however the posters presented illustrate how information may be organized to communicate information amongst the broad range of disciplines involved in this sort of study.

After an initial interpretation of the information, spreadsheets were created that listed the various statistics, thresholds and hydraulic inflection points for each reach. Flows were picked off for key hydraulic inflection points to allow direct comparison with flow-based techniques. Hydraulic inflection points were often inferred from hydraulic results from the riffle sections in the reach. A visual inspection was carried out of the hydraulic results to identify inflection points. The key hydraulic parameters chosen were: flow depth, wetted perimeter, width to depth ratio and Froude number. The results from each of the reaches will be discussed in detail.

Detailed summaries of the indices comparisons may be found in Appendix F. This appendix includes tables containing ranked indices and flow statistics, along with charts graphically presenting indices and statistics. The calculated flow statistics and selected indices were compared with the indices calculated from regional models contained in OFAT. A comparison with OFAT was included since it is one tool that could be used to transfer information to ungauged locations. Understanding the limitations of the OFAT tool an important consideration during the comparison.

7.4.2 Eramosa Reach Results

The Eramosa River reach has a C-type channel form and is relatively inactive fluvially. Results for the Eramosa reach are presented in Appendix F-2. When compared to the Tessmann method, the results for this reach show agreement in some key flow ranges. First, the 7Q series of statistics that infer severe drought conditions agree with the Tessmann threshold for a poor summer condition and fall below the flow needed to maintain connectivity of pools. These statistics also agree with the OLWRP Level 3 indices. This range of flows suggests a severe condition and thus water taking should not occur in this flow range. Flows may recede to this range during a drought condition, however water takings should not force flows into this range. In summary, there is good agreement between extreme low-flow statistics, Tessmann poor quality conditions and the OLWRP Level 3 indices.

The next grouping of flows is in the 0.5 to 0.54 m^3/s range. This range of flows is bounded by the 7Q2 statistic and the OLWRP Level 2 condition. The flow needed to maintain the connectivity of pools, estimated using the HEC-RAS hydraulics model for this reach, is also within this range. The flow connectivity value was also based on a minimum criterion of 20 cm flow depth, recommended by Imhof (pers. comm., 2004). The hydraulic model predicts a flow of 0.5 m^3/s is required to meet the 20 cm depth criteria for the Eramosa study reach. Other hydraulic inflections occur in this flow range suggesting flows have receded to the lower channel thalweg. Takings below this range would be expected to affect habitat space and affect connectivity of pools. Thus, water takings should not force flows below this flow range and as a minimum, takings should be managed to maintain connectivity of pools.

The next grouping of flows is in the 0.75 to 0.8 m^3/s range. This range of flows includes the Tessmann summer flow fair condition, the 60% total summer flow duration statistic and the OLWRP Level 1. This range suggests some impacts have occurred, however based on the Tessmann method, conditions are still fair for flows slightly below half the normal summer baseflow.

The next flow range is 0.9 to 1.1 m^3/s, which is the flow range of the minimum average summer month flow, and the same flow used to establish a normal condition for the OLWRP. Several hydraulic inflection points occur slightly below the minimum flow during the summer months. This likely suggests that the flow has receded to a level that is normally wet and free of terrestrial vegetation. It could also be considered a flow range to which the channel has adjusted over time to efficiently convey frequently occurring flows. Once flow falls below this range, hydraulic changes occur in the width to depth ratio and the wetted perimeter slope, at which point impacts are anticipated. The channel and its ecosystem most likely adjust to the minimum summer month's flow as the normal carrying capacity of the local system.

The final flow range identified was about 1.5 m^3/s. This flow range equates to 50% of the average annual flow. Hydraulic inflections in wetted perimeter and Froude number occur in this flow range. Statistics suggest that 50% of the time water would be present in this flow range; therefore the channel would adjust to efficiently convey these flows. Hydraulic changes begin to occur once flows fall below this range.

High flow results were also investigated. A comparison of thresholds and flow statistics for high flow, defined here as flows greater than the mean annual flow, are illustrated in Appendix F-2. Results in this flow range suggest there is agreement amongst different techniques. The flushing flow estimated using the geomorphic techniques (Parish, 2003) agree well with the flood flow predicted by the Tessmann method. The flushing flow is predicted to occur more frequently than once a year. The bankfull flow and bed mobilizing flow occur more frequently than the 2-year flow and less frequently than the annual flood.

In general, the results for the Eramosa River suggest the Tessmann method tends to agree well with other statistical and hydraulic methods used to predict instream flows. It also appears the OLWRP indices for the Eramosa River agree well with instream flow thresholds.

It should be recognized however, that the Tessmann method is based on monthly mean flows. A monthly mean implies flows on average are above the mean 50% of the time and below the mean 50% of the time. Application of any instream flow method must recognize this variability when developing a taking or management strategy. To illustrate the variability of the supply, Figure 7.18 overlays the Tessmann method instream flow requirements on the percentile flows, for the Eramosa River. This figure illustrates three important points; the variability of supply, the timing of the spring runoff and the implications of using the Tessmann method. The variability of supply is clearly demonstrated by the fluctuations of the flow in the figure. The timing of the spring runoff varies from basin to basin and thus the spring flushing flow requirement of the Tessmann method should be adjusted to align with the timing of the individual basin. The third point to draw from this figure is that applying the Tessmann method suggests water would typically not be available for more than 50% of the time for takings from July 1st through October 1st.

The Tessmann method is a relatively simple desktop procedure and therefore should only be used to scope issues or used as a guide to indicate where further investigation is required. It should not be used as the sole determining basis for instream flow requirements or with respect to the issuance or denial of a PTTW.

The results for the Eramosa River suggest hydraulic inflection points can be identified that infer normal and persistent flow ranges. In addition, hydraulic models could be used to estimate flows needed to maintain connectivity of pools. This suggests hydraulic models could be a means of estimating critical flow ranges in the absence of long-term flow data. Detailed field protocols would be required to collect the necessary information needed to construct the hydraulics models and experienced hydraulic modellers would be needed to construct the models and interpret results. In addition field flow measurements would be required at critical times of the year to verify the hydraulic model and confirm predicted critical flows. These sorts of details would need to be included in a detailed field protocol.

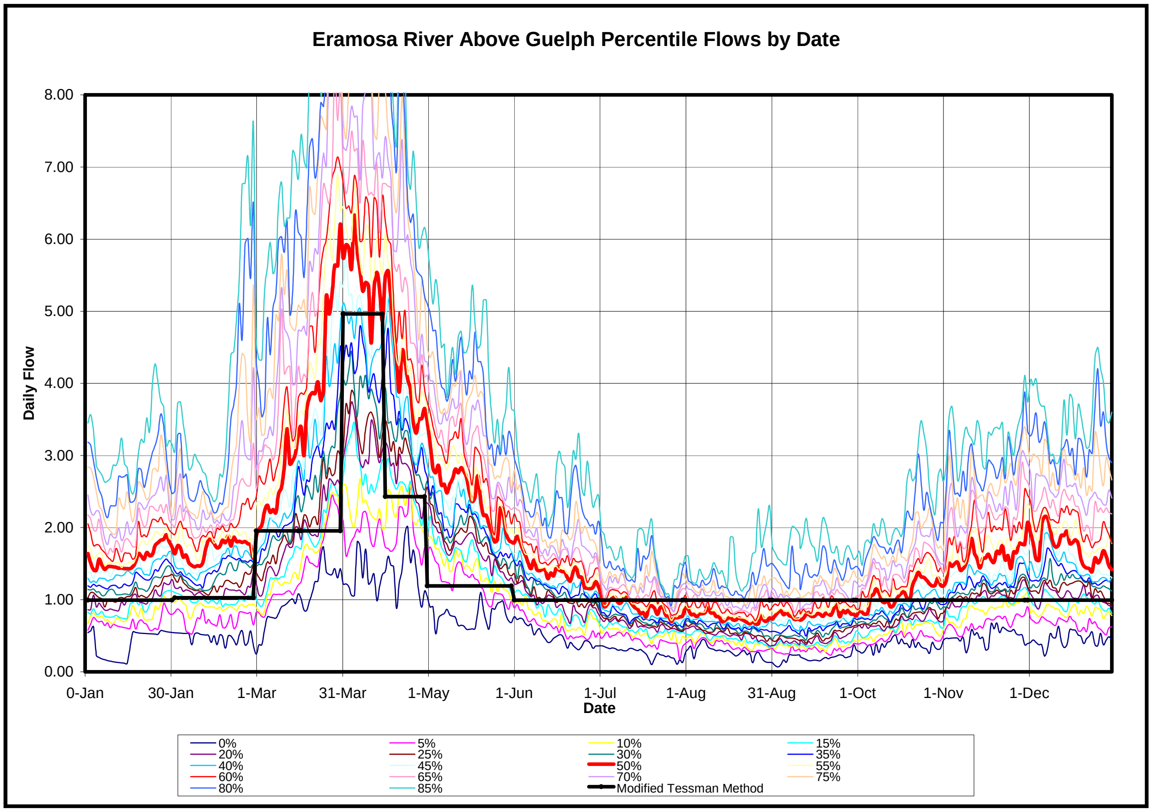


Figure 7.18 Daily flow percentile plot for Eramosa Reach with Tessmann method overlaid

7.4.3 Mill Creek Results

The Mill Creek reach has an E-type channel form and could be classed as a fluvially active reach. The channel form in this pilot reach greatly affects the indices and hydraulic characteristics. As stated previously in this chapter, channel form plays an important role in the sensitivity of a reach to changes in flow, and this type of channel form is less sensitive to changes in flow until extreme low flows are encountered, other channel types are sensitive to changes in flow under less extreme conditions. Hydraulic inflection points are subtle since riffles are not present in this reach. This type of channel form is sensitive to dewatering of the riparian root zone, since the channel stability is dependent on vegetative control. Therefore, if vegetation is lost due to dewatering, channel adjustment may result.

The indices and flow statistics for this reach are presented in Appendix F-4. The results for this reach show a general agreement with the Tessmann method and OLWRP key flow index ranges.

For extreme low-flows, less than 0.2 m^3/s, the results of the Tessmann method support other indices and statistics. Several hydraulic inflection points occur for flows less than 0.2 m^3/s, suggesting dramatic changes in habitat below this flow. Flows less than 0.2 m^3/s are in the range of the extreme 7Q statistics. It must be kept in mind the period of record at this gauge is short (approximately 14 years), and a longer period of record is needed to confirm the 7Q statistics. The OLWRP Level 2 condition is just above 0.2 m^3/s, while the Tessmann method indicates poor quality below this flow, which could be expected. Note that connectivity with respect to fish passage is not a concern in this reach due to the channel form; even at extreme low-flows, fish passage is still maintained.

The 0.2 m^3/s and 0.3 m^3/s flow range bounds the OLWRP Level 1 and 2 conditions, and the Tessmann method predicts fair quality in this range. Just below a Level 1 condition is a critical flow depth with respect to maintaining the root zone for riparian vegetation (0.28 m^3/s). Several hydraulic inflection points also occur just below a Level 1 flow condition. The geomorphic residual pool threshold (0.32 m^3/s) is just above the Level 1 condition. This implies the residual pool threshold may not be a good indicator for channels that are not controlled by riffles as is the case for the Mill Creek reach.

The OLWRP conditions bound the discrete ranges in this reach. The Tessmann flushing flow over-estimates the geomorphic flushing flow estimated for this reach. This is likely related to differences in the composition of substrate material in this reach and reaches where the Tessmann method was developed. It is assumed that the Tessmann method was calibrated on reaches having much coarser substrate material.

Comparison of the Tessmann method to flow percentiles in the Mill Creek reach yields similar results to those found for the Eramosa reach. Figure 7.19 presents a comparison of the percentile flows and the Tessmann criteria. Comparing the Tessmann method to the flow percentiles suggests that between July 1st and October 1st, in excess of 50% of the time, no water would be available for taking.

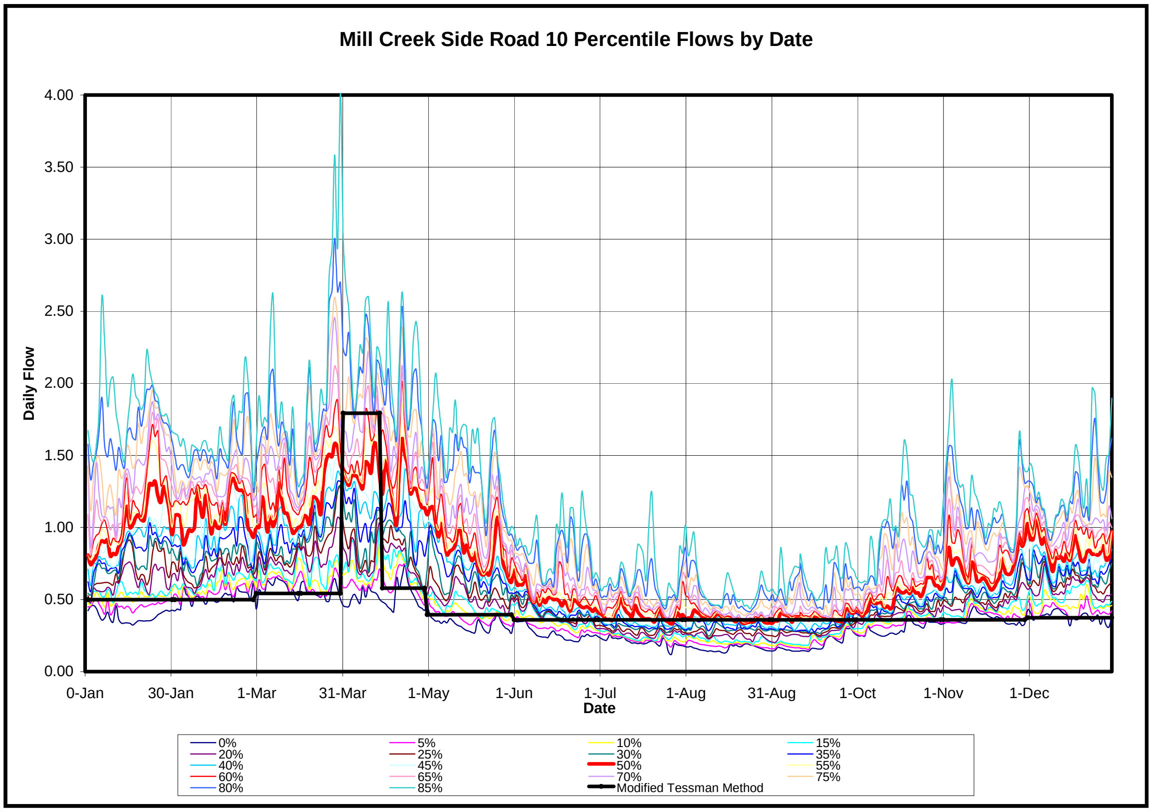


Figure 7.19 Daily flow percentiles for Mill Creek with Tessmann method overlaid

Based on the results for Mill Creek, a cut off flow of 0.28 m^3/s should be considered for water takings. This corresponds to the flow at which the root zone of riparian vegetation is predicted to be dewatered.

7.4.4 Blair Creek Results

The Blair Creek reach has a C-type channel form and is fluvially active. The Blair Creek watershed is within the urban boundary of the City of Kitchener and Cambridge. This reach was selected to investigate how instream flow requirements might be considered in an urban development situation. Thresholds for the existing condition are discussed in this section, while the future urban development condition is discussed later in this chapter. Further results for this reach are presented in Appendix F-3.

The Blair Creek has some unique characteristics that became evident as this reach was analyzed. For instance, very little surfacewater drainage discharges to this stream for two main reasons. First, the surface geology of the Blair Creek catchment is composed of outwash sand and gravels that are very porous and therefore readily accept water. Second, there are large internally drained depressions in this watershed. These two factors combine to limit the amount of surfacewater drainage to Blair Creek and result in significant recharge which acts to maintain baseflows in this stream. A third factor affecting flow in this stream is the constant regional groundwater discharge from the Waterloo Moraine. These factors all combine to create a stream that is well buffered from surface runoff, which also has a very constant baseflow. The result is a stream that operates in a very confined flow range. This stream could be characterized as a groundwater driven stream in its present condition.

The period of streamflow record for this stream is less than 5 years (1998 to 2003), which is too short for statistical analysis. A continuous GAWSER model was originally constructed for this stream as part of the 1996 subwatershed study. It was refined and calibrated to observed streamflow data in 2001 and recently has been further refined as part of a municipal servicing study (Stantec, 2004). The continuous model was updated with flow and climate information to October 2003 producing a continuous simulation period of 1960 to 2003. Simulated data from the continuous GAWSER model was used to represent the existing condition and future developed condition analysed in this study. Flow statistics and indices presented in Appendix F-3 rely on simulated existing condition information from the calibrated continuous GAWSER model.

The unique characteristics of this stream produced unique results (see Figure 7.20). The Tessmann method and the OLWRP conditions do not work well in this situation. The OLWRP conditions have been tested and derived from streams that have much more variability, the same applies to the Tessmann method. Applying either the Tessmann method or the OLWRP method to this stream results in indices that predict a healthy stream condition at values outside the current range of flow observed in this stream. Currently, this stream operates between 0.18 m^3/s and 0.23 m^3/s in the summer months over the 1960 to 2003 period of record. The Tessmann method predicts an outstanding condition at 0.14 m^3/s, and the OLWRP Level 1 also occur at this flow, which is below the minimum daily of 0.17 m^3/s observed during the 1960 to 2003 period.

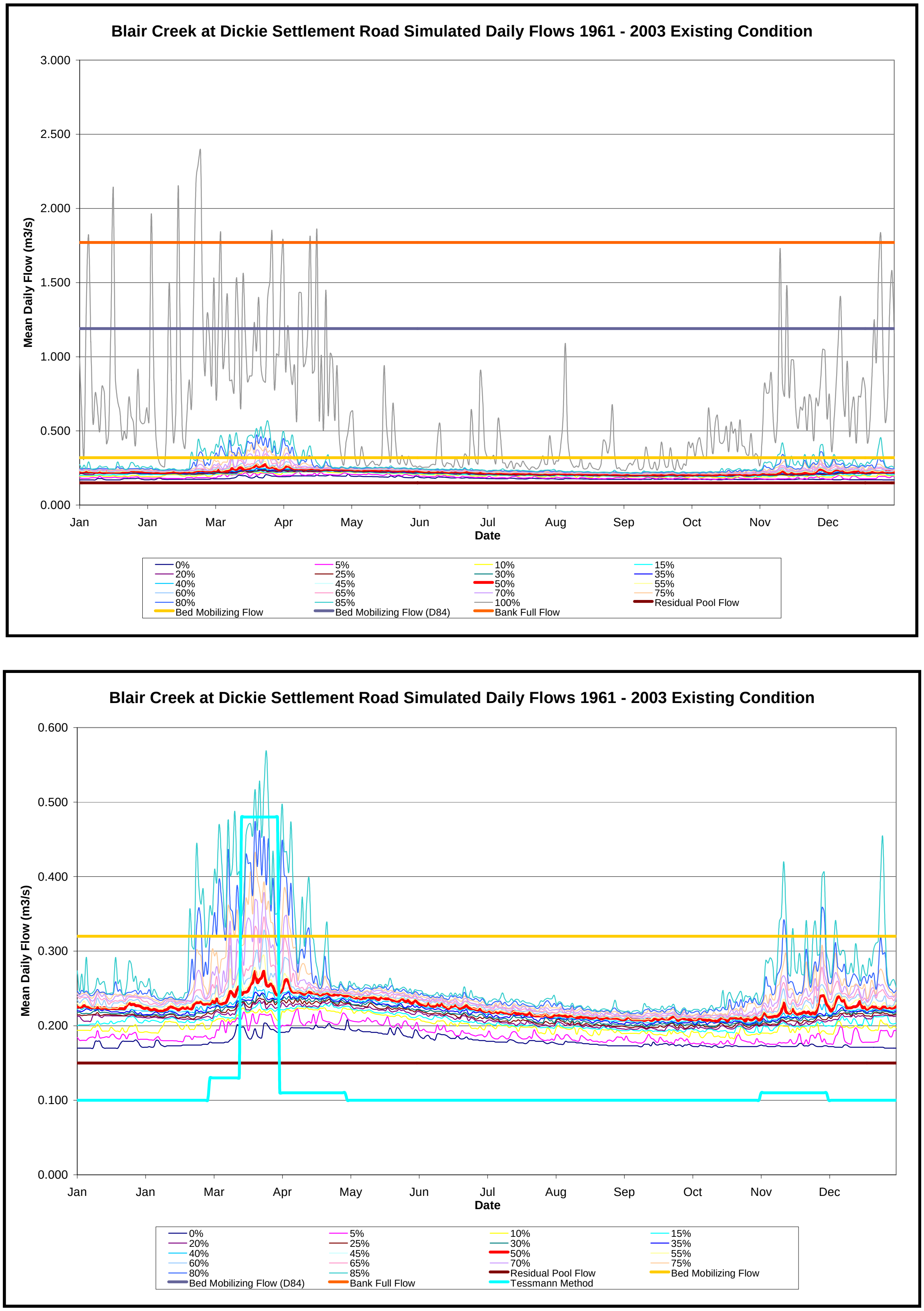


Figure 7.20 Daily flow percentiles for Blair Creek with Tessmann method overlaid

In addition to this stream operating in a very tight flow range, the stream is sensitive from a fluvial perspective to a small change in flow. The mean annual flow for this stream is estimated to be 0.24 m^3/s, while the geomorphic bed mobilizing flow is 0.32 m^3/s. Even slight changes in runoff associated with urban development of the watershed could increase the frequency of bed-mobilizing flows, resulting in channel adjustment and erosion of the current stream bed. This is an important consideration from an urban development perspective. No flushing flow threshold to flush riffles was calculated for this reach by *Parish Geomorphic*. The feasibility of establishing a flushing threshold will be further explored.

The thalweg is not well defined in this channel and the bed is mobile. These combine to result in very subtle hydraulic inflection points. Further interpreting the information presented in Appendix F-3, the hydraulic indices indicate several hydraulic inflection points occur below 0.2 m^3/s. This index is very close to the mean annual flow of 0.24 m^3/s.

The results for Blair Creek are suggesting it would be difficult or impossible to take water from this stream without have negative impacts. The stream operates in a very tight flow range and has a very mobile bed. Considering these constraints, takings would not be recommended that reduce the duration of D_{50} flows or out-of-bank flows. Generally, no takings when flows exceed 0.32 m^3/s and no takings that would lower flows below 0.2 m^3/s the point at which several hydraulic inflections occurs. Overlaying these constraints implies little or no takings from this stream.

This particular stream is somewhat characteristic of a cold, headwater stream. Results from this pilot reach imply taking from headwater cold water streams are likely not practical.

7.4.5 Whitemans Creek Results

Whitemans Creek is a cold water tributary of the Grand River and is seasonally under heavy water taking pressure resulting primarily from agricultural water takings. Through the study reach, Whitemans Creek has a C-type channel form and would be classed as fluvially active.

The Whitemans Creek at Mount Vernon stream gauge is located in the study reach. It has been in operation since 1962. Flows recorded at this gauge have been affected by water taking, so it was not possible to confidently adjust data from this gauge to better represent a natural flow condition. Daily flows were not adjusted and published flows from Water Survey of Canada were used as received when completing flow analysis for this site.

The indices tables and charts presented in Appendix F-5 show good correlation between flow statistics and conditions predicted by the Tessmann method. The Tessmann poor condition occurs just above the 7Q5 statistic. The OLWRP Level 2 and the Tessmann fair to poor condition occur at the same flow (0.86 m^3/s), slightly below where connection for fish migration is first lost, at 1.0 m^3/s. The OLWRP Level 3 condition occurs above a Tessmann poor condition, below a 7Q2 and in a range where several hydraulic inflection points occur. The Level 3 condition flow is currently at 0.52 m^3/s, which is below the point where there is significant loss of connection for fish migration. Consideration should be given to increasing the OLWRP Level 3 threshold condition to above 0.8 m^3/s, however if the OLWRP Level 3 threshold is increased to 0.8 m^3/s, consideration should also be given to increasing the Level 2 condition to 1.0 m^3/s. The geomorphic residual pool, 50% summer flow statistic, 60% of annual baseflow, Tessmann fair condition and several hydraulic inflection points fall in the 1.2 to 1.3 m^3/s range. The 1.6 to 1.8 m^3/s flow range includes the geomorphic flushing flow threshold, OLWRP normal condition, Tessmann good condition and 60% total flow percentile. The geomorphic bed mobilizing flow of 3.06 m^3/s is much less than the flushing flow predicted by Tessmann of 8.73 m^3/s. As discussed previously, this difference in thresholds can likely be attributed to the Tessmann method being calibrated on streams with much coarser substrate material. Overall, the indices and statistics for this reach seem to be complimentary.

The Tessmann method overlaid on the daily flow percentiles is illustrated by Figure 7.21. This figure illustrates that the Tessmann threshold for taking lies below the 50% flow percentile from approximately mid June to late October. This coincides with the period of high agricultural irrigation demand. Although the flow percentiles may be affected by takings in the raw data, it does reveal the fact that the highest demand for water occurs during the period of the year when it is least available. This issue is amplified during periods of drought. The indices information presented in Appendix F-5 is useful from the standpoint of helping identify a cut-off flow or minimum flow that should be maintained, which appears to be a flow of between 0.8 to 1.0 m^3/s. The Whitemans Creek example will be further discussed as a case study later in this chapter.

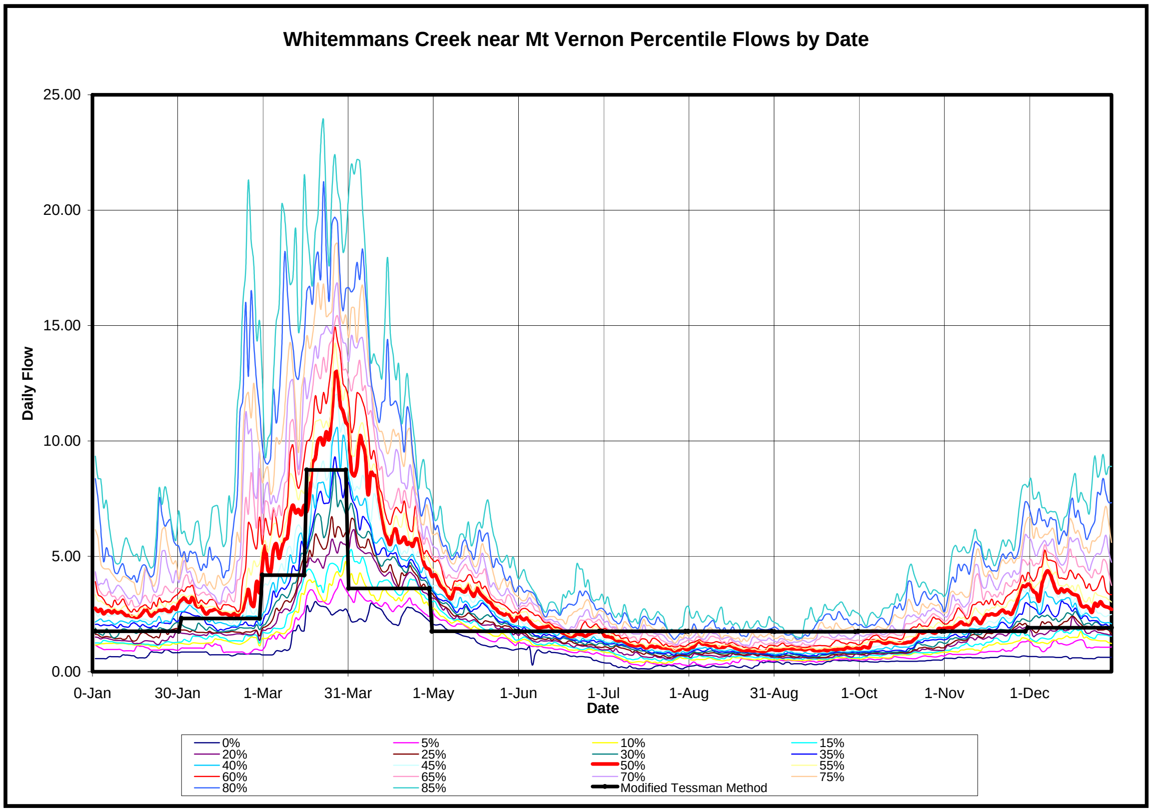


Figure 7.21 Daily flow percentiles on Whitemans Creek with Tessmann method overlaid

7.4.6 Nith River Canning Reach Results

The Nith River is a major tributary of the Grand River with primary water takings being municipal and agricultural. Through the study reach this river has a C-type channel form and would be classed as a moderately active fluvial reach. A stream gauge has been operated by the Water Survey of Canada at the location of this reach since 1948. This gauge provided an excellent flow record to complete the flow analysis.

The indices and flow statistics for this reach are presented in Appendix F-1. The results for this reach show good agreement with the Tessmann method, but the OLWRP levels seem to be too low. Referring to the table of indices in Appendix F-1, the geomorphic residual pool, Tessmann poor and the OLWRP Level 3 condition are below the majority of the 7Q low-flow statistics. The OLWRP Level 2 condition is below the 7Q2 statistic, which is also on the low side. The residual pool threshold, at a value of 0.21 m^3/s, indicates the approach used to calculate the residual pool threshold did not work in this reach. There appears to be a distinct grouping in the 2 to 2.25 m^3/s range which is the hydraulic range where connection for fish passage is lost at several cross sections. The next grouping is in the 3.5 m^3/s range, which corresponds to a Tessmann fair condition, several hydraulic inflection points, and the range at which connection for fish passage is first lost. The OLWRP normal condition occurs at 4.2 m^3/s, 60% of the total annual flow and a Tessmann good condition occur at a flow of 4.5 m^3/s. Normally, the OLWRP normal flow falls in the same range as the Tessmann good condition, and therefore appears to be on the low end for this reach. The next range is 5.25 to 5.7 m^3/s, which corresponds to a Tessmann excellent condition. The Tessmann flushing flow corresponds with the geomorphic bed mobilizing flow in this reach.

When interpreting the results in Appendix F-1, along with the flow percentile information, a cut-off flow or minimum flow in this reach of 2.5 to 2.6 m^3/s would seem to be indicated. This doesn't agree well with current OLWRP thresholds. Based on the results from this study for the Nith River reach, the OLWRP indices for the Canning gauge should be reviewed and, if necessary, revised.

An overlay of the Tessmann method against flow percentiles is presented by Figure 7.22 for the Nith River at Canning reach. Results in this figure indicate limited water would be available for taking from June 1st through to mid November. It is worth noting the tight range of summer low-flow (Figure 7.22). The lower Nith River receives regional groundwater discharge from the Waterloo Moraine, which provides a relatively constant summer baseflow. The case study for this reach will analyse takings in this reach and compare them with the flow statistics and thresholds.

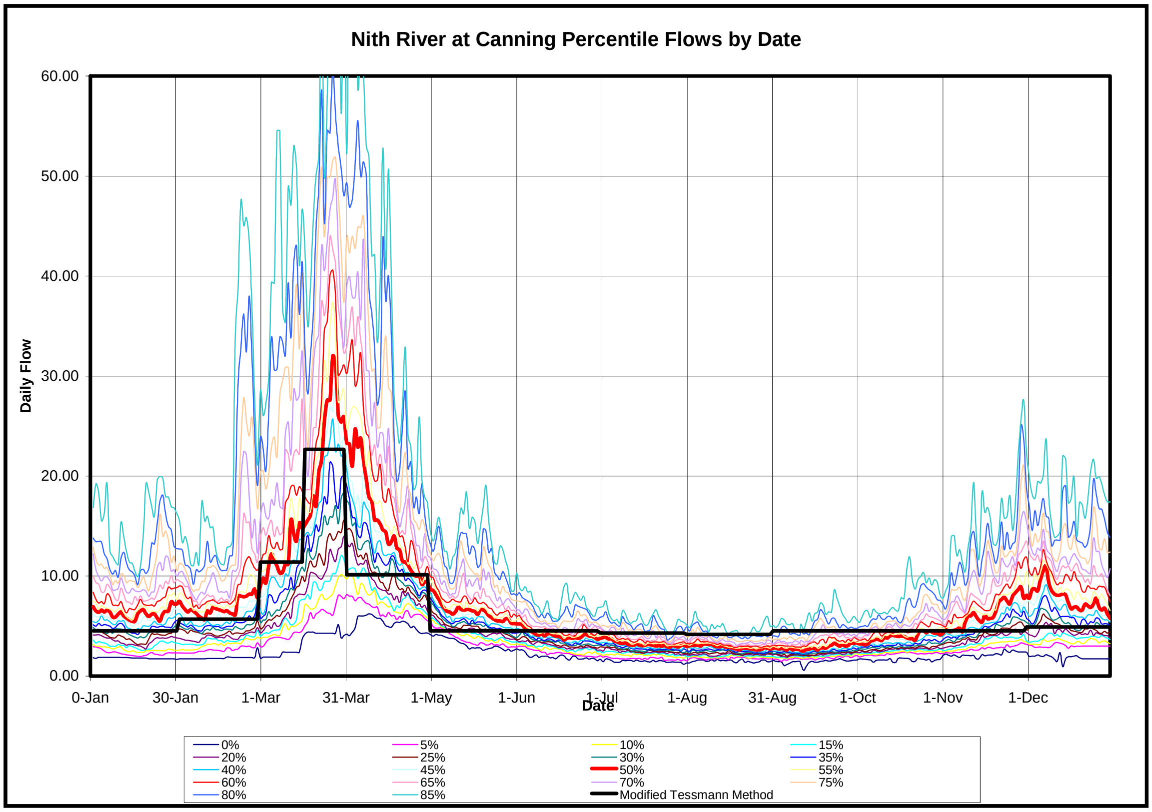


Figure 7.22 Overlay Tessmann method for daily flow percentiles Nith River Reach

7.4.7 Grand River at Blair Reach

The Grand River is regulated through the Blair pilot reach. This reach is one of the most impacted reaches of river in the watershed. Immediately upstream of the Blair reach, the Kitchener sewage treatment plant discharges treated effluent and further upstream of that, the Region of Waterloo withdraws water directly from the Grand River for its Mannheim municipal water supply. The GRCA operates its Doon stream gauge downstream of the Region of Waterloo withdrawal and upstream of the Kitchener STP outfall. A minimum summer low-flow target of 9.9 m^3/s was established at the Doon stream gauge as part of the Grand River Basin Study (GRIC, 1982). This target is intended to be 9.9 m^3/s prior to the Region of Waterloo surfacewater taking. The Region is permitted to take 16 million gallons per day which corresponds to 0.9 m^3/s. Therefore, the low-flow target at the Doon gauge when the Region is withdrawing water is 9.0 m^3/s from May 1st through September 30th. A summary of the Doon low-flow target is presented in Table 7.19.

Table 7.19 Doon low-flow target volumes during the year

Date	Low-flow Target (m^3/s)	
May 1 – Sept 30	9.9	(before Mannheim water-taking of 0.9 m^3/s)
Sept 30 – Dec 31	7.1	(before Mannheim water-taking)
Dec 31 – Feb 29	2. 8	(before Mannheim water-taking)

During the summer low-flow period, in excess of 90% of the flow in the Grand River can be water released from storage in upstream reservoirs. Therefore, this reach can be classed as highly regulated. The Speed River joins the Grand River part way through this reach. The drainage areas upstream and downstream of the Speed River are 2622 km^2 and 3402 km^2, respectively. The Water Survey of Canada operates the Grand River Galt stream gauge immediately downstream of this reach; the drainage area to the Galt stream gauge is 3538 km^2. One reason for studying this reach was to compare the current low-flow target against other indices, hydraulic inflection points and flow statistics.

The Grand River at Blair study reach is a warmwater fishery and the channel can be classified as a C-type channel form with a moderately active fluvial regime. Further detailed results for this reach are presented in Appendix F-6.

Reviewing the information in Appendix F, the following observations can be made. There are distinct flow ranges that emerge from the table and charts presented in Appendix F. There appears to be a lower thalweg in the 4.5 m^3/s range based on hydraulic inflection points. This range is just above the 7Q low-flow statistics, the Tessmann poor conditions and corresponds with an OLWRP Level 3 condition.

The next flow range occurs at 6.5 to 7.0 m^3/s. This range has several hydraulic inflection points, corresponds to a Tessmann fair to poor condition and the geomorphic residual pool threshold. Several hydraulic inflection points occur in the next flow range between 7.5 to 8.5 m^3/s, suggesting there is potential for a loss of aquatic habitat. The next range, between 9.5 to 10.5 m^3/s, corresponds to a Tessmann fair condition, an OLWRP Level 1 condition and includes a few hydraulic inflection points. Some channel adjustment has likely occurred given flows are often in or slightly above this range. The final flow range that stands out is the range from 12.5 to 14 m^3/s, which corresponds to several flow statistics. For example, 50% of the summer flow falls at the top of this range. The Tessmann excellent and outstanding condition fall in the 16.5 m^3/s flow range. The Tessmann flushing flow is approximately half the geomorphic bed mobilizing flow. This can be explained by the large substrate found in the Grand River in this reach. The substrate in this reach was likely much larger than substrate in streams where the Tessmann method was developed. The other geomorphic thresholds seem to make sense; the bankfull threshold is exceeded less frequently than expected, owing to the fact this is a regulated reach and upstream reservoirs are operated to reduce flooding.

The thresholds, indices, statistics and hydraulic inflection points seem to compliment each other in this reach. Consideration should be given to refining the OLWRP Level 2 and 3 criteria for regulated reaches; a tighter range between Level 1, 2 and 3 would make more sense for this reach. It would also make more sense if the OLWRP Level 2 was in the 8.5 m^3/s range and if the OLWRP Level 3 was in the 7.0 m^3/s range. There is little opportunity to change the low-flow target for this reach, as upstream reservoir storage was optimized to provide as much flow on a reliable basis as possible during the summer months. What the results seem to suggest, is that the low-flow target is appropriate just above the 8.5 m^3/s range where several hydraulic changes occur. The case study dealing with regulated reaches later in this chapter will deal with how knowledge gained from this work can be implemented into day-to-day operations and management of the regulated reaches. It should however be recognized that the channel form in regulated reaches will adjust to the regulated flow regime.

The percentile flow plot for Grand River at Doon is presented by Figure 7.23, which illustrates the Tessmann good condition flow criteria against the daily flow percentiles.

This figure illustrates the low-flow target at the Doon stream gauge is not met all the time. It has a reliability of 95%, meaning that 5% of the time flows would be at or below the low-flow target. Figure 7.23 also illustrates that 50% of the time, flows are operated in a range predicted as being a good condition by the Tessmann method. General observations tend to confirm the Tessmann assessment in this reach.

The final point to note about this reach is the effect of aquatic vegetation on water levels. Aquatic plants fill up a portion of the channel in the summer months and can back up water. When the hydraulic model was calibrated for this reach, two hydraulic models were created. One model accounted for the backwater due to aquatic vegetation and the other model assumed no backwater due to aquatic vegetation. The Manning roughness coefficient was adjusted to reflect the backwater effects. The models were calibrated to observations from the staff gauge established in this reach. The backwater effect is in the order of 0.3 (m). The hydraulic inflection points discussed in the above analysis assume a non-backwater condition. The effects of backwater tend to dampen hydraulic changes related to changes in flow and can create anoxic zones along the fringes of the river during specific periods of the year.

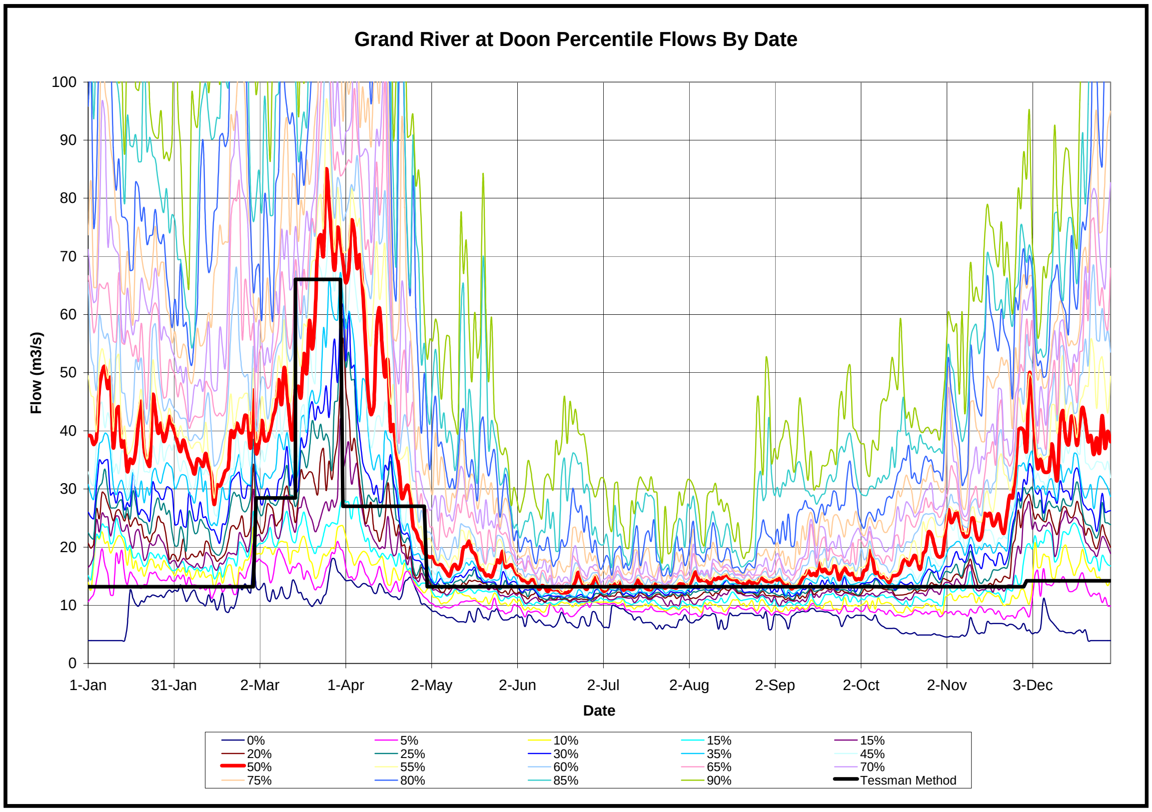


Figure 7.23 Overlay Tessmann method on daily flow percentiles Grand River at Doon

7.4.8 Grand River Exceptional Waters Reach

The Grand River is regulated through the Exceptional Waters pilot reach. This reach starts just downstream of Paris and extends to the City of Brantford. Whitemans Creek joins the Grand River mid way through this reach. The City of Brantford withdraws water in the order of 0.5 m^3/s, at the downstream end of the reach, upstream of the Brantford stream gauge. A minimum summer low-flow target of 17 m^3/s was established at the Brantford stream gauge as part of the Grand River Basin Study (GRIC, 1982). During extreme summer low-flow periods, 60% of the flow in the Grand River at the Brantford gauge can be from water released from storage in upstream reservoirs.

The Grand River through the study reach is a warmwater fishery, with a C-type channel form and could be classed as a moderately active fluvial reach. Results for this reach are presented in F-7 and F-8 of Appendix F, as the reach was broken into two distinct sections; one ends upstream of the confluence with Whitemans Creek and the other begins downstream of the confluence. Flows in the upstream reach were adjusted for the contribution of Whitemans Creek. Geomorphic thresholds were calculated in the upstream reach.

Reviewing the information in Appendix F, the following observations can be made. A large number of cross sections (in excess of 100) were organized for analysis of these two reaches. There were a couple of findings with respect to the hydraulic plots for this reach, as presented in Appendix D-6 and D-7. First, the cross sections echoed the same results, meaning additional cross sections did not necessary add value to the analysis in this report; they did however provide additional confidence in the results. The results tended to suggest that carefully selected cross sections, collected in an appropriate manner, provide sufficient information to characterize the hydraulic characteristics of a given reach. The second key finding was that the hydraulics tended to change in a subtle consistent fashion. There were a limited number of inflection points in the normal flow ranges, as the inflection points tended to occur in flow ranges well below the normal flows experienced in this reach.

The Tessmann poor and fair to poor conditions and the OLWRP Level 2 and 3 values did not agree very well with 7Q low-flow statistics. This likely is a result of flow regulation by upstream reservoirs and due to regional groundwater discharge to this reach that was not present in the Grand River Blair reach. Both reservoir flow regulation and regional groundwater discharge combined to moderate the low-flow statistics through these reaches, resulting in much higher low-flows than expected. This results in a unique condition that may not reflect conditions used to establish OLWRP indices or Tessmann poor and fair to poor thresholds. Hydraulic inflection points coincide with 7Q statistics suggesting flow would move into a lower thalweg if low-flow conditions ever receded to that state. There are some subtle inflection points in the 20 m^3/s range, which corresponds to the range of several of the 60% flow statistics, likely inferring the channel has adjusted to these frequent flows. The next flow range where several hydraulic inflection points occur is in the 25 to 28 m^3/s range, which is in the range of the 50% annual flow percentile. This implies that the channel has adapted to efficiently convey a flow that occurs on a regular basis. The reach upstream of Whitemans Creek exhibits similar characteristics in a flow range when adjusted for the contribution from Whitemans Creek.

It is worth noting the summer of 2001, when much of this field data was collected, that the flow range in the upper reach would have been in the 13 to 14 m^3/s range, a range where several inflection points are occurring, suggesting flow is moving into a lower thalweg. It was in this range that accumulations of rotting aquatic vegetation were observed along the fringe of the river, creating anoxic conditions. Information from the tabulation of indices in Appendix F and the hydraulic information from Appendix D suggests a 2 to 3 m^3/s increase in flows may be sufficient to move flow out of the thalweg and possibly flush the fringe areas. This approach could be tested in the future and could be used as an operational guide when similar conditions manifest themselves, to deal with this type of condition.

The Tessmann flushing flow agrees well with the geomorphic flushing flow calculated for the reach upstream of Whitemans Creek. The bankfull discharge calculated for the upper reach, of 405 m^3/s, is estimated to occur on an annual basis, as expected. This infers a diminished influence of the upstream reservoirs through this reach, which receives much more uncontrolled runoff than the Grand River Blair Reach.

The daily percentile plot for the lower reach is presented by Figure 7.24. This figure suggests the current operation is in the Tessmann fair to good range. As with other sites, the Tessmann method is suggesting flows would be below the good range in excess of 50% of the time between July 1st and mid September.

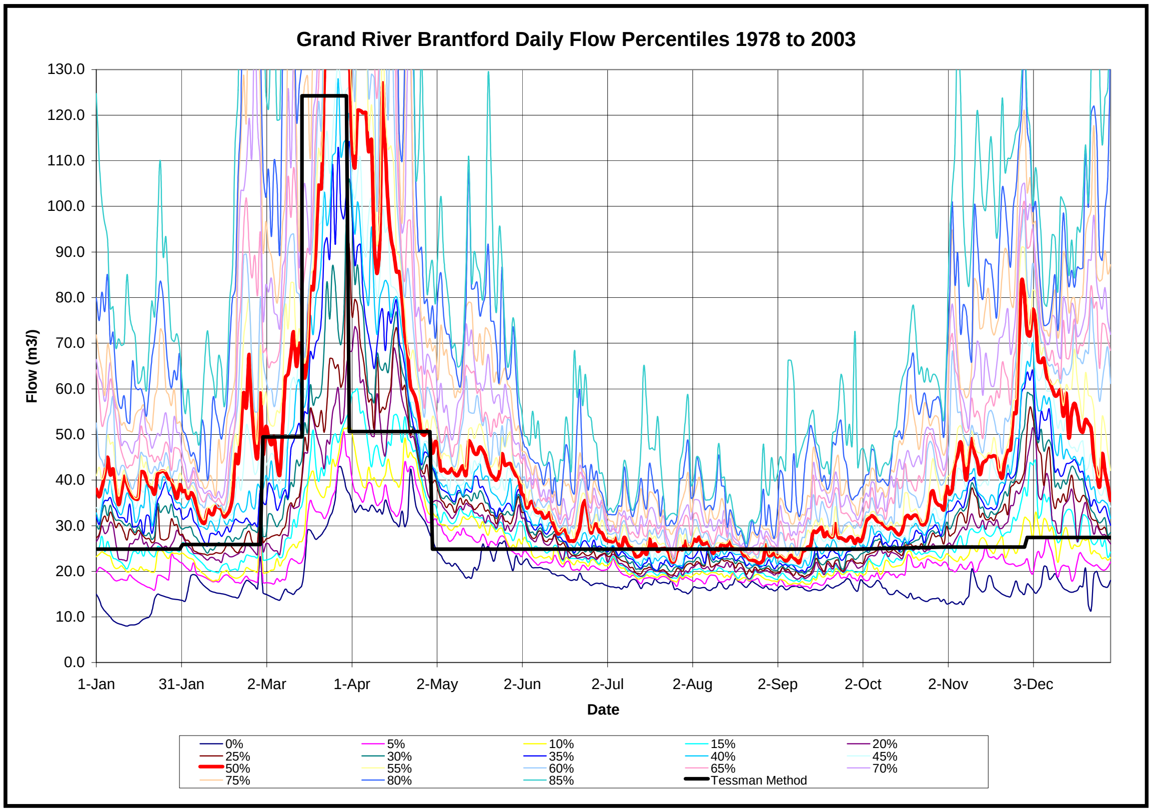


Figure 7.24 Overlay Tessmann method on daily flow percentiles Grand River Brantford

7.4.9 Carroll Creek Reach

An in depth of flow analysis of the Carrol Creek information was not completed as part of this study. The rating curve at the Carrol Creek gauge station was found to be affected by seasonal aquatic plant growth. This resulted in an unstable rating curve, although attempts were made to interpret the flow information, a great deal of interpretation was required. This interpretation could biasis results therefore was set aside at this time.

7.5 Pilot Reach Case Studies: Application of Instream Flow Approaches

The purpose of conducting a detailed study of pilot reaches was to facilitate the application of instream flow approaches to these reaches. The application of instream flow approaches is intended to investigate how instream flow requirements could be incorporated into the PTTW review.

This section of Chapter 7 examines selected study reaches in more detail using a case study approach. The case studies will investigate how information developed earlier in this chapter can be used to make decisions with respect to PTTW's and how conditions attached to PTTW's might better accommodate instream flow requirements of the natural environment.

A common approach is used for selected pilot reaches. Specific steps are followed to analyze streamflows and water takings. This analysis examines taking strategies and their potential impact on the nature environment's flow requirements. The approach taken to analyze selected reaches includes the following:

1. Summarize existing water takings above the study reach (see Chapter 6)
2. Where appropriate and feasible, adjust existing streamflow data to reflect a naturalized condition.
3. Prepare a daily percentile flow plot to include the Tessmann Instream flow requirements (presented earlier in this chapter).
4. Create a synthesized streamflow series by adding water takings back to the river.
5. Apply the IHA model and RVA to interpret how takings are affecting streamflow.
6. Compare RVA summary to expected ecological impacts as suggested by IHA papers.
7. Compare expected change to geomorphic requirements.
8. Where necessary, quantify hydraulic habitat impacts by applying flow hydraulic relationships established by detailed reach hydraulic models.
9. Compare expected hydrologic alteration to fishery requirements in each reach to identify potential impacts.
10. Make recommendations to modify permitted takings to better support the natural environment's ecological flow needs.

The approach is the basis for all the pilot reach case studies. The Grand River at Blair and the Exceptional Waters Reaches are discussed in combination as the Regulated Reaches Case study.

7.5.1 Eramosa River Reach Case Study

The Eramosa Above Guelph study reach, located immediately upstream of Watson Road on the Eramosa River, was discussed in detail in Chapter 5 and earlier in Chapter 7 (Section 7.4.2). It was selected as a study reach because current impacts are minimal, yet it is anticipated to have increasing demands placed upon it from water takings.

Water takings above the Eramosa reach are detailed in Section 6.6 of this report. To summarize, there are limited surfacewater takings upstream of the pilot reach; maximum permitted takings upstream of this reach are estimated to be 0.178 m^3/s. It is not possible comment on whether these takings are actively occurring. The City of Guelph has a variable surfacewater taking with a cutoff flow of 0.42 m^3/s, meaning that if flows are below 0.42 m^3/s, the City of Guelph stops withdrawing water. Metered records of the City of Guelph water taking were obtained from the City of Guelph.

7.5.1.1 Eramosa Case Study: Naturalization of Streamflows

After reviewing takings, a time series was generated reflecting the seasonality of these takings. The maximum permitted taking found in the PTTW database was used; since it was assumed to be continually taken during the active season. To clarify, the active season for irrigation of an agricultural crop would be the period from July through September.

Groundwater takings were further examined to divide them into deep groundwater takings that were believed to be unlikely to affect the surfacewater environment and shallow takings assumed to influence or affect the surfacewater flow environment. The co-ordinates from the PTTW database were compared against the water well database co-ordinates in the same area to link the taking to a specific well. Once linked to a specific well, the taking was classified as either a deep or shallow taking. The PTTW groundwater takings appeared to be from deep sources and thus were not considered in the naturalized flow series.

The time series of takings was used to adjust observed daily streams flows at the Eramosa Above Guelph stream gauge station. A naturalized or adjusted streamflow series was prepared for the 1962 through 2002 period of record by adding the takings back onto the existing observed streamflow series obtained from Environment Canada. In this case study, only the direct Arkell surfacewater takings have been added back onto the daily flow series.

A post-impact taking series was generated by ignoring infrastructure constraints and withdrawing the maximum permitted taking according to conditions in the current PTTW, described in Section 6.6.

7.5.1.2 Eramosa Case Study -Tessmann Instream Flow Requirements

The percentile flow distribution for an adjusted or naturalized flow series for the Eramosa Above Guelph gauge is presented by Figure 7.25. This figure presents the daily percentile flow distribution across the entire year and illustrates the variability of the surfacewater supply. Percentile flow statistics are used to infer the reliability of a flow on any given day of the year. Overlaid on this plot are the Tessmann Method instream flow requirements for good and fair conditions. One modification was made to the Tessmann method in the next chart, presented by Figure 7.26, to line up the flushing flow requirements with the timing of the spring runoff for the Eramosa watershed.

The fiftieth percent flow percentile has been highlighted in Figure 7.26 for comparison with the Tessmann requirements. Comparing the fiftieth percentile with the Tessmann requirements helps identify the tendency for the Tessmann requirements to be met and the periods of the year when these requirements may not be met.

Further information was overlaid on the percentile flow data to illustrate how the Arkell taking matches up with Tessmann requirements and OLWRP objectives (see Figure 7.27). As previously mentioned, the Arkell taking is allowed to occur provided 0.42 m^3/s of flow is present in the river, and thus the Arkell taking would be curtailed prior to a Level 3 Low Water Response condition. Figure 7.27 illustrates how takings would be modified, when potentially less water is available than needed to satisfy the Tessmann requirements. The IHA, RVA and hydraulic habitat analysis will be applied to examine the implications of failing to meet the Tessmann requirements.

7.5.1.3 Eramosa Case Study: IHA and RVA Methods

The Eramosa River data was prepared into two streamflow series for input to the IHA software package. First, a naturalized streamflow series representing the 1962 to 2002 period of record was prepared for Step 2 of the pilot case study approach. Next, a modified ("impacted") streamflow series was prepared by adjusting the naturalized streamflow series to reflect the maximum permitted Arkell surfacewater taking. The impacted streamflow series, with takings removed, was modeled as the period from 2003 to 2042. Both the naturalized (1962-2002) and impacted (2003-2042) flow series were included in one file to serve as input to the IHA software.

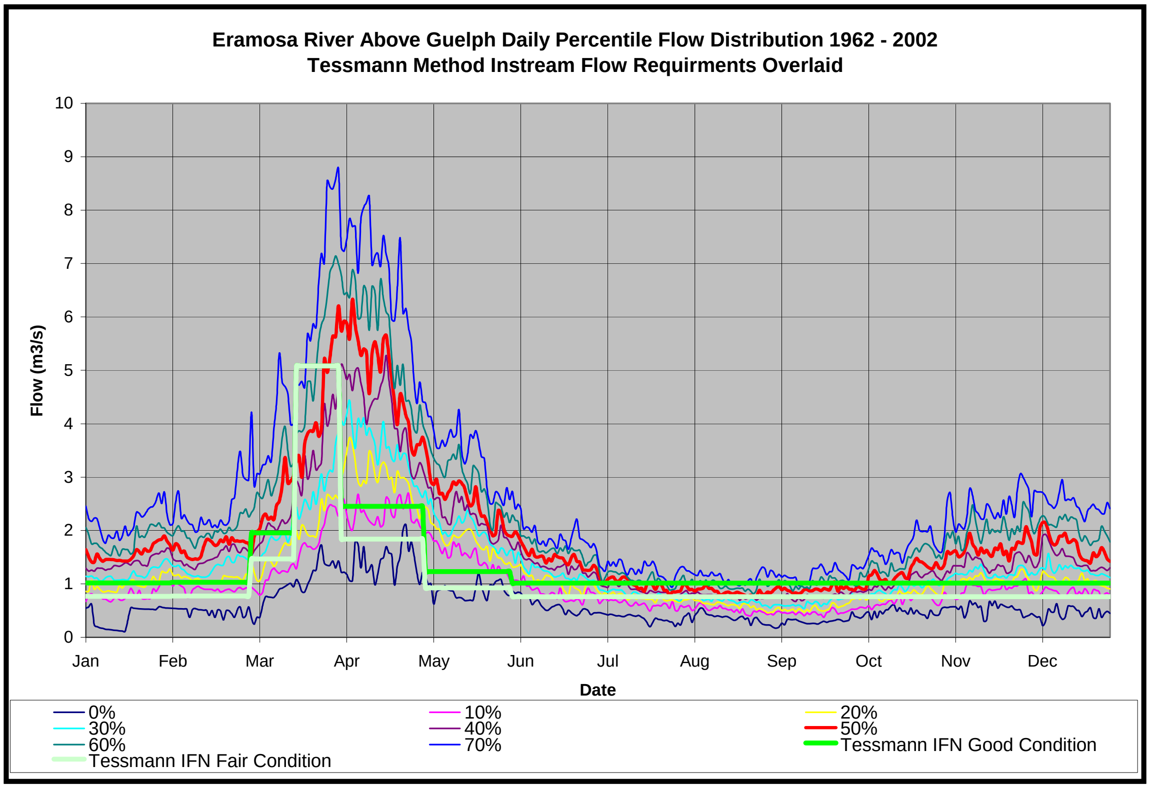


Figure 7.25 Eramosa Percentile Flows with Tessmann Requirements Overlaid

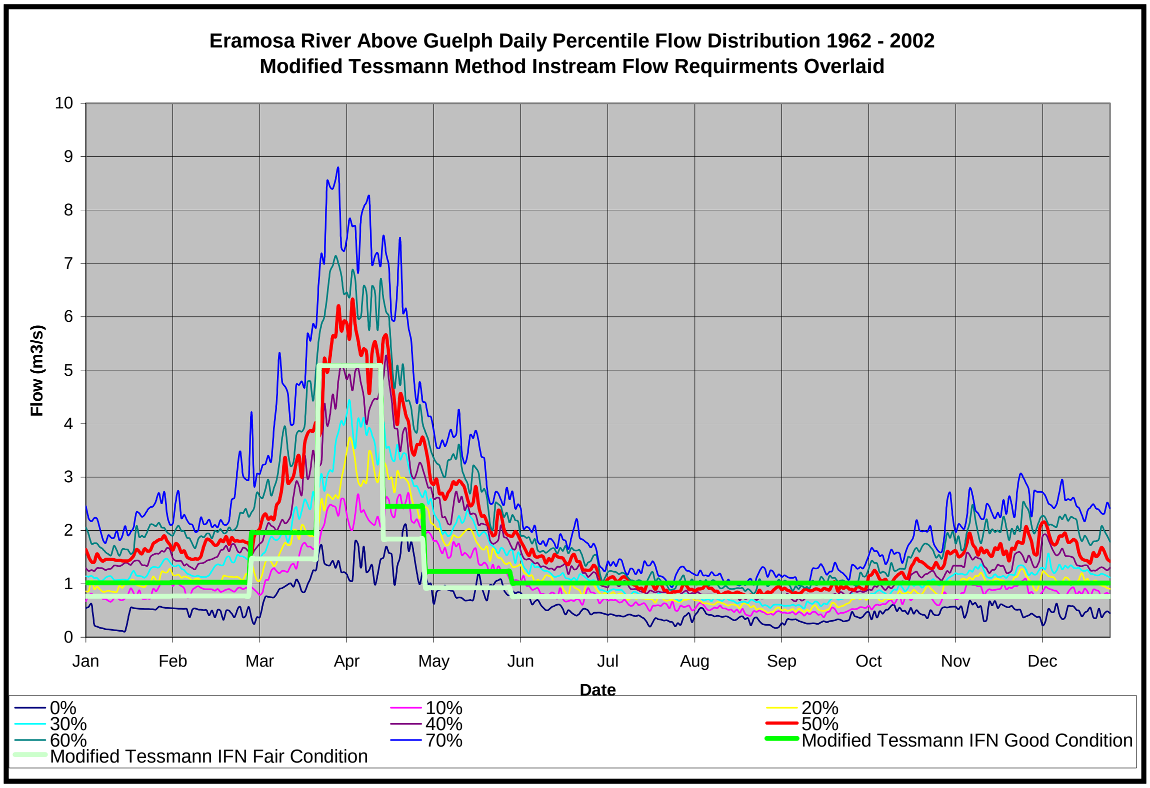


Figure 7.26 Eramosa percentile flows with modified Tessmann Requirements overlaid

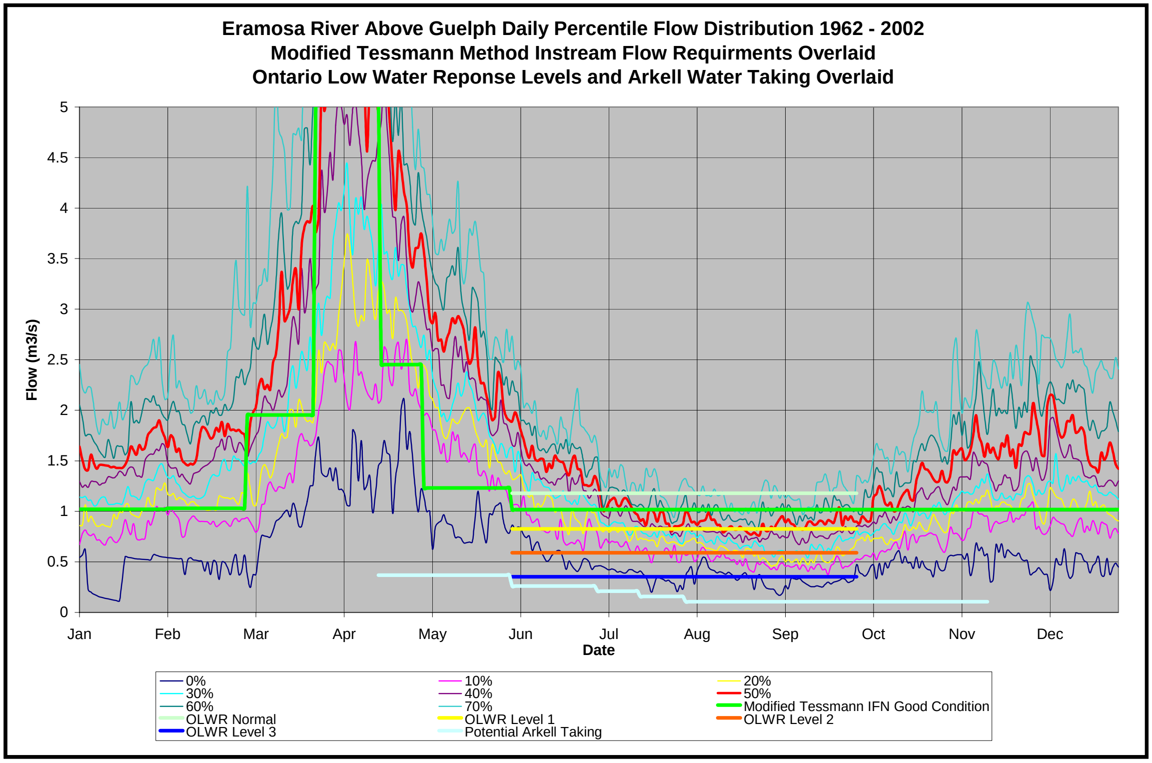


Figure 7.27 Eramosa percentile flows with OLWRP objectives and Arkell taking

The monthly alteration and hydrologic alteration plots for the Eramosa analysis are presented by Figures 7.28 and 7.29, respectively. Figure 7.28 illustrates the range of the middle variability category (between the 33rd and 66th percentiles), for both the pre- and post-impact flow series. This plot illustrates which months are affected by the proposed taking strategy and the degree of alteration. Results for the month of July indicate that the proposed water taking strategy will force flows in that month closer to the lower range of the middle RVA category. The results from Figure 7.28 will help guide further investigation.

Figure 7.29 presents the degree of hydrologic alteration in all three RVA categories, for the 33 different parameters considered by the IHA software. The plot of hydrologic alteration is complex, however it provides a snapshot of results that summarizes alterations to the flow regime. Refer to appendix G for a description of the IHA parameters. The general trend presented by Figure 7.29 indicates an increase in the low category parameters, very little change or a reduction in the middle category and a general reduction in the upper category parameters. The greatest alteration occurs to the 7-day minimum flow, the plot indicates a degree of alteration of 1.6.

Figure 7.28 Eramosa Arkell Taking IHA Monthly Alteration Plot

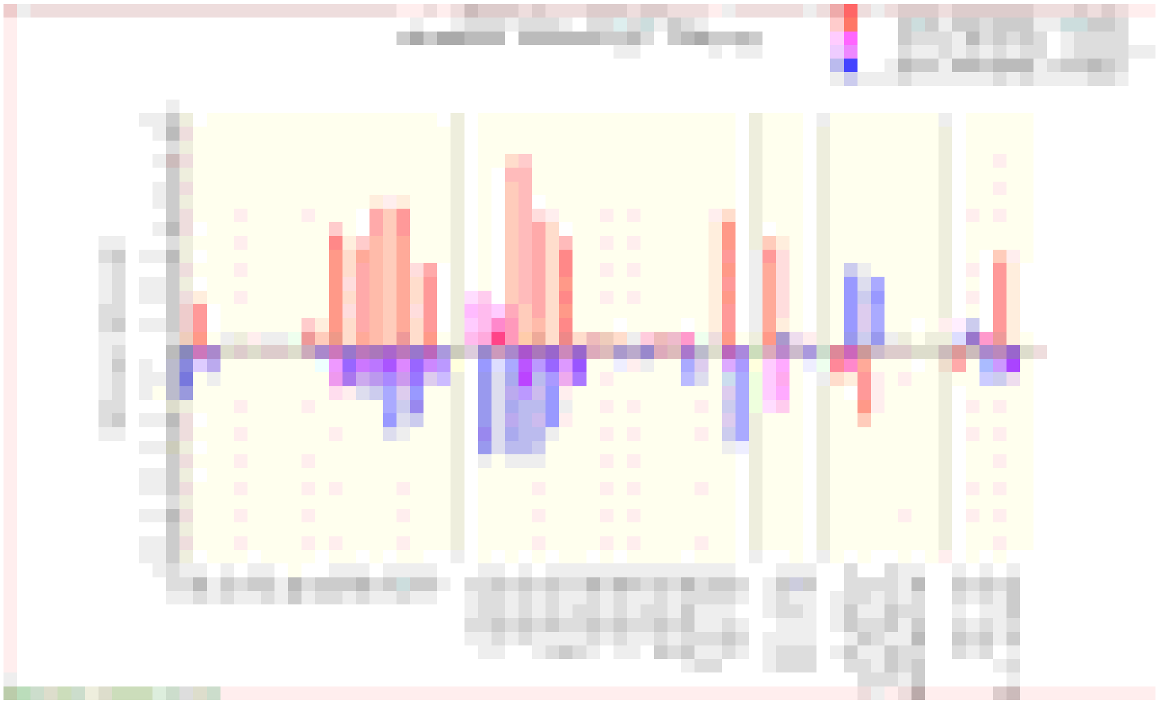


Figure 7.29 Eramosa Arkell Taking IHA Hydrologic Alteration Plot

Information from Figures 7.28 and 7.29 help guide the user to investigate information presented by the scorecards (text reports) and other plots available from the IHA software. Figure 7.30 helps illustrate that an increase in the degree of alteration of the 7-day minimum flow in the lower category translates into lower average 7-day minimum flows. This plot also illustrates the lowering of the 7-day minimum flows is less than one standard deviation of the original flow series and the variability in the post impact flow regime would be reduced, the range is much tighter. Information presented by Figure 7.31 indicates a lowering of the July flow regime of less than one standard deviation and similar variability in the post-impact period.

Figure 7.30 IHA 7-Day minimum flows for the Eramosa Arkell Taking

Figure 7.31 IHA Average July flows for the Eramosa Arkell Taking

Figure 7.32 illustrates the mean and standard deviation for the 7-day minimum flow data for the Eramosa River, and is intended to graphically display all the statistics associated with the 7-day minimum flow parameter. Figure 7.32 is helpful, prior to discussing the scorecards, to pictorially present the different statistics provided by the IHA software.

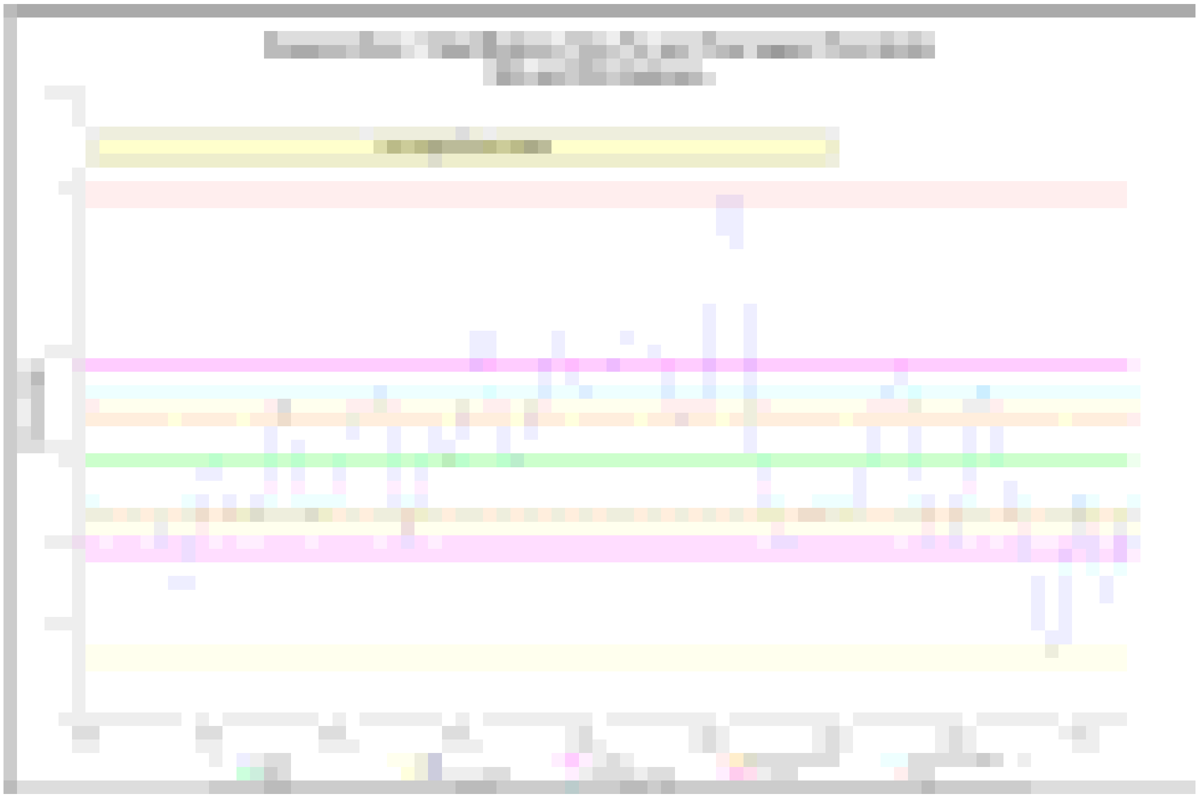


Figure 7.32 Eramosa 7-Day minimum IHA and RVA flow statistics

Results for the IHA analysis and the RVA analysis are presented in Tables 7.20 through 7.24, which present the IHA scorecards that report the statistics for all IHA parameters. The IHA parameters are arranged into the 5 groups as given by the IHA software. Refer to Appendix H for details about the 5 groups.

7.5.1.4 Eramosa Case Study - IHA Scorecard

The IHA scorecard for the Eramosa case study is presented by Table 7.20. In scanning this table, the largest changes that were found relate to the magnitude of changes in columns 6 and 8, which can also be seen illustrated by Figure 7.29.

7.5.1.5 Eramosa Case Study - RVA Scorecard

The RVA scorecard is presented by Table 7.21. The second page in the RVA score card compares the expected and observed frequency distributions in the three RVA categories. The messages and errors that may arise during the calculations are presented in Table 7.22.

7.5.1.6 Eramosa Case Study - IHA Percentile Summary

The IHA percentile summary table presents the pre- and post-impact summary information; the results for the Eramosa analysis are presented by Table 7.23. This table is useful to report the difference in flow percentiles and allows the user to examine the degree to which different parameters are affected.

7.5.1.7 Eramosa Case Study - IHA Annual Summary

The IHA software also produces an annual summary that includes the pre-impact and post-impact values for the entire period analyzed. A copy of this table is presented by Table 7.24. To facilitate analyzing results, this table was imported into an Excel spreadsheet and formulas added to calculate many of the statistics in the scorecard tables. This seemed to be an effective means to organize information and facilitate integration with hydraulic habitat analysis.

The IHA software was used interactively to view plots while referring to information in Table 7.24. The tabular information produced by the IHA software can be intimidating. Fortunately the IHA software has charts for each parameter to concisely and visually express results. Most users would view the graphic output and refer to the tables as necessary.

7.5.1.8 Eramosa Case Study - IHA Results

Results from IHA indicate the largest alteration is associated with the extreme minimum or low-flows, 7-day, 30-day and 90-day low-flows and with the monthly flows during the months of active takings. None of the changes exceeded the IHA guideline of one standard deviation. The results and changes in statistics associated with these parameters must now be combined with hydraulic modeling to quantify habitat impacts Expected may be inferred by comparing habitat impacts to life cycle requirements in chapter 4 figure 4.2 .

Comparing IHA results with Table 7.20 suggest the expected impacts would reduce habitat availability and have potential impacts to geomorphology. These impacts will be examined in a quantitative manner in the next section.

Table 7.20 Eramosa IHA Scorecard

```
                                       IHA Parametric Scorecard
                                       Eramosa Potential Taking

      Pre-impact period: 1963-2002 (40 years)          Post-impact period: 2003-2042 (40 years)

Watershed Area                         1.00
Mean Annual Flow                       2.49                                 2.38
Mean Flow/Area                         2.49                                 2.38
Annual C. V.                           1.20                                 1.25
Flow Predictability                     .49                                  .47
Constancy/Predictability                .75                                  .72
% of Floods in 60d period              1.00                                 1.00
Flood-free season                    366.00                               366.00


                              MEAN          COEFF. of VAR.     DEVIATION FACTOR      DEV. of C.V.

                        Pre       Post      Pre       Post     Magnitude    %      Magnitude   %

             Parameter Group #1
October                    1.6       1.4       .71       .81       -.2     -12.1       .09      13.0
November                   2.2       2.1       .59       .62       -.1      -4.6       .03       4.7
December                   2.3       2.3       .51       .51        .0        .0       .00        .0
January                    2.1       2.1       .55       .55        .0        .0       .00        .0
February                   2.6       2.6       .59       .59        .0        .2       .00       -.3
March                      4.9       4.9       .48       .48        .0        .0       .00        .0
April                      6.2       5.9       .43       .45       -.2      -4.0       .02       4.2
May                        3.1       2.6       .38       .44       -.5     -15.0       .07      17.4
June                       1.9       1.5       .44       .53       -.3     -18.5       .09      20.4
July                       1.3       1.0       .45       .55       -.3     -20.4       .10      22.2
August                     1.2       1.0       .55       .65       -.2     -18.6       .10      17.7
September                  1.4       1.2      1.05      1.18       -.2     -12.1       .13      12.1

 Mean |%| change                                                   8.8                 9.3

             Parameter Group #2
1-day minimum               .5        .4       .36       .25       -.1     -20.0      -.12     -32.5
3-day minimum               .5        .4       .36       .24       -.1     -21.8      -.11     -31.4
7-day minimum               .6        .4       .35       .25       -.1     -23.4      -.09     -26.7
30-day minimum              .7        .6       .37       .35       -.2     -21.3      -.02      -5.2
90-day minimum             1.0        .8       .39       .45       -.2     -18.3       .06      15.0
1-day maximum             22.7      22.6       .43       .43       -.1       -.4       .00       -.1
3-day maximum             19.3      19.2       .39       .39       -.1       -.4       .00        .2
7-day maximum             14.5      14.4       .37       .37       -.1       -.4       .00        .1
30-day maximum             8.1       8.0       .33       .33       -.2      -1.9       .01       1.9
90-day maximum             5.2       5.0       .28       .29       -.2      -3.6       .01       3.1
Number of zero days        .00       .00       .00       .00 999999.00 999999.00 999999.00 999999.00
Base flow                  .23       .19       .24       .22      -.04    -15.52      -.02     -9.17

 Mean |%| change                                                  11.6                11.4

             Parameter Group #3
Date of minimum          234.6     220.0       .16       .16      14.5       7.9       .00       -.5
Date of maximum          115.2     114.3       .21       .21        .8        .5       .00        .2

 Mean |%| change                                                   4.2                  .4

             Parameter Group #4
Low pulse count            9.2      10.1       .58       .42        .9      10.3      -.17     -28.4
Low pulse duration        10.4      12.3       .81       .51       1.9      18.2      -.31     -37.5
High pulse count            .0        .0       .00       .00  999999.0  999999.0 999999.00  999999.0
High pulse duration         .0        .0       .00       .00  999999.0  999999.0 999999.00  999999.0

 Mean |%| change                                                  14.3                33.0

 The low pulse threshold is        .99
 The high pulse level is     76.81

             Parameter Group #5
Rise rate                   .6        .6       .35       .33        .0       4.3      -.03      -7.5
Fall rate                  -.4       -.4      -.30      -.28        .0       3.8       .02      -5.5
Number of reversals      106.6     100.7       .17       .16      -5.9      -5.5      -.01      -4.9

 Mean |%| change                                                   4.5                 6.0
```

Table 7.21 RVA Scorecard

```
                                                               IHA Parametric RVA Scorecard
                                                                 Eramosa Potential Taking

          Pre-impact period: 1963-2002                             Post-impact period: 2003-2042         RVA TARGETS        HYDROLOGIC
                                    Std.       Range Limits                 Std.       Range Limits                         ALTERATION
                         Means      Dev.       Low      High      Means     Dev.       Low      High       Low      High

             Parameter Group #1
October                    1.6        .7        .6       7.0       1.4        .8        .4       6.8       .89      1.98       .00
November                   2.2        .6        .7       7.1       2.1        .6        .6       7.0      1.45      2.61      -.10
December                   2.3        .5        .5       5.6       2.3        .5        .5       5.6      1.43      3.25       .00
January                    2.1        .6        .6       6.3       2.1        .6        .6       6.3      1.28      2.62       .00
February                   2.6        .6        .7       6.9       2.6        .6        .7       6.9      1.44      3.40       .00
March                      4.9        .5       1.4      11.1       4.9        .5       1.4      11.1      3.10      6.05       .00
April                      6.2        .4       2.3      12.1       5.9        .4       2.1      11.8      3.70      7.92      -.05
May                        3.1        .4       1.0       6.5       2.6        .4        .5       6.1      2.31      3.72      -.35
June                       1.9        .4        .7       4.2       1.5        .5        .5       3.8      1.31      2.18      -.25
July                       1.3        .4        .6       3.2       1.0        .5        .4       2.9       .92      1.68      -.25
August                     1.2        .6        .4       3.3       1.0        .6        .4       3.1       .76      1.54      -.30
September                  1.4       1.1        .4       9.2       1.2       1.2        .4       9.0       .62      1.74      -.20

             Parameter Group #2
1-day minimum               .5        .4        .1       1.1        .4        .2        .1        .8       .38       .64       .45
3-day minimum               .5        .4        .1       1.1        .4        .2        .1        .8       .41       .68       .35
7-day minimum               .6        .3        .1       1.2        .4        .3        .1        .9       .45       .72      -.35
30-day minimum              .7        .4        .4       1.7        .6        .4        .3       1.3       .50       .89      -.20
90-day minimum             1.0        .4        .5       2.2        .8        .4        .4       2.0       .71      1.20      -.30
1-day maximum             22.7        .4       5.2      41.0      22.6        .4       5.2      40.8     14.63     29.85      -.05
3-day maximum             19.3        .4       4.9      33.1      19.2        .4       4.9      32.7     13.33     25.87       .00
7-day maximum             14.5        .4       4.0      30.0      14.4        .4       4.0      29.6     10.21     18.26       .05
30-day maximum             8.1        .3       2.9      13.5       8.0        .3       2.8      13.4      6.05     10.13      -.05
90-day maximum             5.2        .3       2.3       8.1       5.0        .3       2.3       8.0      3.88      6.30       .10
Number of zero days         .0        .0        .0        .0        .0        .0        .0        .0       .00       .00       .00
Base flow                   .2        .2        .1        .4        .2        .2        .1        .3       .20       .27      -.15

             Parameter Group #3
Date of minimum          234.6        .2      15.0     366.0     220.0        .2      15.0     311.0    218.50    261.50      -.50
Date of maximum          115.2        .2      16.0     362.0     114.3        .2      16.0     362.0     83.25    108.25       .05

             Parameter Group #4
Low pulse count            9.2        .6        .0      25.0      10.1        .4       3.0      22.0      6.00     11.00      -.17
Low pulse duration        10.4        .8        .0      53.0      12.3        .5       4.1      27.7      6.10     13.26       .00
High pulse count            .0        .0        .0        .0        .0        .0        .0        .0       .00       .00       .00
High pulse duration         .0        .0        .0        .0        .0        .0        .0        .0       .00       .00       .00

 The low pulse threshold is        .99
 The high pulse threshold is      76.81

             Parameter Group #5
Rise rate                   .6        .4        .2       1.5        .6        .3        .3       1.5       .47       .74       .00
Fall rate                  -.4       -.3       -.6       -.1       -.4       -.3       -.6       -.2      -.45      -.28       .10
Number of reversals      106.6        .2      78.0     162.0     100.7        .2      76.0     148.0     96.00    113.00      -.23
```

Table 7.21 – RVA Scorecard (continued)

Comparison of Expected and Actual Frequencies

	Middle RVA Categor			Highest RVA Categor			Lowest RVA Categor		
	Expected	Observed	Alter.	Expected	Observed	Alter.	Expected	Observed	Alter.
Parameter Group #1									
October	20.00	20.00	.00	10.00	6.00	-.40	10.00	14.00	.40
November	20.00	18.00	-.10	10.00	8.00	-.20	10.00	14.00	.40
December	20.00	20.00	.00	10.00	10.00	.00	10.00	10.00	.00
January	20.00	20.00	.00	10.00	10.00	.00	10.00	10.00	.00
February	20.00	20.00	.00	10.00	10.00	.00	10.00	10.00	.00
March	20.00	20.00	.00	10.00	10.00	.00	10.00	10.00	.00
April	20.00	19.00	-.05	10.00	9.00	-.10	10.00	12.00	.20
May	20.00	13.00	-.35	10.00	7.00	-.30	10.00	20.00	1.00
June	20.00	15.00	-.25	10.00	6.00	-.40	10.00	19.00	.90
July	20.00	15.00	-.25	10.00	3.00	-.70	10.00	22.00	1.20
August	20.00	14.00	-.30	10.00	4.00	-.60	10.00	22.00	1.20
September	20.00	16.00	-.20	10.00	7.00	-.30	10.00	17.00	.70
Parameter Group #2									
1-day minimum	20.00	29.00	.45	10.00	1.00	-.90	10.00	10.00	.00
3-day minimum	20.00	27.00	.35	10.00	1.00	-.90	10.00	12.00	.20
7-day minimum	20.00	13.00	-.35	10.00	1.00	-.90	10.00	26.00	1.60
30-day minimum	20.00	16.00	-.20	10.00	3.00	-.70	10.00	21.00	1.10
90-day minimum	20.00	14.00	-.30	10.00	7.00	-.30	10.00	19.00	.90
1-day maximum	20.00	19.00	-.05	10.00	10.00	.00	10.00	11.00	.10
3-day maximum	20.00	20.00	.00	10.00	9.00	-.10	10.00	11.00	.10
7-day maximum	20.00	21.00	.05	10.00	9.00	-.10	10.00	10.00	.00
30-day maximum	20.00	19.00	-.05	10.00	10.00	.00	10.00	11.00	.10
90-day maximum	20.00	22.00	.10	10.00	7.00	-.30	10.00	11.00	.10
Number of zero days	40.00	40.00	.00	.00	.00	.00	.00	.00	.00
Base flow	20.00	17.00	-.15	10.00	2.00	-.80	10.00	21.00	1.10
Parameter Group #3									
Date of minimum	20.00	10.00	-.50	10.00	11.00	.10	10.00	19.00	.90
Date of maximum	20.00	21.00	.05	10.00	9.00	-.10	10.00	10.00	.00
Parameter Group #4									
Low pulse count	23.00	19.00	-.17	9.00	15.00	.67	8.00	6.00	-.25
Low pulse duration	20.00	20.00	.00	10.00	16.00	.60	10.00	4.00	-.60
High pulse count	40.00	40.00	.00	.00	.00	.00	.00	.00	.00
High pulse duration	40.00	40.00	.00	.00	.00	.00	.00	.00	.00
Parameter Group #5									
Rise rate	20.00	20.00	.00	10.00	12.00	.20	10.00	8.00	-.20
Fall rate	20.00	22.00	.10	10.00	7.00	-.30	10.00	11.00	.10
Number of reversals	22.00	17.00	-.23	9.00	7.00	-.22	9.00	16.00	.78

Table 7.22 RVA Scorecard Messages and Warnings

```
   72 Messages:
The parametric low pulse level is <0.  It will be replaced by the 25th percentile value.
The lower RVA limit is outside the range of variability of parameter October                     .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter October                     . The 75th percentile level will be used.
The lower RVA limit is outside the range of variability of parameter November                    .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter November                    . The 75th percentile level will be used.
The lower RVA limit is outside the range of variability of parameter December                    .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter December                    . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter January                     .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter January                     . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter February                    .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter February                    . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter March                       .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter March                       . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter April                       .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter April                       . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter May                         .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter May                         . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter June                        .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter June                        . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter July                        .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter July                        . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter August                      .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter August                      . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter September                   .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter September                   . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter Low pulse count             .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter Low pulse count             . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter Low pulse duration          .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter Low pulse duration          . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter Fall rate                   .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter Fall rate                   . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter Rise rate                   .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter Rise rate                   . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter Number of falls             .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter Number of falls             . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter Number of reversals         .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter Number of reversals         . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 1-day minimum               .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 1-day minimum               . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter Date of minimum             .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter Date of minimum             . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 1-day maximum               .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 1-day maximum               . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter Date of maximum             .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter Date of maximum             . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 3-day minimum               .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 3-day minimum               . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 7-day minimum               .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 7-day minimum               . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 30-day minimum              .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 30-day minimum              . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 90-day minimum              .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 90-day minimum              . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 3-day maximum               .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 3-day maximum               . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 7-day maximum               .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 7-day maximum               . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 30-day maximum              .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 30-day maximum              . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter 90-day maximum              .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter 90-day maximum              . The 75th percentile level will be used
The lower RVA limit is outside the range of variability of parameter Base flow                   .  The 25th percentile level will be used.
The upper RVA limit is outside the range of variability of parameter Base flow                   . The 75th percentile level will be used
Parameter Low pulse count     :   7 yearly values are equal to the upper RVA limit.  Use caution in interpreting expected and observed compliance rates.
Parameter Low pulse count     :  10 yearly values are equal to the lower RVA limit.  Use caution in interpreting expected and observed compliance rates.
Parameter High pulse count    :  80 yearly values are equal to the upper RVA limit.  Use caution in interpreting expected and observed compliance rates.
Parameter High pulse count    :  80 yearly values are equal to the lower RVA limit.  Use caution in interpreting expected and observed compliance rates.
Parameter High pulse duration :  80 yearly values are equal to the upper RVA limit.  Use caution in interpreting expected and observed compliance rates.
Parameter High pulse duration :  80 yearly values are equal to the lower RVA limit.  Use caution in interpreting expected and observed compliance rates.
Parameter Number of reversals :   3 yearly values are equal to the upper RVA limit.  Use caution in interpreting expected and observed compliance rates.
Parameter Number of reversals :   2 yearly values are equal to the lower RVA limit.  Use caution in interpreting expected and observed compliance rates.
```

Table 7.23 IHA Percentile Data

IHA Percentile Data
Eramosa Potential Taking

Pre-impact period: 1963-2002 (40 years)   Post-impact period: 2003-2042 (40 years)

	Pre-Impact						Post-Impact					
	10%	25%	50%	75%	90%	(75-25)/50	10%	25%	50%	75%	90%	(75-25)/50
Parameter Group #1												
October	.68	.89	1.32	1.98	3.05	.83	.49	.68	1.12	1.78	2.85	.98
November	.99	1.45	1.89	2.61	3.47	.61	.89	1.35	1.79	2.51	3.37	.65
December	.97	1.43	1.96	3.25	4.11	.93	.97	1.43	1.96	3.25	4.11	.93
January	.95	1.28	1.82	2.62	3.97	.74	.95	1.28	1.82	2.62	3.97	.74
February	.98	1.44	2.06	3.40	4.86	.95	.98	1.44	2.12	3.40	4.86	.92
March	2.37	3.10	4.20	6.05	7.91	.70	2.37	3.10	4.20	6.05	7.91	.70
April	2.94	3.70	6.07	7.92	10.72	.69	2.69	3.45	5.82	7.67	10.47	.72
May	1.93	2.31	2.77	3.72	4.80	.51	1.46	1.84	2.31	3.25	4.33	.61
June	.98	1.31	1.69	2.18	3.30	.51	.68	.96	1.33	1.82	2.94	.64
July	.71	.92	1.06	1.68	1.80	.72	.54	.65	.78	1.40	1.52	.97
August	.58	.76	.96	1.54	2.29	.82	.44	.56	.73	1.29	2.04	1.02
September	.51	.62	.93	1.74	2.48	1.21	.42	.50	.73	1.53	2.27	1.43
Parameter Group #2												
1-day minimum	.29	.38	.48	.64	.75	.56	.29	.38	.42	.42	.50	.10
3-day minimum	.30	.41	.50	.68	.80	.53	.30	.40	.42	.43	.55	.09
7-day minimum	.35	.45	.56	.72	.85	.48	.34	.41	.42	.47	.60	.16
30-day minimum	.47	.50	.71	.89	1.08	.55	.41	.42	.49	.66	.82	.48
90-day minimum	.57	.71	.92	1.20	1.54	.54	.44	.53	.74	.96	1.26	.58
1-day maximum	11.28	14.63	20.70	29.85	37.45	.74	11.28	14.51	20.57	29.85	37.45	.75
3-day maximum	9.67	13.33	17.40	25.87	29.69	.72	9.58	13.10	17.40	25.63	29.67	.72
7-day maximum	8.37	10.21	14.00	18.26	21.62	.57	8.36	10.21	13.96	18.10	21.62	.57
30-day maximum	4.74	6.05	7.99	10.13	11.88	.51	4.73	5.91	7.85	10.02	11.70	.52
90-day maximum	3.49	3.88	5.10	6.30	7.09	.47	3.21	3.73	4.85	6.08	6.84	.48
Number of zero days	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Base flow	.15	.20	.23	.27	.29	.32	.14	.15	.19	.22	.25	.38
Parameter Group #3												
Date of minimum	192.60	218.50	241.50	261.50	279.00	.12	169.80	192.25	226.00	262.00	277.00	.19
Date of maximum	54.40	83.25	97.50	108.25	254.10	.07	54.40	82.75	97.00	105.75	254.10	.06
Parameter Group #4												
Low pulse count	4.00	6.00	8.00	11.00	15.90	.63	4.00	7.00	10.00	13.00	14.90	.60
Low pulse duration	3.51	6.10	7.83	13.26	18.04	.91	5.53	7.26	10.68	15.94	23.15	.81
High pulse count	6.00	8.00	9.50	12.00	13.00	.42	5.00	8.00	10.00	11.00	13.90	.30
High pulse duration	4.64	6.31	9.43	12.70	15.18	.68	4.54	5.91	8.46	11.60	15.89	.67
Parameter Group #5												
Rise rate	.38	.47	.61	.74	.86	.44	.43	.49	.62	.76	.86	.43
Fall rate	-.52	-.45	-.37	-.28	-.21	-.46	-.55	-.45	-.38	-.31	-.22	-.39
Number of reversals	85.30	96.00	103.50	113.00	129.10	.16	79.30	89.75	99.00	110.75	118.00	.21

Table 7.24 Example IHA Model Output Table for Eramosa Above Guelph

IHA Analysis Eramosa River Above Guelph 1963 to 2002																
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**1-day**	**3-day**	**7-day**	**30-day**	**90-day**
													Min	Min	Min	Min	Min
1963	1.57	2.39	1.57	1.08	0.93	4.59	2.74	2.34	0.87	0.82	0.62	0.52	0.25	0.31	0.35	0.46	0.49
1964	0.5	0.63	0.51	1.22	0.78	2.79	3.62	2.09	1.19	1.26	1.44	0.62	0.1	0.13	0.17	0.43	0.54
1965	0.63	0.72	1.69	2.12	4.58	2.95	10.47	2.59	0.65	0.85	0.75	0.82	0.37	0.45	0.47	0.63	0.74
1966	2.04	2.54	3.62	2.35	2.82	5.23	3.41	2.19	1.46	0.52	0.52	0.42	0.28	0.34	0.36	0.38	0.47
1967	0.5	1.39	2.54	2.07	2.15	3.16	8.56	2.58	3.26	2.94	1.08	0.84	0.23	0.3	0.36	0.5	1.07
1968	1.93	2.25	3.31	1.7	4.3	7.15	3.73	2.26	1.32	1.02	2.85	2.15	0.55	0.58	0.61	0.96	1.24
1969	1.69	2.78	2.75	2.64	2.99	5.48	8.4	3.88	1.58	0.87	0.79	0.41	0.33	0.34	0.35	0.39	0.61
1970	0.66	1.75	0.99	0.82	0.97	1.36	6.49	2.49	0.96	1.14	0.85	1.21	0.36	0.37	0.4	0.66	0.92
1971	1.48	2.2	3.06	1.64	1.95	2.81	7.95	1.99	2	1.48	1.62	1.06	0.47	0.5	0.58	0.74	0.93
1972	0.81	1.06	2.47	1.65	1.48	2.18	12	3.29	2.32	1.71	0.79	0.79	0.52	0.55	0.61	0.73	0.86
1973	1.92	2.18	2.59	3.04	2.91	10.72	5.21	3.65	1.92	0.84	0.84	0.5	0.29	0.29	0.3	0.43	0.69
1974	0.97	2.45	1.79	2.56	2.56	7.56	6.47	6.44	2.32	1.06	0.76	0.64	0.49	0.53	0.55	0.62	0.71
1975	0.78	1.72	1.17	1.49	2.09	4.84	7.36	2.91	1.67	0.71	0.86	1.18	0.4	0.44	0.47	0.61	0.89
1976	1.06	1.54	1.93	1.37	3.75	11.06	6.63	4.74	1.99	1.61	1.46	1.75	0.67	0.7	0.76	0.84	1.46
1977	1.83	1.47	1.24	0.65	0.66	7.9	4.76	1.62	1.06	0.88	1.27	2.23	0.39	0.4	0.46	0.58	0.8
1978	3.41	3.46	4.16	2.66	1.85	3.08	11.27	4.32	1.53	0.72	0.7	1.71	0.45	0.47	0.56	0.62	0.82
1979	1.43	1.66	1.74	1.94	1.43	7.92	8.63	4.19	1.81	1.25	1.49	1.66	0.57	0.68	0.75	1.09	1.44
1980	1.36	2.52	3.64	2.12	1.1	5.34	5.94	3.08	1.95	1.67	0.95	1.03	0.58	0.59	0.63	0.83	1.11
1981	1.44	1.27	1.89	0.94	5.44	2.74	2.99	1.86	1.2	1.66	1.51	2.16	0.57	0.65	0.69	0.89	1.31
1982	2.98	2.8	1.75	1.24	1.11	3.24	10.93	2.63	3.56	1.61	1.18	1.58	0.74	0.75	0.76	1.09	1.21
1983	1.49	3.38	5.6	3.04	3.54	3.86	4.98	5.35	2.15	0.9	1.21	1.22	0.66	0.7	0.73	0.88	1.07
1984	1.24	1.51	1.98	1.11	4.89	4.49	6.08	3.05	1.95	0.91	0.64	1.23	0.49	0.52	0.56	0.63	0.89
1985	1	1.93	2.41	1.82	3.53	9.13	10.69	2.43	1.63	1.55	1.45	2.4	0.57	0.59	0.63	0.83	1.46
1986	1.9	6.09	3.6	2.45	1.99	6.03	3.98	2.82	2.08	3.05	3.21	9.06	0.97	1.02	1.07	1.56	2.19
1987	6.93	3.42	3.47	2.56	1.38	5.43	7	1.83	1.1	1.17	0.75	0.71	0.49	0.49	0.5	0.56	0.75
1988	1.09	1.47	2.43	1.83	2.19	4.35	3.86	1.91	0.62	0.51	0.53	0.71	0.29	0.3	0.3	0.38	0.53
1989	1.14	2	1.49	1.83	1.34	3.56	3.14	2.35	2.7	0.6	0.48	0.39	0.33	0.34	0.35	0.38	0.44
1990	0.65	1.65	0.64	1.64	2.79	6.05	2.88	2.71	1.22	0.87	0.88	0.62	0.36	0.37	0.38	0.6	0.78
1991	2.31	2.66	4.13	3.5	2.87	7.08	7.6	2.98	1.24	1.29	1.14	0.52	0.35	0.35	0.38	0.47	0.68
1992	0.88	0.93	1.94	1.68	1.49	2.35	5.69	3.35	1.49	1.68	2.53	2.95	0.47	0.57	0.59	0.72	1.24
1993	3.2	7.1	3.9	6.32	1.93	3.39	7.47	2.46	2.68	1.28	0.79	0.88	0.56	0.62	0.66	0.78	0.92
1994	1.2	1.44	1.53	0.74	1.58	3.64	5.96	3.53	1.26	0.67	0.48	0.41	0.26	0.27	0.28	0.36	0.48
1995	0.58	1	1.02	4.34	1.15	4.05	3.17	2.63	1.53	0.86	1.43	0.38	0.26	0.31	0.31	0.37	0.87
1996	1.03	3.37	2.17	4.03	3.99	3.93	8.29	5.83	4.08	1.59	1.06	2.96	0.26	0.28	0.64	0.98	1.74
1997	2.73	2.57	4.4	4.72	6.93	7.51	6.59	4.24	1.6	0.84	0.75	0.71	0.4	0.42	0.44	0.61	0.71
1998	0.76	1.29	0.97	2.76	1.8	5.56	3.3	1.64	1.15	0.7	0.44	0.27	0.18	0.19	0.24	0.26	0.38
1999	0.48	0.61	0.87	1.54	1.91	2.14	2.29	0.85	0.81	0.56	0.32	0.48	0.07	0.08	0.11	0.25	0.4
2000	0.84	1.95	1.41	1.05	2.04	2.49	2.77	3.53	3.85	2.06	2.26	0.93	0.41	0.43	0.51	0.53	0.87
2001	0.76	1.25	1.23	1.03	6.2	3.18	6.14	2.09	1.56	0.81	0.43	0.44	0.15	0.16	0.16	0.29	0.52
2002	1.34	1.47	2.47	1.64	3.02	3.79	5.09	3.8	2.08	0.85	0.54	0.56	0.36	0.37	0.38	0.46	0.64
Min	0.48	0.61	0.51	0.65	0.66	1.36	2.29	0.85	0.62	0.51	0.32	0.27	0.07	0.08	0.11	0.25	0.38
Average	1.51	2.15	2.30	2.12	2.56	4.85	6.11	3.01	1.79	1.18	1.09	1.28	0.41	0.44	0.49	0.63	0.90
Max	6.93	7.10	5.60	6.32	6.93	11.06	12.00	6.44	4.08	3.05	3.21	9.06	0.97	1.02	1.07	1.56	2.19
25th Percentile	0.80	1.43	1.47	1.34	1.47	3.14	3.70	2.24	1.22	0.84	0.69	0.52	0.29	0.31	0.35	0.43	0.63
75th Percentile	1.85	2.55	3.12	2.58	3.15	6.04	7.69	3.56	2.08	1.56	1.43	1.60	0.53	0.57	0.62	0.79	1.08
Std. Deviation	1.15	1.29	1.18	1.18	1.50	2.35	2.65	1.18	0.82	0.58	0.66	1.45	0.18	0.19	0.20	0.27	0.39

(Table 7.24 continued)

IHA Analysis Eramosa River Above Guelph 1963 to 2002

Year	1-day Max	3-day Max	7-day Max	30-day Max	90-day Max	Zero Days	Base Flow	Date Min	Date Max	Lo Pulse	#Low Pulses	LHi Pulse	#Hi Pulse	LRise Rate	Fall Rate	Reversals
1963	24.4	22.03	15.99	6.01	3.28	0	0.21	237	88	13	11.92	14	2.79	0.77	-0.58	102
1964	8.75	7.93	5.89	4.05	2.9	0	0.12	211	99	24	6.71	11	4.55	0.52	-0.36	158
1965	26.6	25.2	22.63	11.14	6.37	0	0.2	285	103	18	9.89	8	9.13	0.68	-0.53	162
1966	13.9	9.36	8.33	5.38	3.92	0	0.16	255	362	4	27.5	15	7.07	0.5	-0.4	110
1967	29.4	25.23	19	9.53	5	0	0.14	281	95	11	6.73	10	8.9	0.62	-0.44	121
1968	21	16.17	13.34	8.75	5.09	0	0.21	213	237	14	3.86	14	6.5	0.74	-0.46	111
1969	17.4	15.3	13.87	10.3	6.04	0	0.12	258	97	4	19.75	8	12.38	0.67	-0.4	115
1970	13.7	12.73	9.85	6.5	3.49	0	0.24	279	101	24	6.33	5	7.6	0.33	-0.22	103
1971	16.5	15.23	14.07	7.98	4.41	0	0.24	220	105	10	5.8	12	6.25	0.53	-0.36	91
1972	35.1	33.03	29.93	12.5	5.96	0	0.24	260	109	12	8.17	11	5.91	0.5	-0.35	117
1973	26	22.63	19.17	12.15	6.69	0	0.1	253	72	5	18.4	13	9.08	0.72	-0.4	124
1974	34.8	29.77	21.15	7.93	6.95	0	0.19	230	139	7	13	13	8.46	0.83	-0.59	118
1975	39.9	28.47	17.05	7.86	5.39	0	0.21	236	111	11	8.36	5	14.4	0.6	-0.37	107
1976	29.4	26.4	21.67	11.62	8.07	0	0.23	239	82	8	5	7	15.86	0.76	-0.47	112
1977	40.8	31.9	21.04	9.41	4.89	0	0.22	211	74	9	13.78	5	11.8	0.68	-0.36	104
1978	23.9	20.63	17.83	11.32	6.31	0	0.17	226	103	4	18.75	10	13.3	0.64	-0.38	109
1979	33.1	25.9	16.23	10.76	7.05	0	0.26	267	106	12	3.17	7	13.43	0.62	-0.41	113
1980	37.5	28.47	16.52	9.07	5.08	0	0.24	242	82	13	5.77	10	8.5	0.73	-0.46	97
1981	18.2	17.37	14.49	6.37	3.82	0	0.33	184	52	10	6.7	8	6	0.44	-0.26	96
1982	37	32.33	22.41	11.33	5.92	0	0.26	229	92	6	4.33	13	8	0.65	-0.36	105
1983	13.6	12.19	8.99	5.79	4.79	0	0.24	201	361	6	5.33	12	13.58	0.6	-0.38	96
1984	11.8	11.13	10.67	7.12	5.44	0	0.23	241	98	9	8.33	7	13.29	0.38	-0.2	84
1985	28.7	26.07	19.8	13.44	8.11	0	0.19	220	97	7	6	11	9.55	0.87	-0.42	83
1986	40.9	28.9	18.22	11.81	6.79	0	0.28	198	256	1	1	12	12.42	1.49	-0.6	80
1987	24.2	20.4	13.91	8.63	4.84	0	0.17	238	275	8	9.88	8	12.75	0.43	-0.34	86
1988	18	15.47	11.23	6.05	3.57	0	0.17	192	87	10	13.8	10	4.7	0.51	-0.27	101
1989	17.2	15.1	10.52	5.12	3.43	0	0.2	244	89	5	25.2	10	4.5	0.38	-0.25	99
1990	30	23.2	16.08	6.43	4.05	0	0.2	279	74	11	13.09	12	4.58	0.55	-0.29	104
1991	20.3	17.43	12.05	9.15	6.03	0	0.12	256	89	5	15.2	16	9.13	0.76	-0.45	111
1992	14.9	12.77	9.55	7.03	4.69	0	0.26	311	109	9	6.22	12	5.5	0.55	-0.34	91
1993	24.9	21.43	15.14	8.68	5.88	0	0.19	240	91	6	9.33	8	18.38	0.96	-0.46	78
1994	10.3	9.66	7.92	6.33	4.43	0	0.15	241	119	9	17.33	6	10.83	0.42	-0.21	100
1995	16.2	14.73	11.2	4.7	3.44	0	0.17	262	16	10	13.2	9	6.44	0.61	-0.3	88
1996	16.9	14.77	12.2	8.84	6.36	0	0.18	277	105	6	6.17	10	15.1	0.88	-0.46	88
1997	32.4	25.57	18.06	9.29	7.5	0	0.12	218	54	5	16.2	9	18.11	0.86	-0.47	97
1998	14.5	13.43	10.11	5.65	3.78	0	0.14	265	89	13	12.31	9	6.33	0.43	-0.25	114
1999	5.24	4.95	4	2.86	2.32	0	0.11	247	25	14	15.71	5	4.4	0.24	-0.15	91
2000	15.3	13.85	8.85	4.16	3.52	0	0.24	305	58	13	7.85	12	5.33	0.76	-0.39	100
2001	14.2	13.3	11.95	6.68	5.13	0	0.08	259	100	13	10.08	6	11.67	0.45	-0.21	92
2002	11.22	9.69	8.7	5.38	4.59	0	0.17	254	105	5	17.4	10	8.4	0.49	-0.3	128
Min	5.24	4.95	4.00	2.86	2.32	0.00	0.08	184.00	16.00	1.00	1.00	5.00	2.79	0.24	-0.60	78.00
Average	22.70	19.25	14.49	8.08	5.13	0.00	0.19	244.10	115.15	9.60	10.84	9.83	9.37	0.63	-0.37	104.65
Max	40.90	33.03	29.93	13.44	8.11	0.00	0.33	311.00	362.00	24.00	27.50	16.00	18.38	1.49	-0.15	162.00
25th Percentile	14.80	13.40	10.42	6.04	3.90	0.00	0.16	224.50	85.75	6.00	6.21	8.00	6.19	0.50	-0.45	91.75
75th Percentile	29.55	25.65	18.10	9.72	6.11	0.00	0.24	260.50	106.75	12.25	14.15	12.00	12.50	0.75	-0.30	112.25
Std. Deviation	9.77	7.55	5.38	2.64	1.44	0.00	0.06	29.27	76.15	4.92	6.01	2.90	4.02	0.22	0.11	17.76

7.5.1.9 Quantification of Hydraulic Habitat Impacts

A comparison of pre- and post-impact 7-day minimum flows series is presented by Figure 7.33. This figure graphically illustrates a shift in the mean and a significant change in the variability of the 7-day flow in the post scenario. What is unknown from this plot is how the change in the minimum 7-day flows affects habitat. One means of quantifying impacts on habitat is to combine the flow information from Figure 7.33 with results from the hydraulic model for the Eramosa study reach.

Selected cross sections were chosen from the Eramosa study reach by visually inspecting plots of flow versus a specific hydraulic parameter. The hydraulic parameters chosen for investigation included wetted perimeter, depth, flow area and flow velocity.

The hydraulic parameter values corresponding to flows statistics presented in Figure 7.33 were extracted for the selected cross sections. Flow statistics generated from IHA for the

7-day, 30-day, 90-day minimums and monthly statistics for June, July, August and September were also considered. The corresponding hydraulic parameters for each of the flow statistics were extracted.

Results for wetted perimeter are presented by Tables 7.25 and 7.26, for minimum daily and monthly flow statistics, respectively. Analysis focused on the change in the maximum, minimum and mean, as well as the spread of range between ±1 standard deviation and the RVA high and low. The results imply the change in mean wetted perimeter is much less than the change in mean flow for example for the minimum daily and monthly statistics.

Tables 7.27 and 7.28 provide summaries for all flow statistics for both wetted perimeter and flow depth. Results in these tables also appear to confirm that minimum, maximum and mean changes in hydraulic habitat are much less than the change for the minimum, maximum and mean flow statistics. This implies that flow may be a conservative indicator for change in hydraulic habitat. It is expected that this change in hydraulic habitat would be very much dependent on channel shape.

7.5.1.10 Geomorphic Threshold Analysis

Much of the analysis in the case study to this point has focused on flow, but changing the flow has geomorphic implications. The pre- and post-impact flow series were compared to geomorphic thresholds previously developed to assess the potential impacts to sediment transport and stream morphology.

The biggest change with respect to geomorphic parameter threshold exceedances is the residual pool threshold exceedance. This directly related to the cutoff flow in the PTTW conditions of 0.42 m^3/s. This cutoff flow is below the residual pool threshold of 0.44 m^3/s, and therefore the residual pool threshold is exceeded more often. If the criteria in the PTTW conditions were set to the residual pool threshold, the result would be little or no impact to the geomorphic threshold exceedances (Table 7.29).

Figure 7.33 Eramosa Case Study pre- and post-impact 7-Day minimum flow statistics from IHA and RVA

Table 7.25 Change in wetted perimeter associated 7-day and 30-day minimum flow statistics

7-Day Min Statistic	Change in Flow			Change in Wetted Perimeter									Ratio of WP/Flow Change %	Ratio of RVA, SD Change %
				X-Section 106064			X-Section 106383			X-Section 106059				
	Pre m^3/s	Post m^3/s	%Change %	Pre (m)	Post (m)	Change %	Pre (m)	Post (m)	Change %	Pre (m)	Post (m)	Change %		
Min	0.13	0.13	0%	4.85	4.85	0%	5.77	5.77	0%	5.92	5.92	0%	0%	
- 1 S.D.	0.38	0.33	-13%	9.39	9.00	-4%	12.85	12.61	-2%	11.64	11.36	-2%	22%	56%
RVA Low (25%)	0.45	0.42	-7%	9.96	9.72	-2%	13.68	13.24	-3%	11.93	11.83	-1%	32%	19%
RVA Low (33%)	0.48	0.41	-15%	10.17	9.62	-5%	14.08	13.06	-7%	12.02	11.79	-2%	33%	26%
Mean	0.58	0.44	-23%	11.28	9.91	-12%	15.16	13.59	-10%	12.52	11.91	-5%	39%	
RVA High (67%)	0.68	0.46	-32%	11.86	10.03	-15%	16.12	13.83	-14%	12.80	11.96	-7%	37%	
RVA High (75%)	0.72	0.47	-34%	12.03	10.11	-16%	16.44	13.97	-15%	12.96	11.99	-7%	37%	
+ 1 S.D.	0.78	0.56	-29%	12.40	11.01	-11%	17.03	14.94	-12%	13.49	12.39	-8%	37%	
Max	1.17	0.86	-26%	14.84	13.33	-10%	20.55	18.33	-11%	14.64	13.91	-5%	33%	

30-Day Min Statistic	Change in Flow			Change in Wetted Perimeter									Ratio of WP/Flow Change %	Ratio of RVA, SD Change %
				X-Section 106064			X-Section 106383			X-Section 106059				
	Pre m^3/s	Post m^3/s	%Change %	Pre (m)	Post (m)	Change %	Pre (m)	Post (m)	Change %	Pre (m)	Post (m)	Change %		
Min	0.35	0.34	-3%	9.16	9.07	-1%	12.71	12.66	0%	11.47	11.41	-1%	0%	
- 1 S.D.	0.45	0.37	-19%	9.98	9.30	-7%	13.73	12.79	-7%	11.94	11.58	-3%	30%	75%
RVA Low (25%)	0.52	0.45	-14%	10.58	9.94	-6%	14.60	13.66	-6%	12.20	11.93	-2%	36%	53%
RVA Low (33%)	0.56	0.42	-25%	11.05	9.72	-12%	14.98	13.24	-12%	12.41	11.83	-5%	38%	70%
Mean	0.72	0.57	-21%	12.06	11.14	-8%	16.48	15.05	-9%	13.00	12.45	-4%	32%	
RVA High (67%)	0.82	0.60	-27%	12.80	11.53	-10%	17.60	15.38	-13%	13.74	12.64	-8%	38%	
RVA High (75%)	0.88	0.64	-27%	13.63	11.69	-14%	18.75	15.73	-16%	14.01	12.71	-9%	48%	
+ 1 S.D.	0.99	0.77	-22%	14.36	12.32	-14%	19.88	16.90	-15%	14.32	13.38	-7%	53%	
Max	1.66	1.33	-20%	15.96	15.31	-4%	21.78	21.01	-4%	15.62	14.98	-4%	20%	

Table 7.26 Change in wetted perimeter associated with selected monthly flow statistics

Month of June	Change in Flow			Change in Wetted Perimeter									Ratio of WP/Flow Change %	Ratio of RVA, SD Change %
				X-Section 106064			X-Section 106383			X-Section 106059				
	Pre m^3/s	Post m^3/s	%Change %	Pre (m)	Post (m)	Change %	Pre (m)	Post (m)	Change %	Pre (m)	Post (m)	Change %		
Min	0.72	0.47	35%	12.05	10.11	-16%	16.48	13.97	-15%	13.00	11.99	-8%	0%	
- 1 S.D.	2.52	1.87	26%	14.57	12.11	-17%	20.22	16.56	-18%	14.45	13.08	-10%	-58%	58%
RVA Low (25%)	3.11	2.65	15%	15.27	14.55	-5%	20.97	20.19	-4%	14.95	14.44	-3%	-26%	100%
RVA Low (33%)	3.40	2.93	14%	15.51	14.21	-8%	21.23	19.63	-8%	15.17	14.25	-6%	-53%	100%
Mean	3.66	3.20	13%	16.32	15.85	-3%	22.24	21.52	-3%	15.96	15.54	-3%	-23%	
RVA High (67%)	4.29	3.82	11%	16.63	16.00	-4%	22.56	21.86	-3%	16.28	15.65	-4%	-33%	
RVA High (75%)	6.54	6.08	7%	16.76	16.21	-3%	22.75	22.11	-3%	16.41	15.85	-3%	-45%	
+ 1 S.D.	0.53	0.72	-36%	17.12	16.85	-2%	24.08	23.62	-2%	17.06	16.59	-3%	6%	
Max	1.47	1.06	28%	17.93	17.82	-1%	24.56	24.49	0%	17.82	17.69	-1%	-2%	

Month of July	Change in Flow			Change in Wetted Perimeter									Ratio of WP/Flow Change %	Ratio of RVA, SD Change %
				X-Section 106064			X-Section 106383			X-Section 106059				
	Pre m^3/s	Post m^3/s	%Change %	Pre (m)	Post (m)	Change %	Pre (m)	Post (m)	Change %	Pre (m)	Post (m)	Change %		
Min	0.61	0.42	-31%	11.56	9.72	-16%	15.45	13.24	-14%	12.65	11.83	-6%	0%	
- 1 S.D.	0.71	0.46	-35%	11.98	10.02	-16%	16.36	13.80	-16%	12.90	11.96	-7%	37%	97%
RVA Low (25%)	0.94	0.67	-28%	14.07	11.81	-16%	19.40	16.00	-18%	14.18	12.77	-10%	51%	97%
RVA Low (33%)	0.95	0.66	-31%	14.15	11.75	-17%	19.54	15.87	-19%	14.23	12.75	-10%	49%	106%
Mean	1.28	1.02	-21%	15.19	14.48	-5%	20.88	20.07	-4%	14.89	14.39	-3%	19%	
RVA High (67%)	1.38	1.11	-19%	15.42	14.69	-5%	21.15	20.39	-4%	15.08	14.54	-4%	21%	
RVA High (75%)	1.66	1.37	-17%	15.96	15.40	-4%	21.78	21.13	-3%	15.62	15.07	-4%	19%	
+ 1 S.D.	1.86	1.58	-15%	16.28	15.88	-2%	22.19	21.62	-3%	15.92	15.55	-2%	17%	
Max	3.15	2.87	-9%	17.50	17.34	-1%	24.26	24.16	0%	17.43	17.32	-1%	7%	

Table 7.27 Summary of wetted perimeter change at selected cross sections

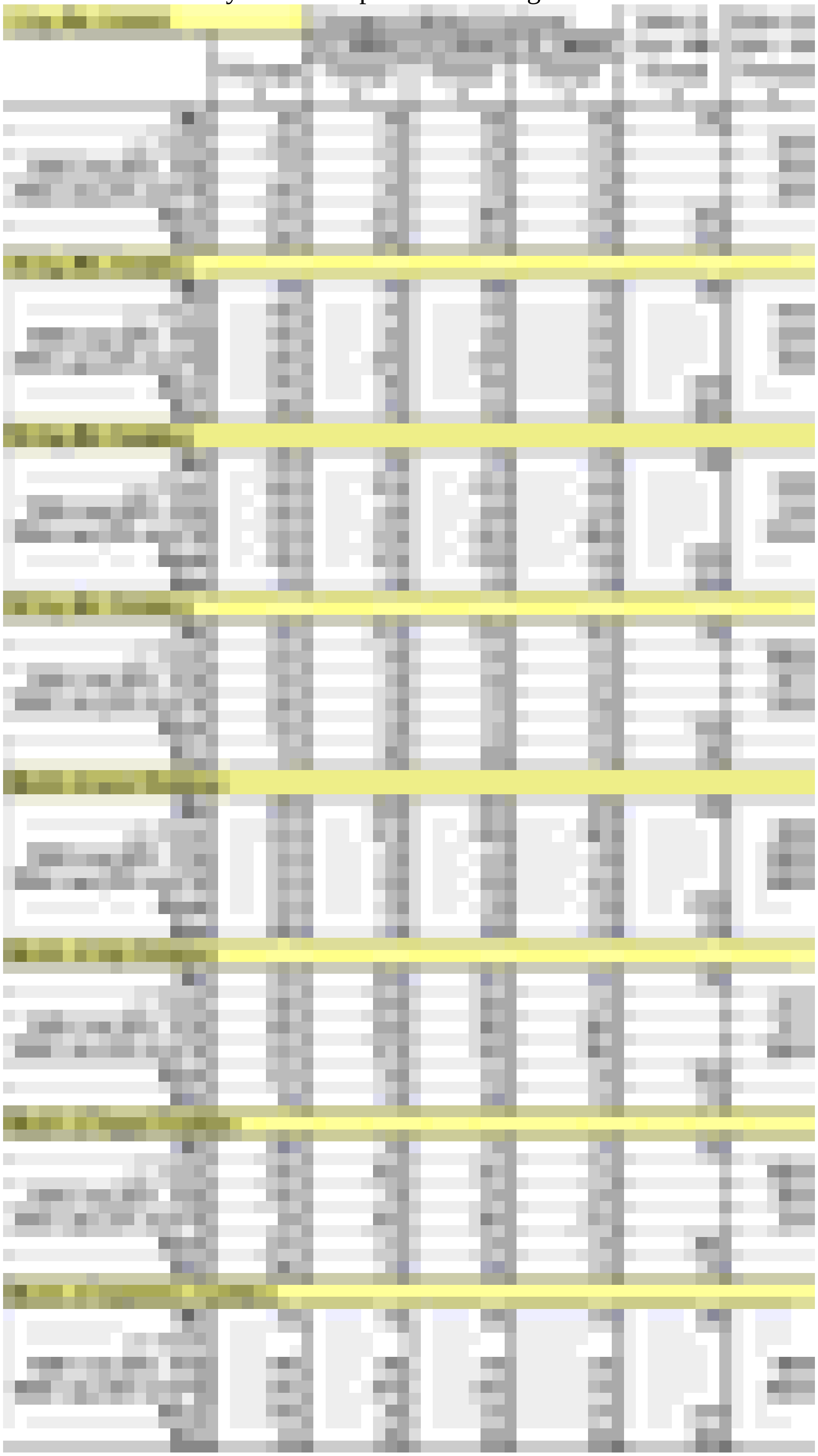


Table 7.28 Summary of depth change at selected cross sections

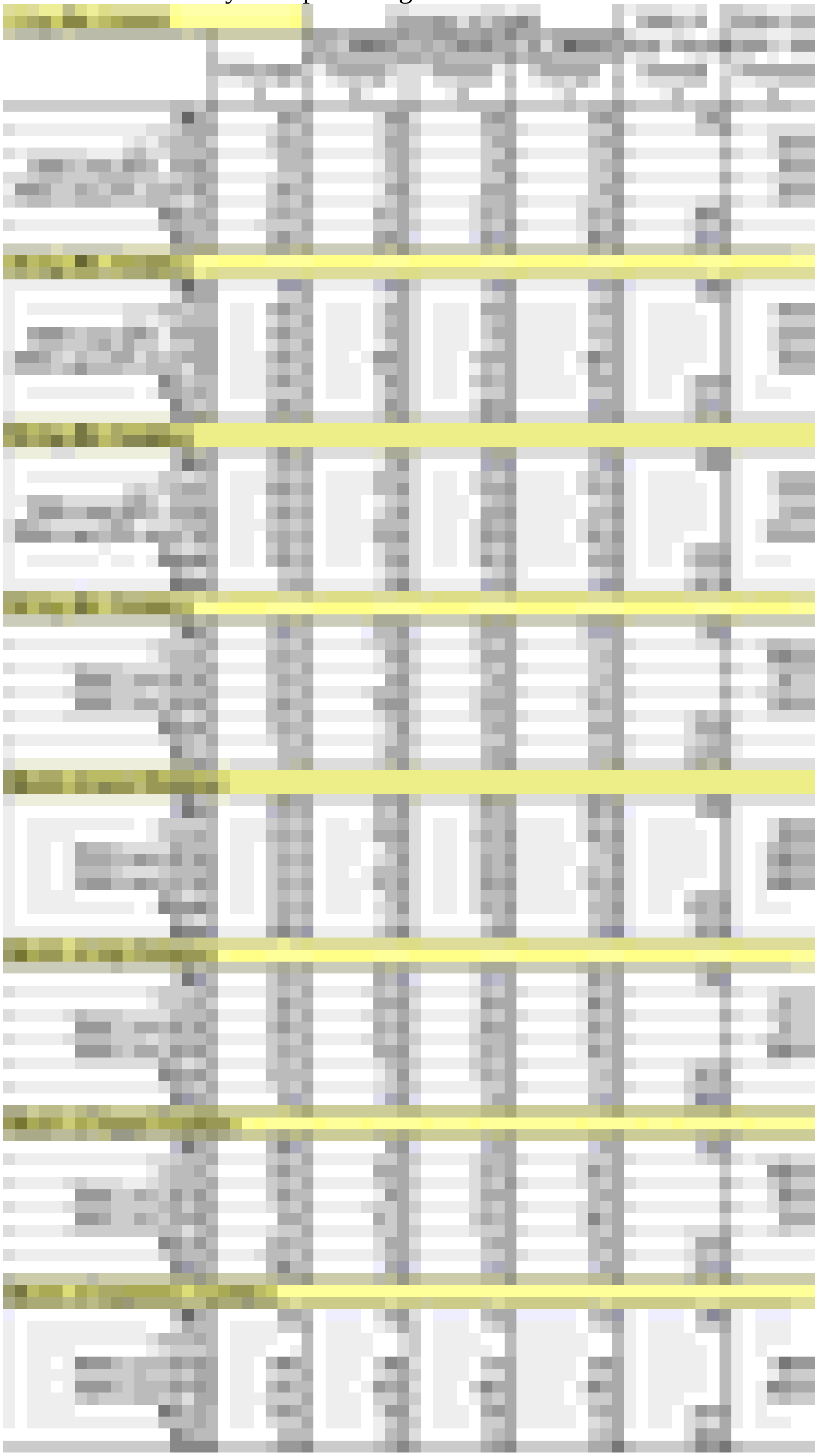


Table 7.29 Eramosa Case Study geomorphic threshold exceedances

Geomorphic Threshold		Days Criteria Exceeded		%Time Criteria Exceed		% Change
Description	**Threshold (m3/s)**	**Naturalized Condition**	**Potential Taking Condition**	**Naturalized Condition**	**Potential Taking Condition**	
Residual Pool	0.44	14,604	13,525	98%	91%	7%
Flushing Flow	5.38	1,461	1,371	10%	9%	1%
Bankfull Flow	15.5	132	131	1%	1%	0%
Bed Mobilizing Flow	21.8	61	61	0%	0%	0%

7.5.1.11 Eramosa Case Study Summary

The Eramosa Case Study analysis was intended to illustrate how tools such as IHA could be applied to quantify the expected changes associated with a water taking scenario. The existing conditions attached to the Eramosa River surfacewater taking had already built in several ecological considerations, such as the concept of a variable flow, need for a variable taking and the concept of a lower cutoff flow. These are all measures that could be incorporated into permits to consider the environment’s needs.

The example case study also illustrates how the hydraulic modeling can be used to transform flow statistics to hydraulic quantities. The key missing factor is biological response, but relating changes in hydraulic parameters to biological response requires additional study.

Figures 4.2 and 4.3 were developed to communicate life cycle requirements for selected fish species. Until biological response is better understood, one option might be to develop life cycle requirements for a range of different aquatic organisms to allow qualitative assessment of potential impacts.

It is not expected that this level of analysis would be completed for all water takings, but rather for those with potential for significant environmental impact or in reaches where over taking is an issue.

7.5.2 Blair Creek Case Study

The Blair Creek case study examines the potential impacts to the flow regime associated with the proposed servicing of development in the Blair Creek Watershed. The existing and proposed flow series is simulated with the GAWSER model. The latest GAWSER model was obtained from Stantec Consultants, the consultant completing the Blair Creek Servicing Study (Stantech 2005). The continuous simulation period provided by Stantec included the 1960 to 1999 period of record, but this period was extended through to October 2003 to allow comparison with observed streamflow data available for the 1998 to 2003 period. The existing conditions (1960-2003) were simulated with the GAWSER *existing condition* watershed model, while the proposed conditions were simulated with the *future condition* watershed model (2004-2046). The future condition model included proposed mitigation measures designed to manage future development flows.

Continuous flows for the existing and future condition, at the Dickie Settlement Road stream gauge immediately upstream of the instream flow reach, were extracted from the GAWSER model results. Continuous daily peak flows and mean daily flows were organised using an MS-Excel spreadsheet and formatted to be compatible with the IHA software. The IHA software was then used as a diagnostic tool to analyse the existing and proposed continuous flow series.

The continuous simulation using the GAWSER model is based on an hourly time step. A daily peak flow series and a mean daily flow series were created to analyze how both event flows (max daily) and daily mean flows would change in a future condition. Selected plots were extracted from the IHA software to analyse the impacts.

The peak daily flows were analysed first. Results from the monthly alteration (Figure 7.34) and the hydrologic alteration (Figure 7.35) plots indicate that the March through September monthly daily flow peaks are expected to increase, along with the 3-day to 90-day daily minimum peak daily flows. Other parameters also indicated a measure of change but not as much as the 3-day to 90-day minimum flows.

Similar plots were extracted for the mean daily flows and are presented for monthly alteration by Figure 7.36 and for hydrologic alteration by Figure 7.37. Note the very tight flow range of the predicted change.

Figure 7.34 Blair Creek Case Study peak flows monthly alteration plot

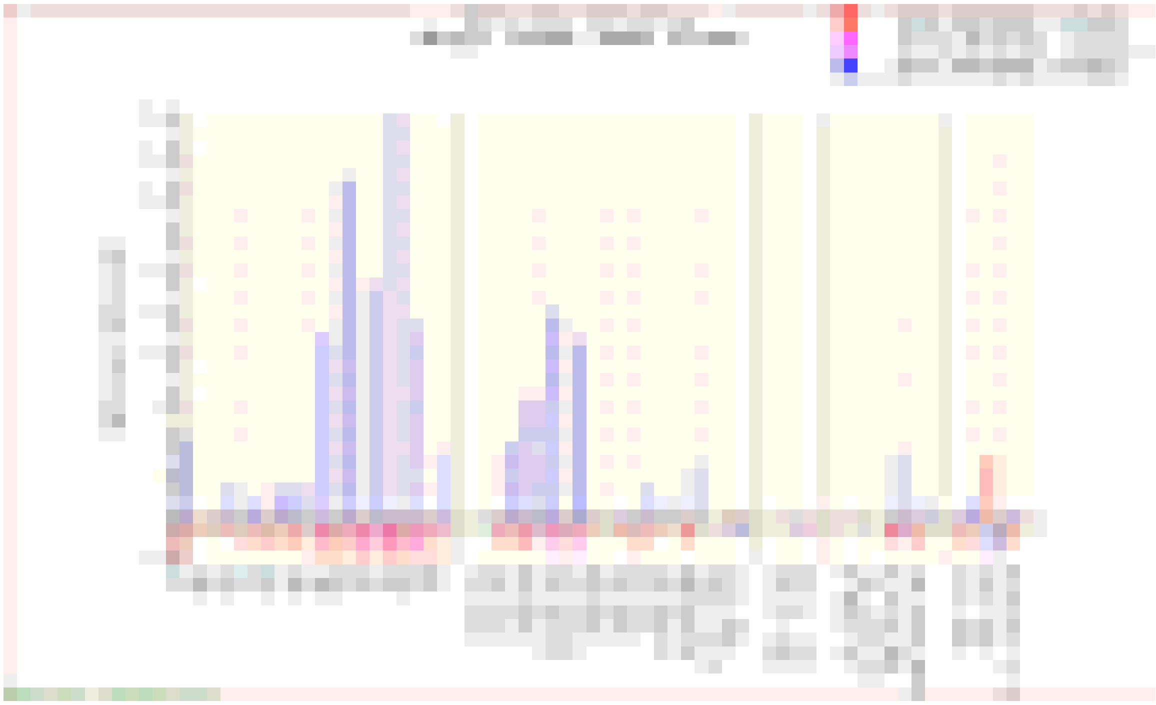


Figure 7.35 Blair Creek Case Study peak flows hydrologic alteration plot

Figure 7.36 Blair Creek Case Study daily average flows monthly alteration plot

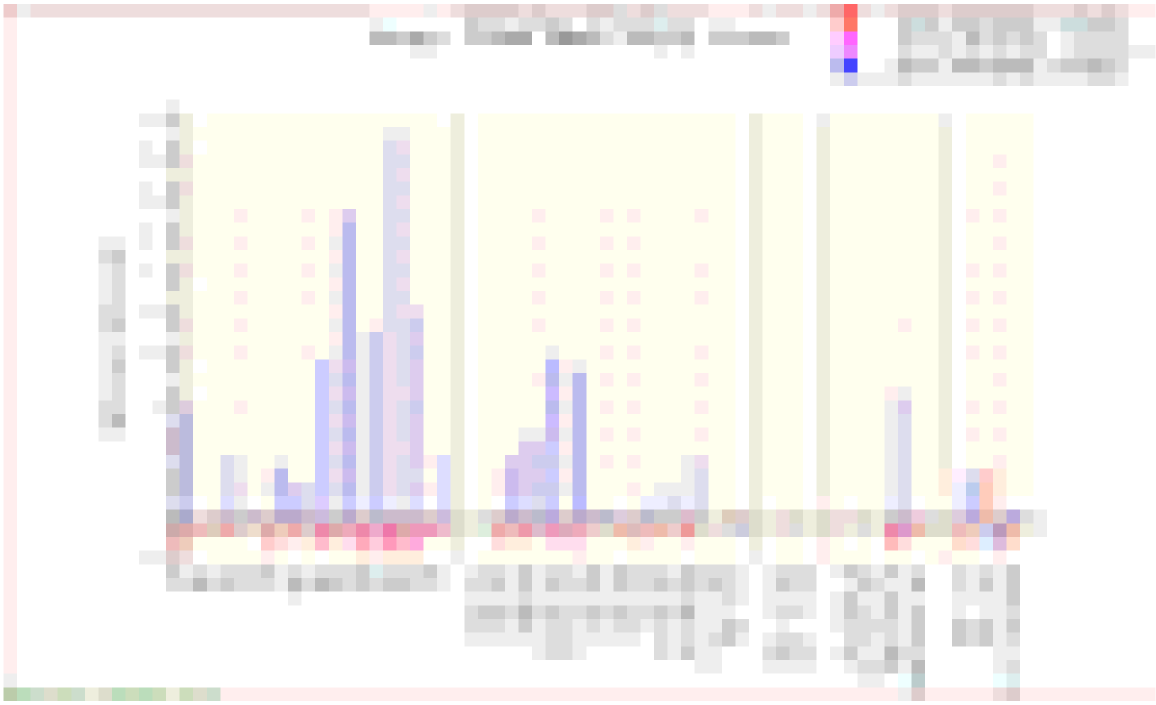


Figure 7.37 Blair Creek Case Study daily average flows hydrologic alteration plot

Next, monthly peak daily flow plots for the months of March (Figure 7.38) and July (Figure 7.39) were produced from the IHA software, as well as mean daily flow plots for both months (Figure 7.40 and 7.41, respectively).

Figure 7.38 Blair Creek Case Study peak flows average March flow plot

Figure 7.39 Blair Creek Case Study peak flows average July flow plot

Figure 7.40 Blair Creek Case Study average daily flows average March flow plot

Figure 7.41 Blair Creek Case Study average daily flows average July flow plot

The results suggest that the proposed management measures used can effectively mitigate peak flows, but that volume management may be an issue that will have to be monitored. The proposed mitigation measures are designed to avoid discharging directly to the stream and are geared to put water back into the ground. However, development will increase the volume of runoff, which translates into higher mean daily flows and higher peak daily flows in some months. These higher values move the streamflows closer to the D_{50} geomorphic threshold (see Table 7.30), which could result in channel adjustment. The increased duration and occurrence of bed mobilizing flows will be examined in the servicing study.

Table 7.30 Blair Creek threshold comparison existing versus future condition

Threshold	Threshold Flow (m^3/s)	Existing Condition Occurrences	Future Condition Occurrences	Percentage Change
Residual Flow	0.15	15,704	15,704	0%
D_{50}	0.32	1,696	3,202	89%
D_{84}	1.19	128	152	19%
Bankfull Flow	1.77	43	46	7%

7.5.3.1 Blair Creek Case Study Summary

The unique situation and characteristics of the Blair Creek watershed have driven the need to consider non-standard approaches to effectively manage storm water to the very fine tolerances. Other developing urban watersheds may have different characteristics and issues. The IHA software, along with the geomorphic and hydraulic modeling approaches applied in this study, offer a means to better quantify anticipated impacts of urban development on the natural environment. Better knowledge and quantification of anticipated impacts offers the opportunity to implement measures intended to protect or enhance environmental functions in a watershed or subwatershed.

Water takings in the Blair Creek Watershed are currently confined to groundwater takings. There are no permitted surfacewater takings at the present time. The subwatershed study recommends groundwater takings should be from the deep groundwater aquifer and not the shallow groundwater aquifer, to avoid takings that would impact the stream.

7.5.3 Whitemans Creek Case Study

Water use in the Whitemans Creek watershed is substantial and the natural flow regime has been altered. For this case study, the focus is on maintaining a balance between human needs and the environmental flow needs. This case study will demonstrate how indices calculated for the pilot reach could be used to make decisions with respect to water takings in the Whitemans Creek watershed. The PTTW database, along with observed flow information and indices developed earlier in the chapter are used to examine the present situation and suggest some alternate management strategies.

7.5.3.1 Assessing Supply and Demand

Water use from the PTTW database in Whitemans Creek was divided into surfacewater takings and groundwater takings. Short-term permits such as pumping tests were removed, as were permits that are considered non-consumptive, such as Ducks Unlimited ponds and stream reservoirs operated by the GRCA. Generally, this leaves agricultural irrigation and golf course irrigation as the major consumptive takings in the watershed (see Tables 6.11 and 6.12 in Section 6.8).

To compare the supply with demand, the mean daily flows from the stream gauge at Mount Vernon on Whitemans Creek were plotted against the total value of the surfacewater or groundwater permits (expressed as flow rates), as well as the combination of the two. The taking season was considered from May to October to illustrate the impact of the water takings on the streamflow in Whitemans Creek by irrigation. Figure 7.42 shows the impact that the surfacewater takings alone would have on the mean daily streamflow (1961-2002). The surfacewater takings amount to 1.49m^3/s, and put the creek into negative flows four times, for several days at a time in July and August. Streamflows with the surfacewater takings removed, for the rest of July and August and even until mid-October are also very low, never surpassing 1m^3/s. Normal flows during this time range from over 1.2 to almost 2.5m^3/s.

It should be noted that observed flows at the Mount Vernon gauge include the effects of historical takings. No effort was made to create a natural flow series, since this could not be achieved with any known degree of accuracy. With this in mind, the comparison illustrated by Figure 7.42 confirms the potential taking (the demand) relative to the flow in Whitemans Creek (the supply), is substantial. Long-term average flows were calculated for each day of the active irrigation season from 1961 to 2002. The average daily flows for a given date across the period of record helps dampen the impacts of takings and provides some indication of the magnitude of a more natural streamflow.

The values of groundwater and total takings are also shown on Figure 7.42 to illustrate their potential impact on the Whitemans Creek flows. Groundwater takings are even more substantial than the surfacewater taking, at 2.12m^3/s, which would put July through to September into negative flows, except for a few days. The sum of all groundwater and surfacewater takings (shown by the yellow line in Figure 7.42), would put the remainder of the taking season after mid-May into negative flows, leaving nothing in the creek for fish and wildlife. This condition has not been observed, since the storage in the groundwater system acts as a reservoir or buffer. Still, it is important to realize there is a very direct connection between groundwater takings in Whitemans Creek and surfacewater flows. The surface geology of the lower Whitemans Creek region dominated by the Norfolk sand plain allows for more connectedness between surfacewater and groundwater. This sand plain is a reasonably homogeneous feature which could be thought of as a large sponge that contains water. Water from this formation seeps diffusely into Whitemans Creek. Groundwater takings that are extracted from the aquifer are thus likely impacting the Whitemans Creek watercourse. The degree, to which the groundwater takings impact the watercourse, is uncertain. For the analysis it is assumed the groundwater takings would have shown up in the watercourse if they were left in the environment. Summing the groundwater and surfacewater takings will result in a deficit of flows during a large portion of the taking season for the Whitemans Creek subwatershed.

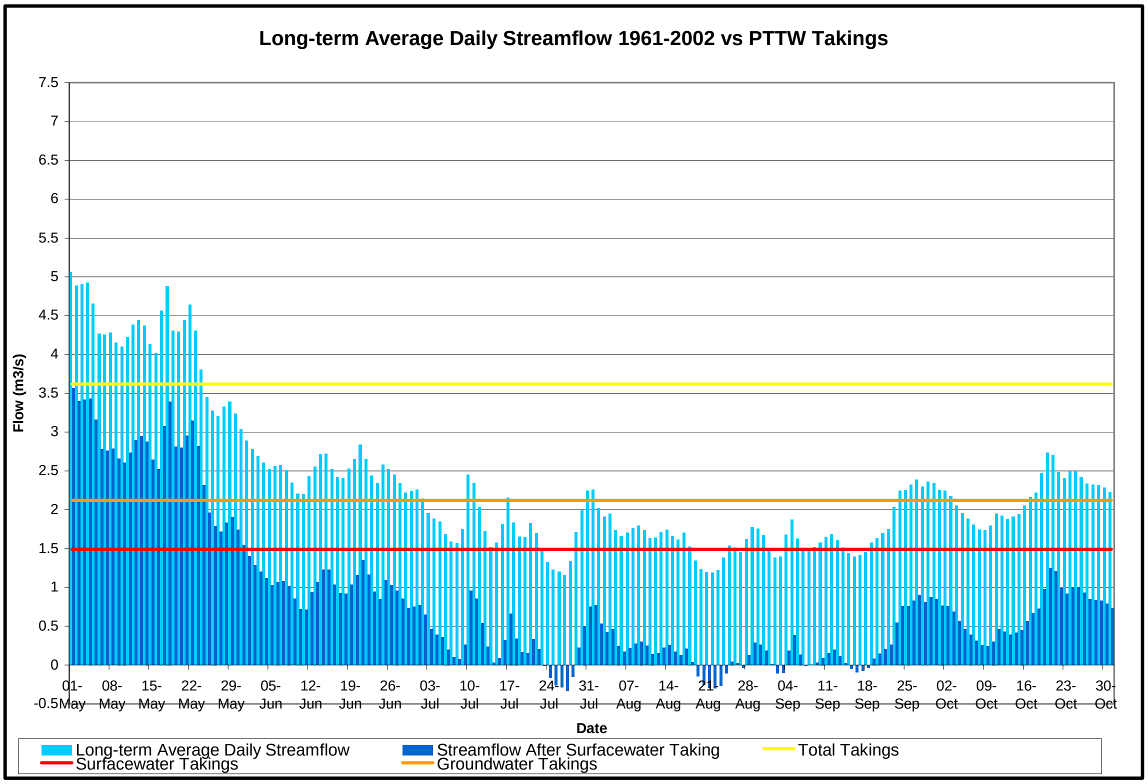


Figure 7.42 Daily Streamflow averages for Whitemans Creek with PTTW takings

The resultant flows after the surfacewater, groundwater and the combination of these takings were removed are illustrated in Figure 7.43. The zero-flow line is highlighted (dashed line) to show when flows are no longer available, and shows how detrimental the water takings would be if they were all directly removed from the Creek at the same time. It should be noted that takings from the groundwater system have a delayed impact on the Creek, affecting the magnitude of baseflow discharged to the Creek, while surfacewater takings have a direct impact to streamflow at the time of the taking. Both have to be managed to maintain flows in Whitemans Creek.

It is clear that the permitted rates far exceed the availability of water in Whitemans Creek, and if they were extracted simultaneously at the maximum permitted rate, there would be nothing left for the aquatic environment. Figures 7.42 and 7.43 convey the magnitude of the challenge of managing demand and available supply, which is further compounded by the rising demand during drought periods when supply naturally decreases.

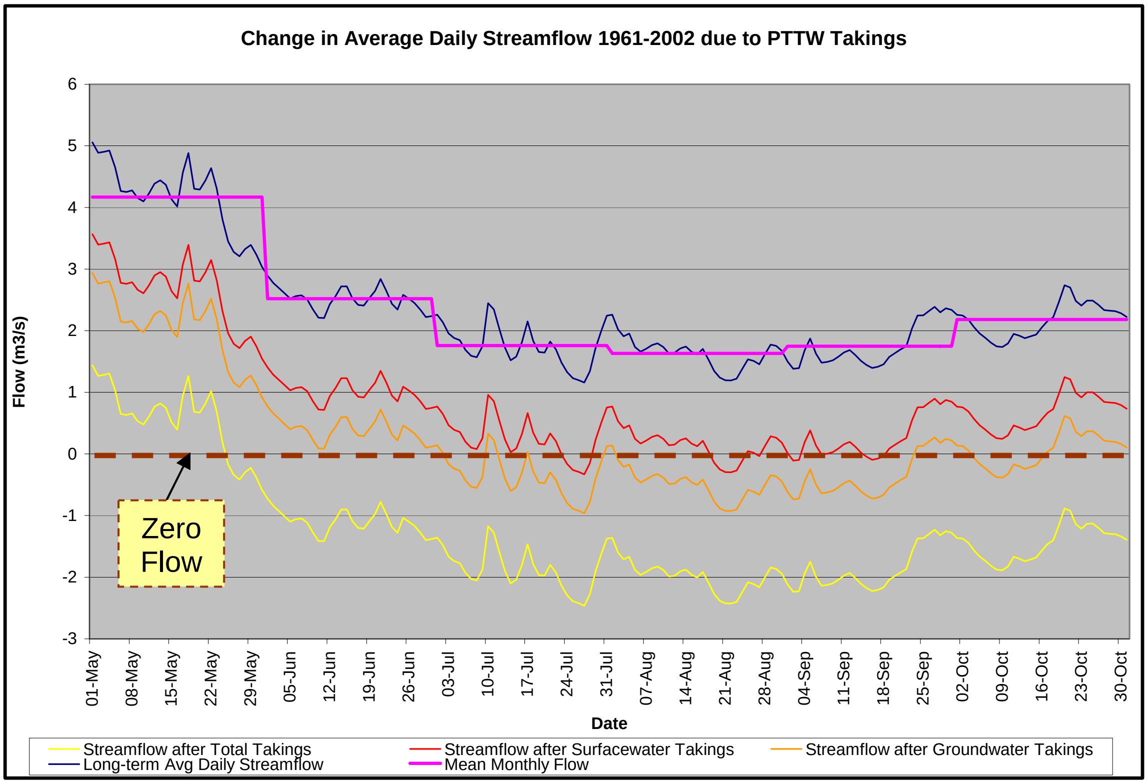


Figure 7.43 Whitemans Creek flows before and after takings were removed.

The analysis based on long-term average flows does not adequately emphasize the situation of the past several years in this watershed. The watershed has been experiencing more drought years than normal, with about 5 years of drought-level conditions in this last decade. If the last several years have been any indication, the situation of water takings and streamflow is much more severe than indicated by the preceding discussion. Figure 7.44 shows the daily streamflow averages for 1995-2002 in the taking season from May to October.

The streamflow from 1995-2002 shows much more sinuosity in the first half of the water taking season, and the summers have been experiencing much lower streamflow values during this time. Also, the surfacewater takings alone are critical, putting almost all of August and the first half of September into negative flows. Negative flows also occur in July for a period of 5 days. The flows also get critically low in October with the surfacewater takings removed; below 0.5m^3/s. The combination of both groundwater and surfacewater takings (3.62m^3/s), as shown by the yellow line in Figure 7.44, would put almost all of July to October into negative flows. The past decade has also been detrimental to the groundwater supply due to lack of recharge to the aquifers. The ability of the system to buffer the impacts of overtakings in Whitemans Creek is lessened when the groundwater supply is also being depleted faster than it is recharged. The concern of cumulative impacts of water takings is a definite issue in this watershed. There must be simple approaches to ensure that there is enough water the environment, while also accommodating for some human uses such as irrigation in this watershed.

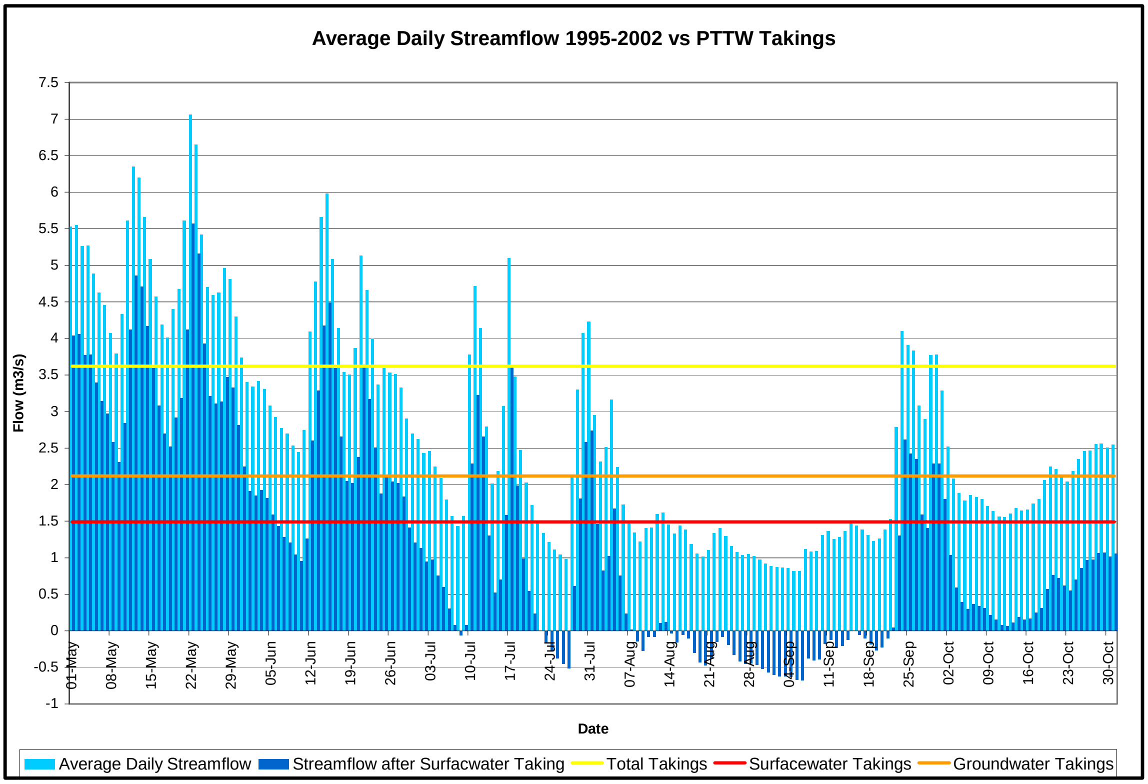


Figure 7.44 Average daily streamflow with surfacewater takings removed, 1995-2002

7.5.3.2 Management Options

Management options are available to manage the issues that exist in the Whitemans Creek watershed. When considering management options, the social and economic impacts must be considered, along with the practical application of management actions.

Demand management and how it is scaled relative to the severity of the situation are important considerations. In addition, equitable application of demand management is an important consideration. The objective of demand management is to ensure sufficient water is maintained in the Whitemans Creek to sustain the ecosystem.

The analysis completed earlier in this chapter (see Section 7.4.5) suggested that a cut-off flow of 0.8 m^3/s may be a criterion to consider for Whitemans Creek through the pilot reach. The cut-off flow is based on the flow at which hydraulic connection begins to be lost between pools. The practicality of applying this cut-off flow and the potential impact it may have on farmers reliant on Whitemans Creek as a source of irrigation water is examined in the next sections. The investigations include number of days when daily flows are below the prescribed cutoff-flow, the sensitivity of varying the cut-off flow and the demand reductions required to maintain the cut-off flow.

7.5.3.3 Cut-off Flows

A cut-off flow is suggested to try to limit takings during low-flow periods, and is set to limit the effects on the ecology of the creek due to water takings. The cut-off flow, at $0.8m^3/s$ for the pilot reach in Whitemans Creek, is generally below the 50% flows, as seen in Figure 7.45, plotted with the percentile flows for Whitemans Creek at Mount Vernon. The cut-off flow is an indicator to water users that flows are getting critically low.

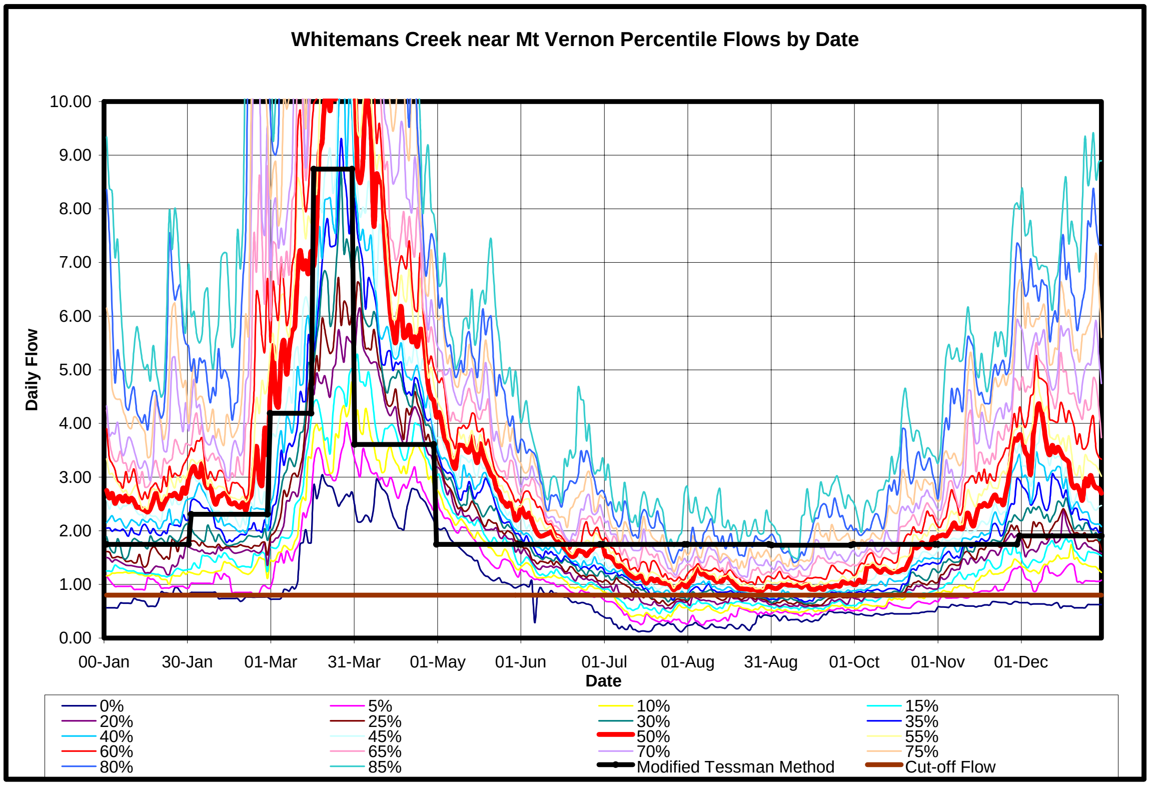


Figure 7.45 Cut-off flow for Whitemans Creek compared to percentile flows

The cut-off flow of $0.8m^3/s$ was based on the threshold for significant loss of hydraulic connectivity for fish passage between pools (see Appendix F-5). Below this cut-off flowrate, it is thought that there would be significant loss of hydraulic connectivity, which would prevent fish from moving between pools to avoid predators, find refuge and select suitable habitats. During drier years, flows lower than the cut-off does occur. The daily occurrences of flows below this cut-off flow for each year are seen in Figure 7.46. From Figure 7.46, it can be seen that daily average flows below the 0.8m^3/s cut-off occur quite frequently in years of lower flows.

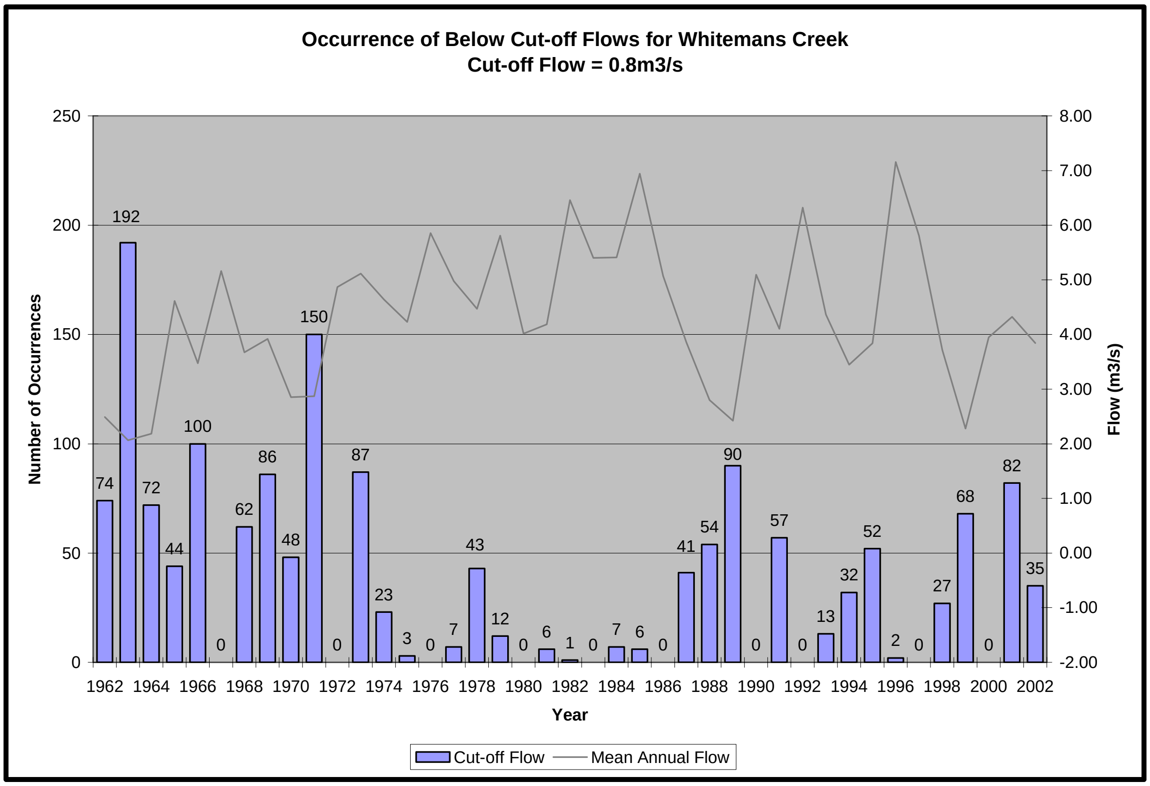


Figure 7.46 Count of flows below cut-off flows each year in Whitemans Creek

Water users, especially farmers, are most susceptible to a cut-off flow stipulation. If farmers were required to alter their water use to accommodate a limitation on water supply, there would be economic and social considerations. The number of days a farmer’s water use is limited could affect the quality and quantity of crops produced that season. Figures 7.47a and 7.47b break down the number of occurrences of flows below the cut-off flows by month between July and October.

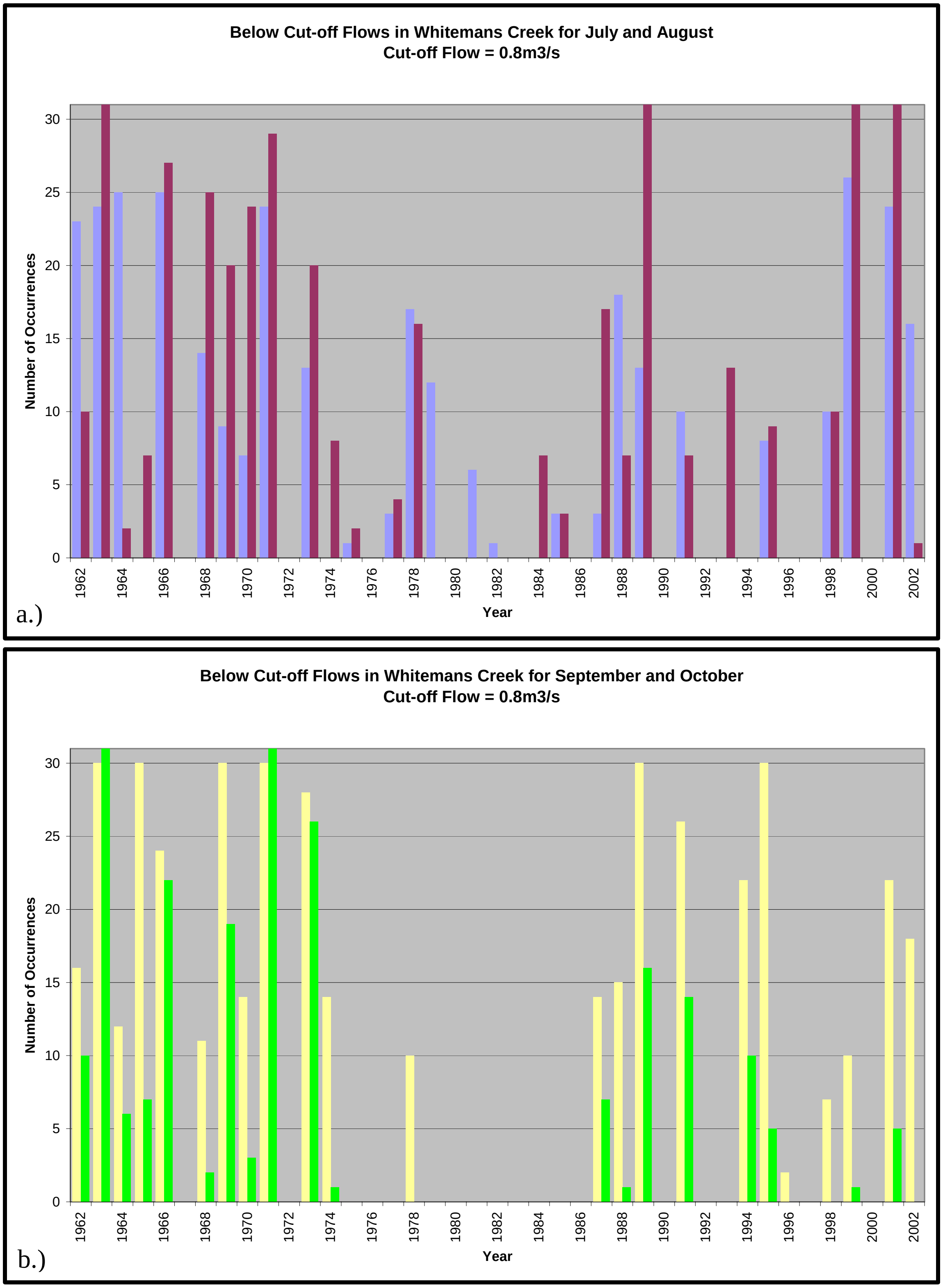


Figure 7.47 Count of daily flows below cut-off flows in Whitemans Creek for a.) July, August, and b.) September, October.

The data in Figure 7.47 shows the annual occurrences of flows below the cut-off flows historically and in the more recent past. Often, entire months (especially September and August have critically low flows below the cut-off. September has a high occurrence of below cut-off flows, often having the greatest number of daily flows in a month not reaching the cut-off flow. The month of September is a critical time for many farmers, as it is approaching the harvest and many crops including potatoes, vegetables, and sod often require supplemental water at this time to ensure that quality is at its peak. The loss of crops or loss in value results if a farmer doesn't irrigate at specific times of the growing season, thus there must be a water management plan for this watershed to balance human and environmental needs for water.

Since the occurrence of flows below this rate is quite high during the taking season, it is unreasonable to assume that farmers will not be affected by having a cut-off flow of $0.8m^3/s$. There are socio-economic consequences of limiting water for entire months or longer; there must be consideration in the management of water resources in Whitemans Creek to account for all users. To try to find a balance between environmental and human needs, a sensitivity analysis was completed to determine if a modest reduction in the cut-off flow would reduce the occurrence of below cut-off flows. First, the cut-off flow was lowered to $0.7m^3/s$. Unfortunately, the occurrences of flows below the new cut-off flow only lessened (see Table 7.31). Using the flowrate of $0.6m^3/s$, the number of days when the average flow was below the cut-off were on average, 68% less.

Table 7.31 Count of daily flows below various cut-off flows for Whitemans Creek

Flows (m3/s)	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**
< 0.8	74	192	72	44	100	0	62	86	48	150	0	87	23	3
< 0.7	38	173	42	29	67	0	35	73	27	135	0	64	6	2
< 0.6	23	100	21	4	25	0	25	55	3	87	0	50	0	1
< 0.5	13	56	8	0	16	0	7	33	0	50	0	27	0	0
	1976	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**
< 0.8	0	7	43	12	0	6	1	0	7	6	0	41	54	90
< 0.7	0	1	18	9	0	5	0	0	0	0	0	17	33	75
< 0.6	0	0	8	6	0	4	0	0	0	0	0	4	20	57
< 0.5	0	0	4	5	0	3	0	0	0	0	0	0	19	12
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	
< 0.8	0	57	0	13	32	52	2	0	27	68	0	82	35	
< 0.7	0	40	0	2	13	46	0	0	23	65	0	76	20	
< 0.6	0	22	0	0	1	25	0	0	8	61	0	73	15	
< 0.5	0	6	0	0	0	0	0	0	1	60	0	64	10	

The occurrences of flows below the cut-off flow of $0.6m^3/s$ were further broken down by month, as seen in Table 7.32, to get an indication of when during the taking season most of the occurrences happened. Most of the occurrences are in the months of July, August and September, with September being the month with the highest count of flows below the cut-off. There are still entire months under the cut-off flow, but overall, the setting of a cut-off flow at 0.6m3/s seemed to give more consideration to the socio-economic issues. Further study would need to be done to determine if the severity of the ecological consequences of lowering the flow rates to this level ($0.6m^3/s$) on a regular basis.

Table 7.32 Count by month of flows below a cut-off flow of 0.6m^3/s in Whitemans Creek

Cut-off=0.6	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	16	6	10	0	19	0	9	7	0	8	0	5	0	0
August	0	18	2	0	0	0	16	11	3	26	0	15	0	1
September	7	30	0	4	6	0	0	29	0	30	0	22	0	0
October	0	31	0	0	0	0	0	8	0	19	0	8	0	0
MONTH	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**
June	0	0	0	0	0	0	0	0	0	0	0	0	4	0
July	0	0	8	6	0	4	0	0	0	0	0	0	16	2
August	0	0	0	0	0	0	0	0	0	0	0	1	0	22
September	0	0	0	0	0	0	0	0	0	0	0	3	0	24
October	0	0	0	0	0	0	0	0	0	0	0	0	0	9
MONTH	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	
June	0	0	0	0	0	0	0	0	0	0	0	0	0	
July	0	5	0	0	0	2	0	0	0	24	0	22	11	
August	0	2	0	0	0	2	0	0	6	31	0	30	0	
September	0	12	0	0	1	19	0	0	2	6	0	21	4	
October	0	3	0	0	0	2	0	0	0	0	0	0	0	

7.5.3.4 Water Management Planning for Whitemans Creek Watershed

Without a water management plan for the Whitemans Creek watershed, the agricultural sector is facing insufficient supply for their needs. Given the potential impacts to water uses, blindly applying a cut-off flow of 0.8m^3/s would not be feasible. A cut-off flow could potentially cause major oscillations in the streamflow, if users reduce their takings one day due to low-flows, causing the stream to rebound and consequently giving users the appearance of higher flows and the ability to draw flows back down again. Thus, it seems more reasonable to use the flow target of 0.8m^3/s as a demand management objective. As flows begin to approach the 0.8m^3/s cut-off flow, demand should be reduced equitably among all takers to maintain flows at or above the flow objective. Scaling the demand can be equated to sharing the resource or sharing the burden of maintaining the resource.

The sharing of water or considerations to limits of water taking would be beneficial in a watershed like Whitemans Creek to ensure that the ecological flow requirements are met. Staff gauges showing water levels of sufficient flows, average flows and low flows could be associated respectively with the ability to take, the suggestion of conservation and the inability to take, could be a method of introducing the issue to farmers in a clear way. The farmer will be able to see when there are sufficient flows for their needs as well as other uses (including environmental needs), and when there is a lack of to satisfy the human and environmental needs, requiring water takings.

The possibility of organizing water takings, using the Irrigation Advisory Committee in the Whitemans Creek watershed, to stagger takings over the course of a day or a week, could also prevent flows from falling below the cut-off limit or flow objective. In the investigation, the average daily flows were used to determine whether flows were above or below the cut-off flows, but the hourly data could show a wider range and be both above and below the cut-off, depending on the time of day. As can be seen in Figure 7.48, the mean daily flow on July 29, 1998 was 0.62, yet the hourly flows ranged from 0.55 to 0.65, with a drastic drawdown occurring in the middle of the afternoon. This could have been due to a combination of factors (climatic and human-induced), including several water takings for irrigation occurring simultaneously. If water takings were staggered throughout the day, the range of hourly flows could be tightened and the cut-off flow sustained for the entire day to allow for fish passage.

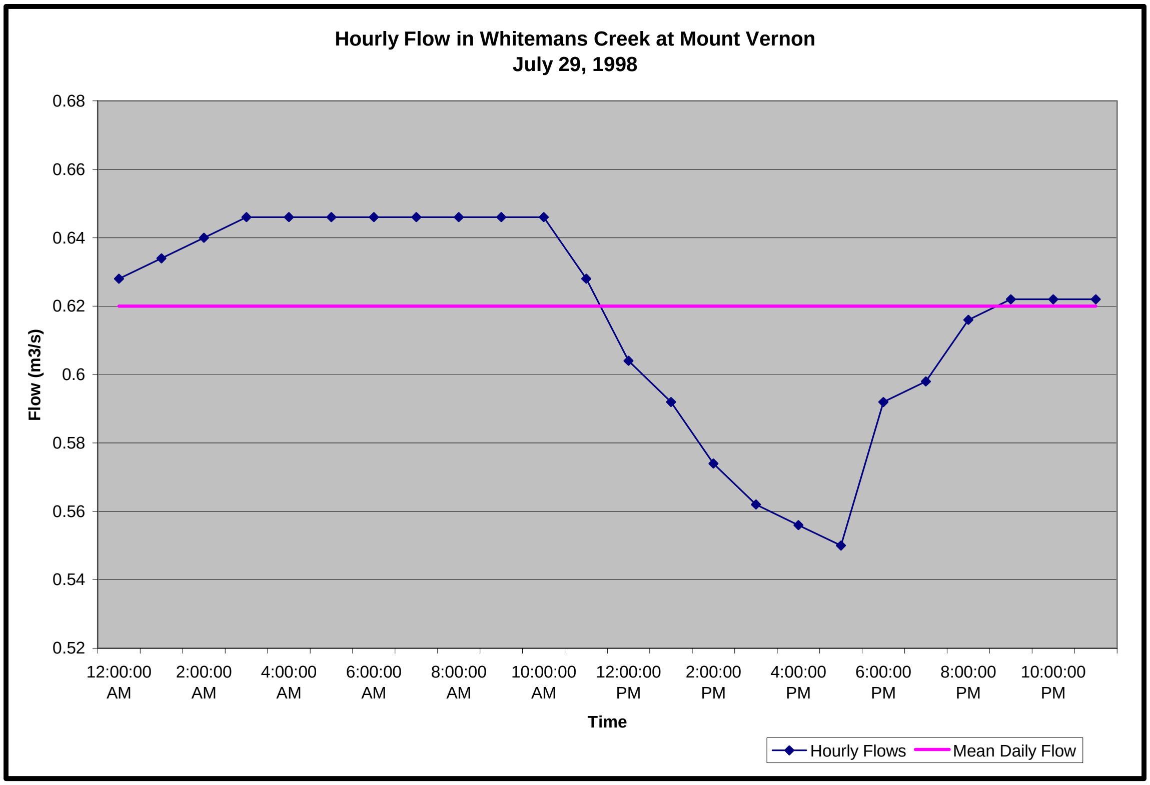


Figure 7.48 Hourly flows in Whitemans Creek at Mount Vernon, July 29, 1998.

Another approach to examine is a taking reduction across all surfacewater and groundwater takers. Since surfacewater and groundwater takings affect streamflow differently, different approaches are needed for the management of these takings. As mentioned previously, surfacewater takings have an immediate impact on the stream whereas groundwater takings have a delayed impact.

An analysis was completed that examined the percentage reduction in surfacewater takings needed to achieve the flow objective based on the historical flow series. The surfacewater reductions would be more instantaneously seen in the streamflow than a groundwater reduction. A similar analysis was completed to determine the groundwater taking reductions required to maintain a flow objective of 0.8m^3/s. These reductions were based on calculating the volume of deficit, then spreading that deficit over the groundwater takers for the whole period of the operating season. Groundwater takings are expected to affect the perennial baseflow, and therefore volume management was considered. Groundwater reductions would be more a climatically-based trigger, since there is a lag in the response seen in the taking from an aquifer.

Tables 7.33 and 7.34 present the results of the analysis of independent reductions in surface takings and groundwater takings. The results are interesting in that the maximum reductions are in the range of the Ontario Low Water Response Plan Level 2 voluntary reductions of 20%, if reductions were considered collectively. One qualification regarding the reductions in these tables is that they assume maximum permitted takings.

Table 7.33 Amount of reduction in surfacewater takings to maintain cut-off flow

Surfacewater Takings		Average Reduction (%)		
Month	Dates	Average	Min	Max
June	16 to 30	4.44	0.07	11.98
July	1 to 15	14.77	1.14	34.58
July	16 to 31	14.69	1.72	38.24
Aug	1 to 15	13.90	1.21	38.05
Aug	16 to 31	9.97	0.98	33.96
Sept	1 to 15	12.71	1.44	27.74
Sept	16 to 30	11.04	1.59	24.23
Oct	1 to 15	6.50	0.13	22.53
Oct	16 to 31	6.04	1.21	22.25

Table 7.34 Amount of reduction in groundwater takings to maintain cut-off flows

Groundwater Takings		Average Reduction (%)			Average Reduction (m^3/day)		
Month	Dates	Average	Min	Max	Average	Min	Max
June	16 to 30	3.12	0.05	8.42	5722.01	86.40	15419.08
July	1 to 15	10.38	0.80	24.31	19008.53	1468.80	44519.04
July	16 to 31	10.33	1.21	26.88	18916.53	2217.60	49231.80
Aug	1 to 15	9.77	0.85	26.75	17888.29	1555.20	48988.80
Aug	16 to 31	7.01	0.69	23.87	12838.98	1267.20	43718.40
Sept	1 to 15	8.93	1.01	19.50	16356.72	1857.60	35709.78
Sept	16 to 30	7.76	1.12	17.03	14214.77	2052.00	31190.40
Oct	1 to 15	4.57	0.09	15.84	8363.22	172.80	29007.36
Oct	16 to 31	4.53	0.85	15.64	8295.01	1555.20	28641.60

The Whitemans Creek case study illustrates the supply and demand issues present in the Whitemans Creek watershed. The case study illustrates that a low-flow objective rather than a cut-off flow would be a better approach in Whitemans Creek. This case study also seems to confirm the 20% reduction in takings during extreme conditions is in the right order of magnitude.

7.5.4 Mill Creek Case Study

The Mill Creek subwatershed currently has few water takings, both surfacewater and groundwater takings amount to $0.186m^3/s$. Figure 7.49 shows the period of record streamflows as well as the flows that would result from the reduction by all water takings in the watershed. These takings result in a reduction in flows, but still maintain water in the stream to satisfy other needs. Mill Creek is not nearly as stressed from a water taking perspective as Whitemans Creek. Figure 7.49 also shows the amount of groundwater and surfacewater takings that are on record from the Permits to Take Water database in this subwatershed. Most takings in this region are from groundwater sources. Mill Creek is a much more complex watershed, and assuming all takings are directly linked to the stream may not be a valid assumption. Therefore we are assuming a worst case scenario by assuming surface water and groundwater takings are coincident and are being taken at the maximum permitted rate. The period of record for the Mill Creek watershed is only from 1991-2004.

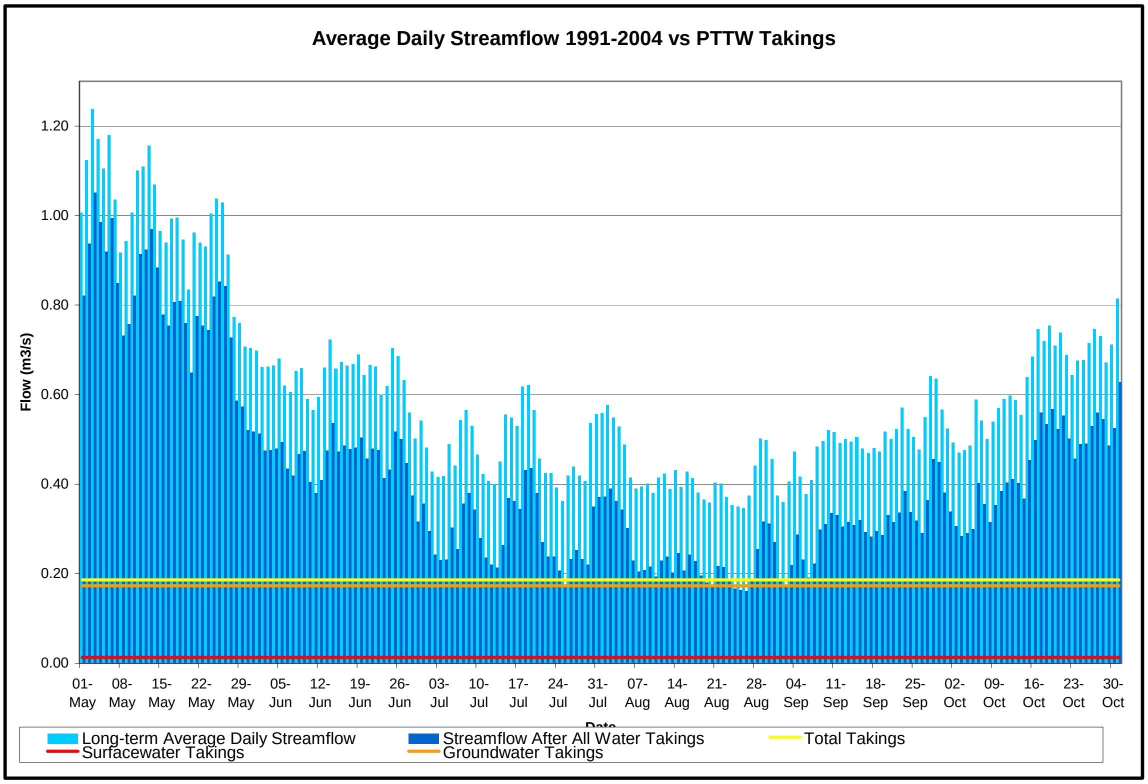


Figure 7.49 Average daily streamflow before and after all water takings removed

Mill Creek through the pilot reach has a threshold for root zone maintenance. A flow level should be maintained at a depth no lower than 30cm below the bankfull depth to ensure that the roots of the bank vegetation are in or touching the saturated zone of the river bank. If the root zone is depleted of water for an extended period of time, the vegetation might be lost and instability of channel could result. The root zone threshold translates into a flow of 0.28m^3/s for Mill Creek in the pilot reach. Flows below this rate for an extended period of time during the taking season are a concern. The frequency of occurrence of daily flows below this threshold is shown for the period of record in Figure 7.50. The mean annual flow gives some context of the flows, but the seasonal (May to October) flows give a better indication of the streamflow rates as they average the flows during the taking season, both are shown in Figure 7.50.

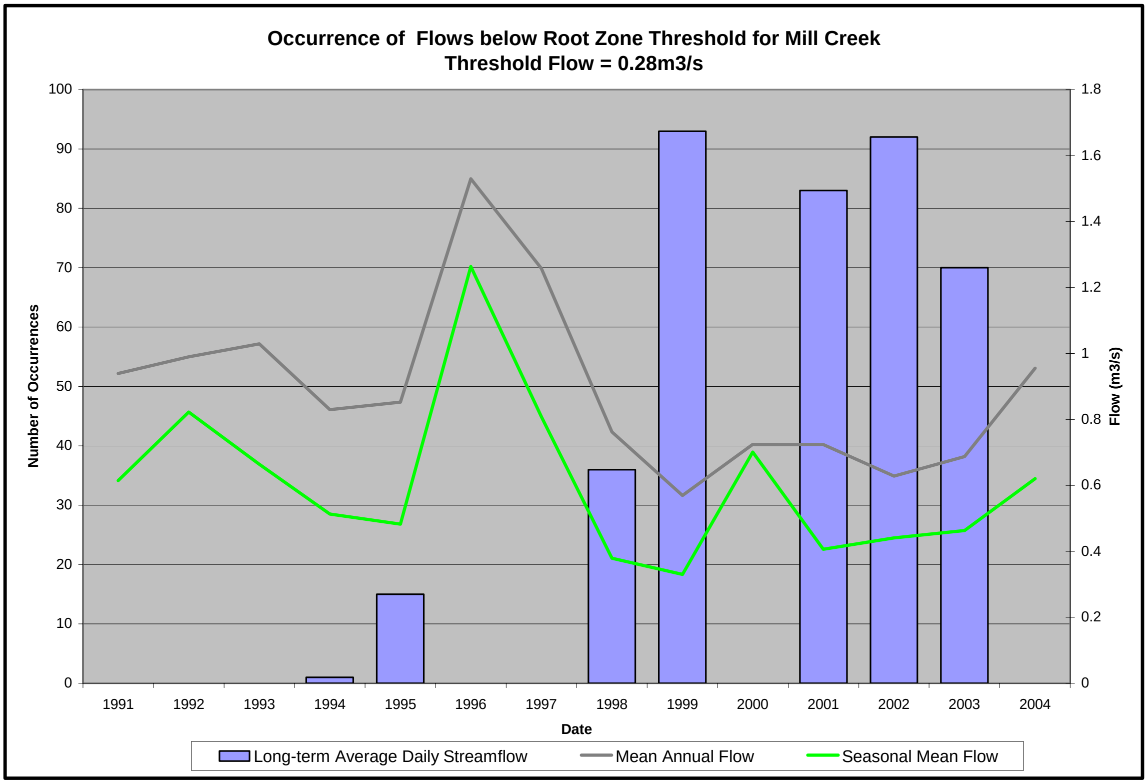


Figure 7.50 Occurrences of flows below root zone threshold in Mill Creek pilot reach

The last several years throughout the Grand River watershed have experienced drought conditions and lower flow levels, as indicated by Mill Creek showing a higher occurrence of flows below the threshold in Figure 7.50. In the past several years, Mill Creek has been subjected to flows below the root zone maintenance flows, getting as low as 0.13m^3/s.

Root zone flow maintenance is only a concern during the months between May and October, the growing season for vegetation. All the occurrences of flows below this threshold were contained in the months of May through October (inclusive), with the month of August having the highest daily occurrences of any month during the taking season (see Figure 7.51). Figure 7.51 shows only those years that had flows below the threshold.

Frequent dewatering of the root zone is likely to result in scorched or desiccate vegetation that eventually dies. If this occurs, the banks lose their ability to maintain their channel form due to vegetative control if the vegetation is lost. In E-type channels like the Mill Creek pilot reach, vegetative controls are very important for stability. These channels are very sensitive to disturbance, and if the stability were to be lost, the creek could experience rapid adjustment to other stream types (Rosgen, 1996).

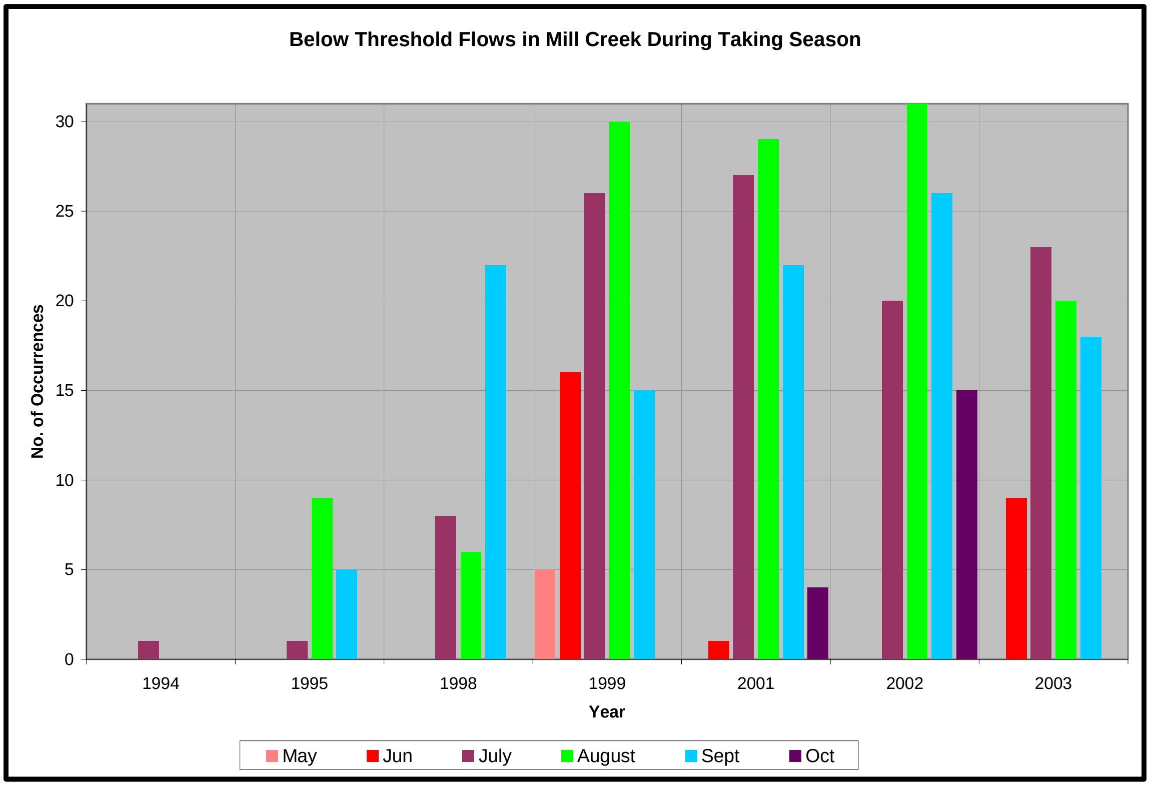


Figure 7.51 Number of days below threshold flow in Mill Creek per month

7.5.4.1 PTTW Scenario

Removing the water takings from the PTTW database from the subwatershed lowers the flows in the creek, as seen in Figure 7.49. The number of occurrences of flows below the root maintenance threshold that would occur in an average year after the takings, are seen in Table 7.35. With the takings removed, an average year would result in 47 instances throughout the taking season when the root maintenance flows are not reached. July (17 days) and August (24 days) have the majority of the below threshold flow occurrences. In comparison, an average year for the actual data in the period of record (1991-2003), has no occurrences of below threshold flows. Only dry years during the period of record (for example 1994-95, 1998-99 and 2001-2003) had flows below the threshold, but an average year did not. This means that if the water takings were to removed, not only would the dry years experience below threshold flows, but an average year would also experience approximately 47 days of flows below the threshold during the growing season. The consequences of these takings on the watercourse could be detrimental, given the sensitivity of the system. Consecutive days of hot air temperatures and low water levels below the threshold are more detrimental than having intermittent flows below the threshold which could allow for uptake of water by the roots.

Table 7.35 Number of days of flows below the threshold if all water takings were removed from Mill Creek

Month	Number of Occurrences in an Average Year after Takings Removed
May	0
June	0
July	17
August	24
September	6
October	0
Total	47

If more takings are suggested for this region, the flows could continue to recede below the root zone maintenance flows. Timing is also an issue here, if the flows recede too quickly, the roots will not have time to adapt. A slow decline in flows may prompt individual plants to send out more roots or increase root depth, but a sudden decline in flows will not give the plants the time to successfully adapt in this way. Further monitoring will have to be completed to examine how vegetation is adapting and to further confirm the root zone threshold.

This case study was intended to provide an example of how other factors such as riparian vegetation requirements need to be considered in a study on ecological flow requirements.

7.5.5 Nith River at Canning Case Study

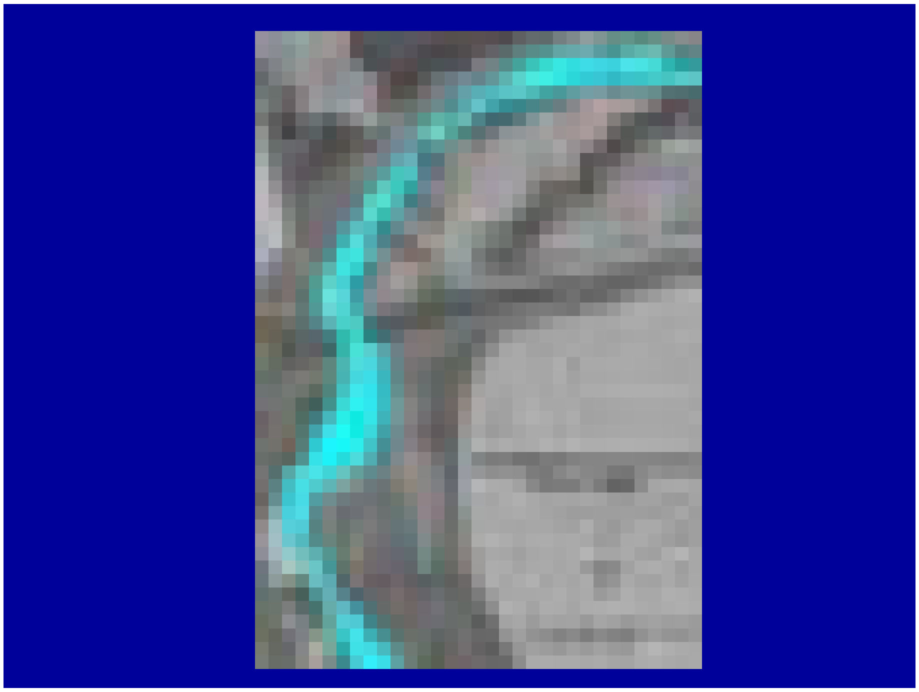


Figure 7.51 Nith River At Canning Flow Simulation
(double click to open, ESC to close)

A detailed case study was not completed for the Nith River at Canning reach. What was completed on this reach was construction of a detailed 3-dimensional seamless above water and below water Digital Elevation Model DEM. The DEM constructed for this reach served three primary purposes. First it formed the basis for development of a detailed Hec-Ras model. Second it allowed for the visualization of water surface extent at different flow rate. Third it demonstrated detailed hydraulic models could be used to develop or check rating curves at a flow gauging station.

The Dem provided useful in the development of a Hec-Ras model for this reach of river. The Hec-Ras model was able to replicate the rating curve produced from manual gauge measurements. This demonstrated the use of hydraulic models can compliment development and management of rating curves at stream gauge stations. Further when coupled with geomorphic investigations the stream gauge data can be further leverage to investigate and quantify geomorphic processes and events. The geomorphic thresholds may aid in managing rating curve shifts at stream gauge stations.

The visualization of changing habitat with flow is illustrated by figure 7.51. By clicking on this figure a video sequence is started that allows the user to view how habitat extent changes with flow. This is a useful communications tool to illustrate the dynamic nature of habitat and the importance's of riparian zone.

Environment Canada shared under water survey information with the study team to make construction of the seamless DEM possible. The information from this study has been shared back to Environment Canada. It is hoped that instream flow and geomorphic thresholds are eventually developed at other stream gauge sites to further leverage the value information collected by the stream gauge network across Canada.

The information based developed for the Nith River Canning reach offers great potential for additional research and study. Opportunities will be pursued with universities.

7.5.6 Regulated Reaches Case Study

The main Grand River from Legatt through Dunnville is a regulated reach of river. The central portion of the river through Kitchener-Waterloo is the most regulated portion, regulated by Shand, Conestogo, Luther and Woolwich reservoirs. Two of the pilot reaches in the Grand River pilot study were selected to investigate how instream flow requirements might be applied to regulated river reaches, the Grand River at Blair and Grand River Exceptional Water reaches.

The influence of regulation is different in both these reaches, given the regulated upstream drainage area. In the Grand River at Blair Reach above the Speed River confluence, 56% of the upstream drainage area is regulated by upstream reservoirs, while downstream of the Speed River confluence, 43% is regulated. In the Grand River Exceptional Waters Reach 36% of the upstream drainage area is regulated upstream of the confluence with Whitemans Creek and 33% downstream of the confluence.

7.5.6.1 Effects of Water Taking

Water takings or commitments affecting the regulated reaches can be grouped into four categories. These include the effects of the major reservoirs, municipal water takings, discharge of treated effluent and the river’s ability to assimilate the treated effluent and other permitted takings along the regulated reaches. These activities alter the natural flow regime (Poff *et al*., 1997) and can place stress on aquatic communities (see Section 4.7).

The largest influence on the overall flow regime is the major reservoirs, Shand Dam, Conestogo Dam, Guelph Dam, Luther Dam and Woolwich Dam. These are multipurpose dams with primary objectives being flood control and low-flow augmentation. The reservoirs above these dams are filled with runoff from the spring freshet, which usually occurs in March or early April. They are topped off with runoff from rainfall in April and are typically at their maximum storage capacity for flow augmentation by the first week of May. Once the May 1st storage is achieved, very little storage is available for flood control; water held in storage is released over the summer months of May through early October. During dry years there may be insufficient runoff to completely fill these reservoirs and during wet years there may be insufficient capacity to regulate floods. These reservoirs are operated as a system, the system operation of these reservoirs was reviewed as part of the Environmental Assessment of Water Control Structures in 1976 and their operation optimized as part of the 1982 Grand River Basin Study (GRIC, 1982).

The reservoirs were designed and are operated to reduce floods, therefore, one impact from an environmental flow perspective is reduced out-of-bank flow conditions. More specifically, less riparian zone flooding and potentially reduced occurrences of bed mobilizing flows. The other main influence of the major reservoirs is increased low-flow volumes, through flow augmentation. The flow augmentation season typically runs from June through early October, however during dry years may extend from late April through the remainder of the year. The 1998 operating season is an example of an augmentation season from April through December. Flow augmentation in the Grand River at Blair reach can approach in excess of 90% of the flow in the river and through the Grand River Exceptional Waters reach can approach 60% of the water in the river during summer low-flow periods. Low-flow targets have been established for the Grand River at Blair reach of 10 m^3/s upstream of the Region of Waterloo water taking and 17 m^3/s downstream of the City of Brantford water taking. The reservoirs have a dramatic effect on the flow regime in both pilot reaches.

7.5.6.2 Effects of Major Reservoirs

To analyse the effects of reservoir regulation on the pilot reaches, two analyses were completed. First, streamflow series with and without the effects of the major reservoirs were created for the Grand River at Doon, Galt and Brantford monitoring stations for the 1974 through 2003 operating period. The observed flows were used to represent the regulated condition; a deregulated daily streamflow series was created at each stream gauge station to represent the non-reservoir influenced condition. Once the streamflow series were assembled, the number of occasions that the bankfull flow and geomorphic bed mobilizing flows were exceeded was calculated for each pilot reach for both regulated and deregulated conditions. A summary of this analysis is presented by Table 7.36.

Table 7.36 Occurrences of bankfull and bed mobilizing flows in regulated reaches

Exceedance Count	Doon Observed		Doon Naturalized		Galt Observed		Galt Naturalized		Brantford Observed		Brantford Naturalized	
MONTH	**Bankfull**	**Bed Mob**	**Bankfull**	**Bed Mob**	**Bankfull**	**Bed Mob**	**Bankfull**	**Bed Mob**	**Bankfull**	**Bed Mob**	**Bankfull**	**Bed Mob**
JAN	0	11	3	15	1	14	6	24	4	62	12	67
FEB	0	32	3	36	1	22	9	42	11	88	26	99
MAR	6	50	22	109	15	95	42	154	43	227	72	268
APR	6	46	16	60	14	87	27	112	33	183	45	186
MAY	2	8	3	10	4	13	5	16	5	30	9	38
JUN	1	3	1	7	1	5	2	9	2	8	3	12
JUL	0	0	0	0	0	0	0	0	0	0	0	0
AUG	0	2	0	3	0	2	0	4	1	9	1	8
SEP	0	6	3	7	2	12	4	10	4	18	5	18
OCT	0	1	0	2	0	6	1	4	2	12	2	13
NOV	0	4	1	9	1	10	2	15	3	27	5	46
DEC	0	34	1	13	0	8	3	17	3	37	8	47
TOTAL	15	197	53	271	39	274	101	407	111	701	188	802

Values in Table 7.36 represent the potential occurrences of out-of-bank flows and geomorphic flows that could occur if reservoirs were not operated to reduce floods, illustrating the dramatic effects of the major reservoirs. The effects of reservoir regulation diminish in downstream reaches, as additional unregulated drainage areas contribute to the river. It should be kept in mind that the unregulated reservoir condition doesn't reflect a natural or pre-settlement condition; the reservoirs were built to put more storage back onto landscape after forests were removed and several of the nature wetlands were drained. Therefore, the regulated condition may be closer to a pre-settlement condition.

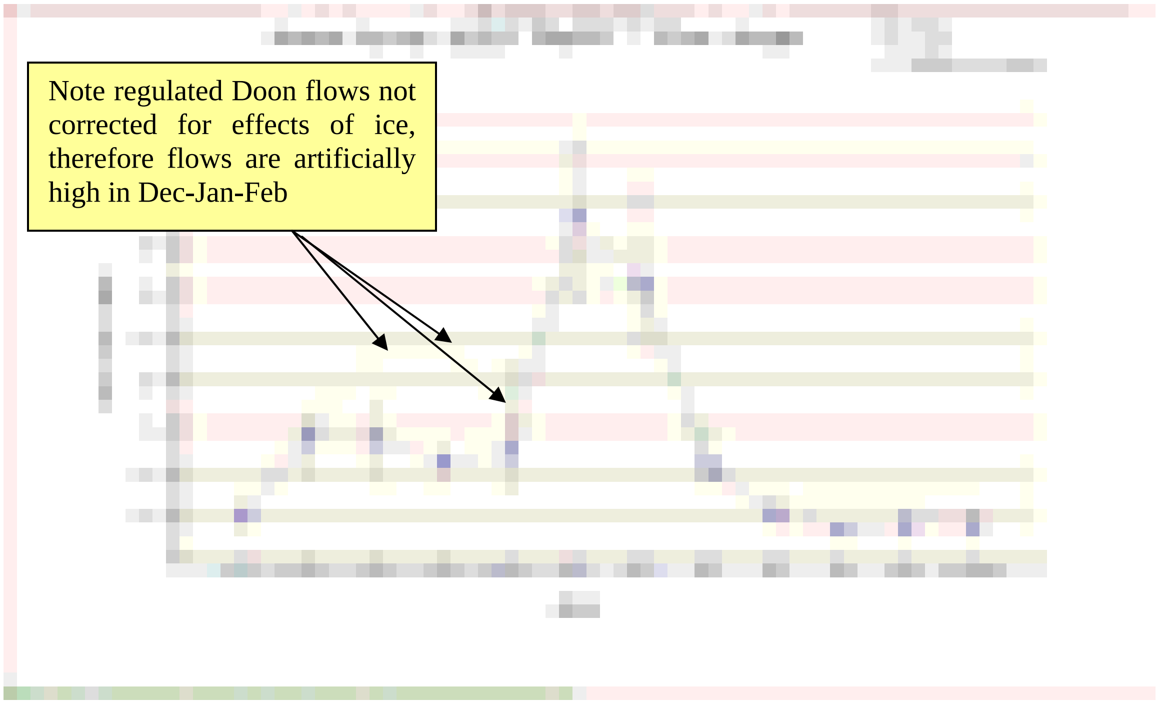
Flooding of the riparian zone is important; additional work would have to be completed to find the thresholds along reaches that would allow flooding of the riparian zone while at the same time avoiding flooding of structures or causing undue flood damages. As these thresholds are developed, they could be added as another objective or consideration to be included when reservoir operations are considered. The bed mobilizing flow threshold is a more practical flow that could be implemented to improve ecological integrity. As Jack Imhof (2004, pers. comm.) states, the bed mobilizing flow can be thought of as re-setting the assimilative capacity or resilience of a river reach, since the bed mobilizing flow replenishes key habitats. One operational objective that could be considered, is to attempt to maintain a natural frequency of occurrence of bed mobilizing flows. During dry years such as 1999 when runoff was low, the geomorphic mobilizing flow was not achieved through the Grand River at Blair reach, however it was achieved on 6 occasions through the Brantford Exceptional Waters reach due to the additional unregulated drainage area contributing to that reach. During dry years, re-setting the habitat is an important consideration. With respect to reservoir operation, the value of achieving a geomorphic mobilizing flow versus achieving reservoir storage targets would have to be weighed. The information in this study provides a broader consideration of options to assist environmental function during stress period such as droughts.

The analysis completed for the regulated reaches used the IHA software, to analyze information for the three stream gauges in the respective reaches. This analysis was completed to demonstrate the ability of the IHA software as a diagnostic tool to analyze the effects of the reservoir regulation on each reach. A similar set of plots were generated for each stream gauge and are presented by Figures 7.52 to 7.69. The plots include: a plot of the input data analysed, plot to illustrate alteration by month, a plot of maximum hydrologic alteration to illustrate which of the 33 parameters are most effected, plots of the annual 1-day maximum and annual 7-day minimum flows, and finally, plots of the July and August flows. Plots of selected parameters were based on interpreting the plot of maximum hydrologic alteration to determine which parameters were most affected.

The 1-day maximum plots were selected to illustrate the flood reduction aspects of the major reservoirs. The 7-day minimum flows were selected to illustrate the impact on low-flows of flow augmentation provided by the major reservoirs. Selected monthly plots were produced to illustrate the effects during specific months.

The results presented by these plots illustrate several points. First, the monthly alteration plots illustrate the filling cycle in the spring and the summer augmentation effects on monthly flows. The hydrologic alteration plots are complex to interpret, however they illustrate several key points. These plots illustrated expected results: the maximum annual flows are decreased and that minimum flows are increased. Other subtle information presented by these plots are the changes in different categories. The flow regime is partitioned into an upper, middle and lower category analogous to the upper third, middle third and lower third of the flow regime. An interesting point is that in the lower third of the flow regime, maximum flows are increased. This is not in a category of flows that result in flooding, and thus illustrates how these tools can be used to tease out subtle effects on the flow regime.

This exercise on the regulated reaches was completed to illustrate how the IHA software could be used to diagnose impacts to the flows regime. The IHA manual relates the 33 hydrologic parameters to components of the flow regime, and provides a framework to interpret flow information and relate potential impacts back to the environment.



Note regulated Doon flows not corrected for effects of ice, therefore flows are artificially high in Dec-Jan-Feb

Figure 7.52 Monthly alteration for Grand River at Blair reach Doon gauge

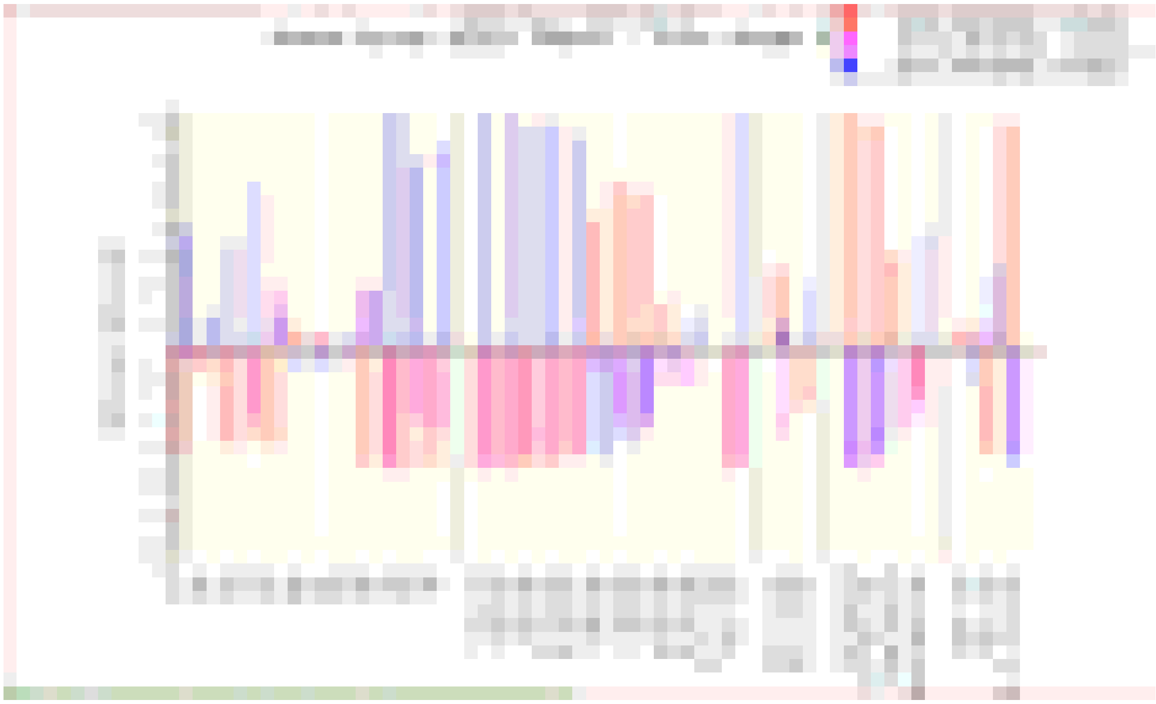


Figure 7.53 IHA Alteration Plots Grand River Doon Gauge Station 1978- 2003

Figure 7.54 IHA Max 1-Day Flow for the Grand River Doon gauge station

Figure 7.55 IHA Minimum 7-Day flows for the Grand River Doon gauge station

Figure 7.56 IHA July monthly flow plots Grand River Doon gauge station

Figure 7.57 IHA August monthly flow plots Grand River Doon gauge station

Figure 7.58 IHA monthly alteration plot Grand River Galt gauge station 1978- 2003

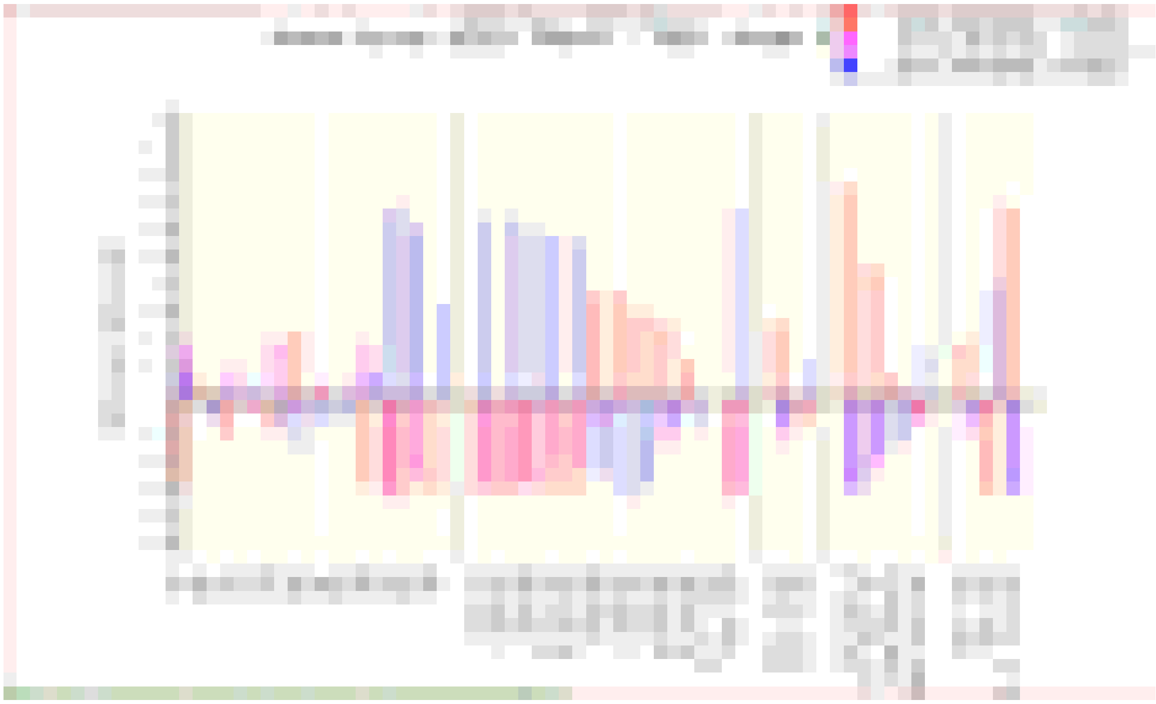


Figure 7.59 IHA hydrologic alteration plot Grand River Galt gauge station 1978-2003

Figure 7.60 IHA Max 1-Day Flow for the Grand River at Galt gauge station

Figure 7.61 IHA minimum 7-Day flows for Grand River at Galt gauge station

Figure 7.62 IHA July monthly flow plots Grand River Galt gauge station

Figure 7.63 IHA August monthly flow plots Grand River Galt gauge station

Figure 7.64 IHA monthly alteration plot Grand River Brantford gauge station 1978- 2003

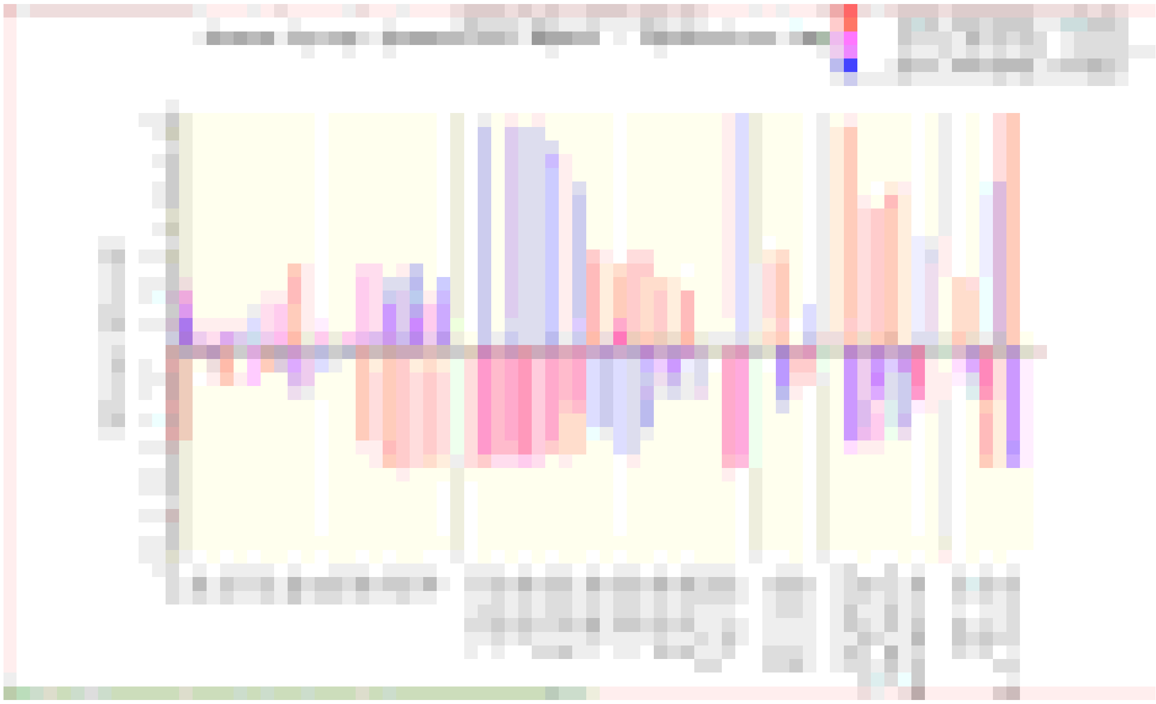


Figure 7.65 IHA hydrologic alteration plot Grand River Brantford gauge station 1978-2003

Figure 7.66 IHA Max 1-Day Flow Grand River Brantford

Figure 7.67 IHA Minimum 7-Day flows Grand River Brantford

Figure 7.68 IHA July Monthly Flow Plot Grand River Brantford Gauge

Figure 7.69 IHA August Monthly Flow Plot Grand River Brantford Gauge

7.5.6.3 Effects of Municipal Water Taking and Effluent Discharges

Next to the major reservoirs, municipal water takings and treated effluent discharges to the regulated reach have the next largest potential environmental impact. The major municipal takings and the effects of treated effluent discharges were considered in a systematic manner as part of the Grand River Basin Study in 1982. Water and wastewater supply master plans, completed by the municipalities, have updated the information from the 1982 basin study.

A water quality simulation model was used to simulate in-river water quality for the summer months of June through September. Aquatic plant growth resulting from an over-abundance of nutrients, specifically phosphorus and nitrogen, continues to be the primary water quality issue along the main Grand River. The simulation model helps assess different water quality management options on behalf of watershed municipalities. Both the Region of Waterloo and the City of Brantford have updated their long-term water supply plans. Approximately 20% of the Region of Waterloo's supply is withdrawn directly from the Grand River and all the City of Brantford's supply is withdrawn from the Grand River. The reliability of major reservoirs to maintain minimum flow targets at Brantford and Kitchener was confirmed as part of the Region of Waterloo's long-term water supply strategy update in the late 1990's.

The key message here is that the municipal takings and effluent treatment requirements are being considered in a systematic manner. Certificates of Approval have being considered in a systemic manner in an effort to protect the natural environment. The instream flow indices comparisons earlier in this chapter relate the minimum flow target that can be achieved to hydraulic characteristics in the study reaches. Other indices and statistics provide other information to consider, which benefit the municipal master plans, and this additional information can be considered when establishing Certificates of Approval. In the case of 1999 when water was in short supply, water mangers from municipalities, the GRCA and provincial ministries met to discuss the situation and amend the operating procedures to deal with reduced supplies. This worked well. Since 1999, the OLWRP has been developed to deal with periods of low water conditions and offers a framework for voluntary conservation of other PTTWs beyond the municipal takings.

7.5.6.4 Regional Municipality of Waterloo Surfacewater Taking

The Region of Waterloo (ROW) was granted a surfacewater taking by MOE in 1988 (PTTW #88-P-2804). Conditions attached to this permit recognize the variability of the Grand River flows, as conditions attached to this permit specify the permitted taking by month, summarized in Table 7.37.

The ROW's taking from the Grand River is limited by infrastructure capacity. Currently, the infrastructure in place is capable of taking 16 million gallons per day (MGD) which translates to 0.84 m^3/s. The current infrastructure in place doesn't allow for a variable taking, and thus withdrawal is carried out over a portion of the day at a rate of 0.84 m^3/s

Although no cut-off flow is specified, it must be kept in mind that for the summer months from May 1st through to October 31st, a reservoir yield analysis was completed to confirm the reliability of meeting the low-flow target of 10 m^3/s upstream of the Region's intake. This analysis was based on a period of record from 1950 to 1998 and confirmed the low-flow target of 10 m^3/s can be met 95% of the time. The most recent reservoir yield analysis confirmed the reliability of meeting the low-flow target and was completed as part of the Region's update to its long-term water supply strategy in 1999.

Table 7.37 Region of Waterloo permitted surfacewater takings by month

Month	Region of Waterloo Surfacewater PTTW	
	MGD	m^3/s
Jan	27	1.42
Feb	27	1.42
Mar	27	1.42
Apr	54	2.84
May	54	2.84
Jun	16	0.84
Jul	16	0.84
Aug	16	0.84
Sep	16	0.84
Oct	54	2.84
Nov	40	2.11
Dec	40	2.11

The ROW's taking is overlaid with daily percentile flows in Figure 7.70. This figure illustrates the Region's taking is much smaller than the flow that is typically available in the river. Experience during recent low-flow years of 1998 and 2002 indicate that low-flows which are lower than summer flows can occur in the winter months and late fall. This is primarily a result of reduced groundwater discharge to the river and reduced water in upstream reservoirs to augment downstream flows. During the early winter of 2003, a combination of low-flows and a cold winter that resulted in virtually 100% ice cover, resulted in high ammonia levels in some regulated reaches of the Grand River. These years demonstrated the need to consider the potential for low-flow conditions during later fall and early winter. The Water Managers Working Group has been and continues to be an effective forum to communicate watershed conditions and discuss options, strategies and actions to manage situations and reduce stress on the river system. The Water Managers Working Group is composed of CA, municipal and provincial agency water management staff.

As noted previously, the ROW water taking is dynamic over the course of a day. Currently, the pumps are operated for a portion of the day at capacity ($0.84 m^3/s$) and rest for the remainder of the day. An example of daily flow information from the Doon gauge immediately downstream of the withdrawal is illustrated by Figure 7.71. The effect is most prevalent in the reach immediately downstream of the taking to the confluence with the Speed River. Information from other gauge stations presented by Figure 7.71 help illustrate how the effects of the taking are dampened further down river.

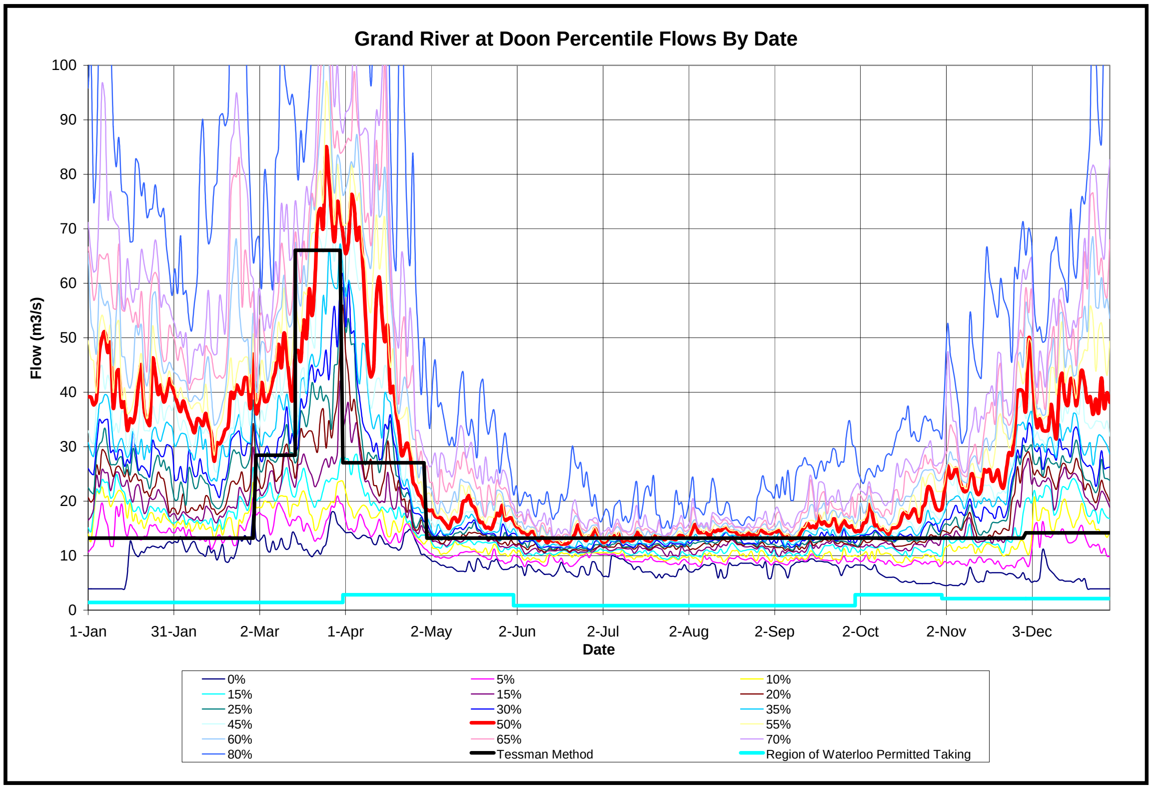


Figure 7.70 Doon Daily flows with Region of Waterloo Water Taking Overlaid

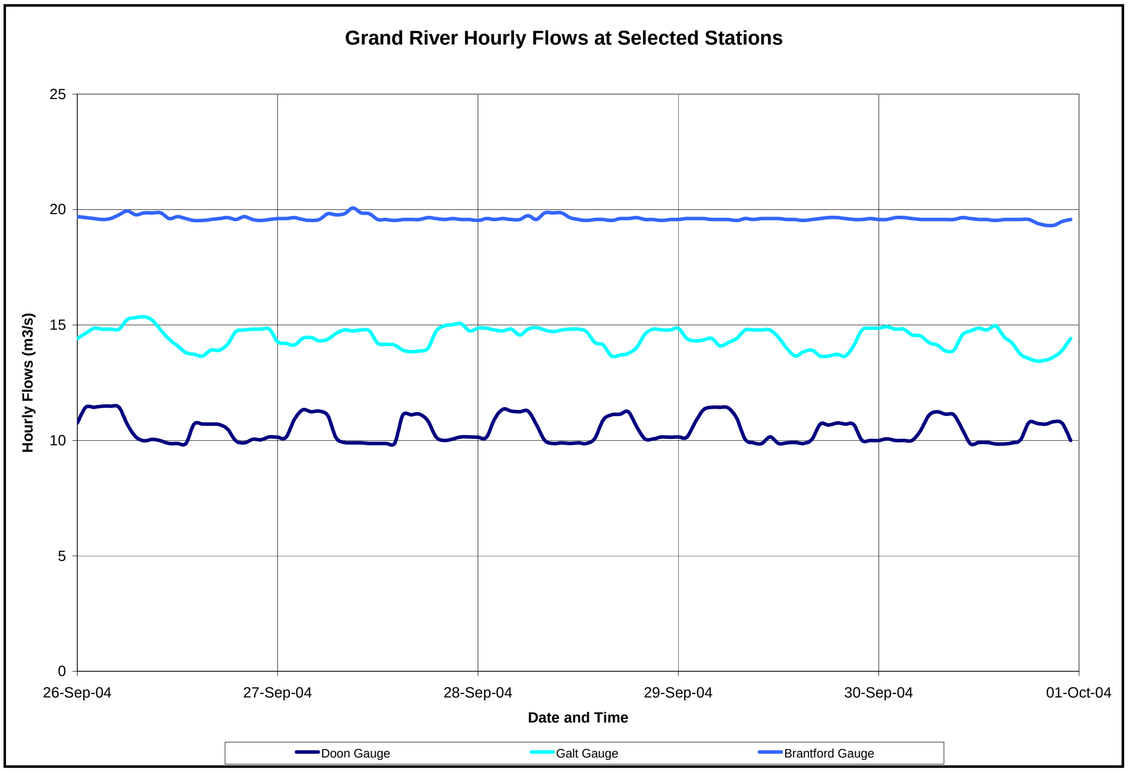


Figure 7.71 Hourly streamflows at selected stations on the Central Grand River

An example of how information from the current study can link the impact of the taking to habitat is presented by Figure 7.72. In this figure, the hydraulic model output (in this case wetted perimeter), is combined with hourly flow information to produce hourly wetted perimeter fluctuation in the Blair study reach. The hourly wetted perimeter fluctuations can be used to quantify how wetted perimeter in the study reach is affected by the water taking. Figure 7.72 is intended to illustrate how information generated in the present study could be applied to quantify or assess the influence of water taking on hydraulic habitat.

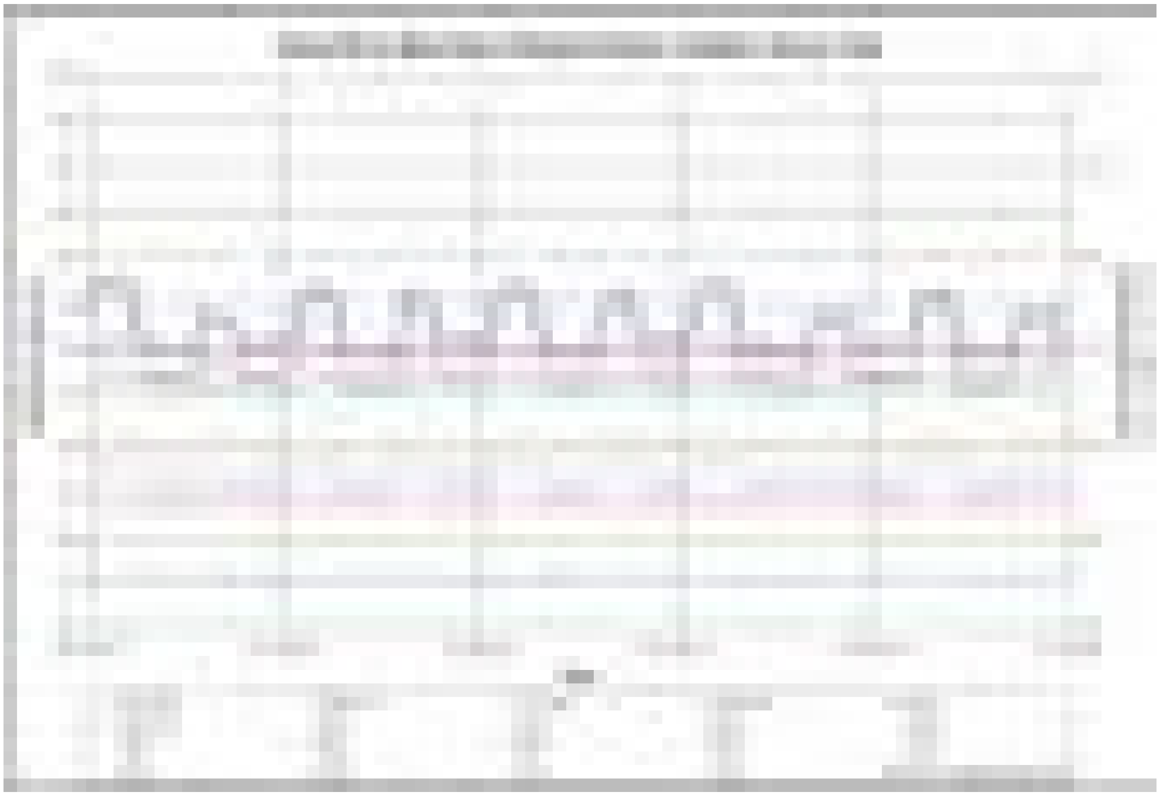


Figure 7.72 Hourly streamflows and wetted perimeter in the Grand River at Blair Reach

Figure 7.72 illustrates the extent to which wetted perimeter is influenced by the water taking varies at different cross sections and would vary depending on the flow range at the time of the taking. For example, with a flow range of between 10.8 to 11.2 m^3/s, prior to the taking, the maximum fluctuation in wetted perimeter occurs at cross section 2800 and is in the 8% range. This range is in the same order of magnitude as the taking is, relative to the flow range in the river. Figure 7.72 also illustrates impacts associated with the municipal taking vary throughout the reach.

The Brantford municipal water taking is a constant withdrawal water taking. Given the character of the river and flow regime at that point in the river system, a constant withdrawal type of taking is appropriate. Water conservation targets related to OLWRP levels have been incorporated in the conditions for the City of Brantford taking and provide a good example of integrating OLWRP objectives with permitted takings.

7.5.6.5 Other Permitted Taking Within the Regulated Reach

Other PTTWs affecting the regulated reach also need to be managed in a systematic fashion. The OLWRP offers a framework to manage these other permits. Permitted takings upstream of the regulated pilot reaches were presented in Chapter 6, based on extracting available information from the PTTW database. Two issues were encountered with information from this database. First, variable permits like the Region of Waterloo municipal withdrawal and the GRCA major reservoirs have a zero value, apparently because the withdrawal is time-variable. The database should be modified to deal with these variable withdrawals. Second, it is difficult to relate water takings that might impact the regulated reach beyond direct surfacewater takings. An approach was taken when extracting information for the regulated reach that is presented in chapter 6 to included takings within 1 kilometre of a specific class of stream; however this approach is still too coarse. As mentioned in Chapter 6, additional information is needed to relate a permitted taking to the affected surfacewater features. In a perfect situation, the permits that affect the regulated reaches beyond just direct surfacewater takings could be identified and possibly managed through the OLWRP. Managing other permits on regulated reaches is important to avoid potentially creating a non-compliance situation, or placing additional stress on the environment during dry periods. The OLWR Program could be used to communicate conditions and scale back other takings. The Level 3 criteria in the OLWRP becomes an important level since it would be at this level that other takings beyond municipal takers would be asked to stop taking water. The approach discussed here with respect to the OWLRP on regulated reaches applies equally to unregulated reaches.

Figures 7.73 and 7.74 present other direct surfacewater takings from regulated reaches, exclusive of municipal takings. These takings could be managed through the OWLRP. Other takings affecting the regulated reaches are harder to quantify at this time.

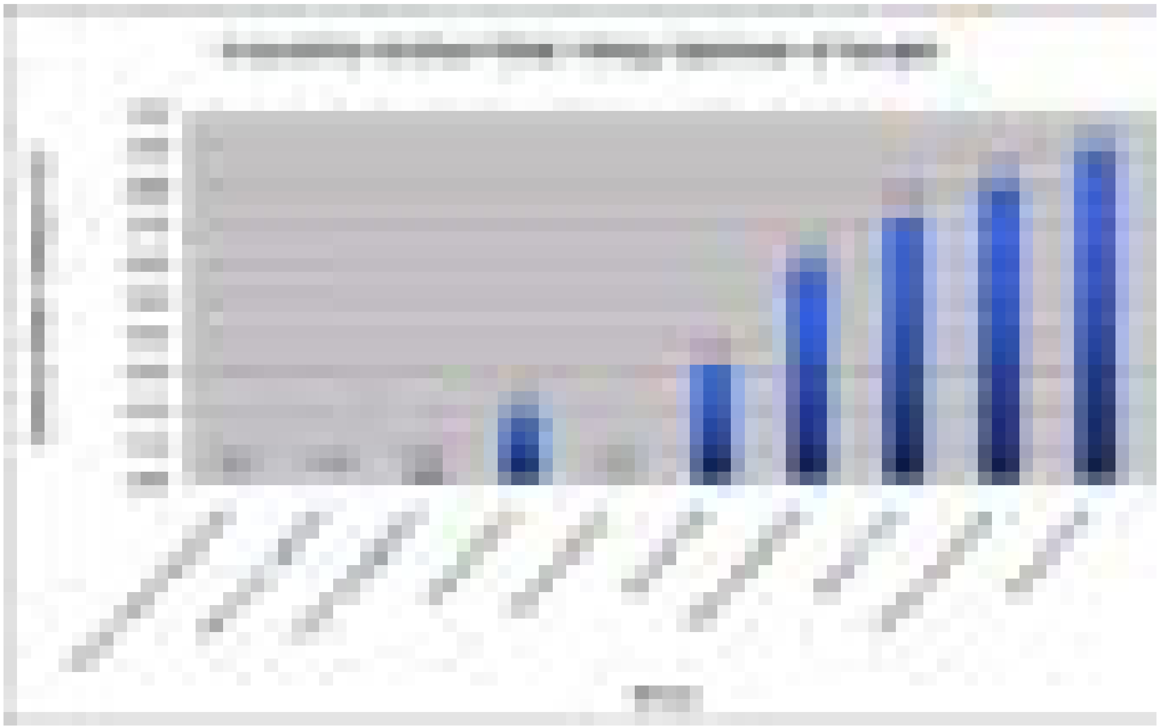


Figure 7.73 Cumulative surfacewater takings upstream of stream gauges

Figure 7.74 Surfacewater takings by reach and by type in selected reaches

7.5.7 Carroll Creek Case Study

The drainage area of the Carroll Creek pilot reach changes mid-way through the reach as a tributary enters Carroll Creek just below Middlebrook Road. The influence of this additional drainage area is studied in this pilot reach by looking at the change in hydraulic indices above and below the tributary in Carroll Creek. The tributary outlets into Carroll Creek between reach 32 and 38, or between the 7th and 8th reach from the top of the pilot reach (see Figure 5.13). At this point, the drainage area changes drastically from approximately 45.5 km^2 to 58.3 km^2, due to the additional area collected by the tributary. To simplify, the reaches were numbered sequentially as seen in Table 7.38.

Table 7.38 Carroll Creek Pilot Reach identification numbers

Reach Number	Distance from Outlet to Grand (and Reach Identification Number)
Upstream 1	74
2	68
3	62
4	56
5	50
6	44
7	38
8	32
9	26
10	20
11	14
12	8
Downstream 13	2

7.4.7.1 Hydraulic Inflection Points for Carroll Creek

The use of hydraulic inflection point such as those seen when plotting wetted perimeter to flow is considered a hydraulic rating method. Hydraulic rating methods develop curves based on hydraulic parameters and flow, or habitat-discharge curves, to determine the variation of a physical habitat parameter with discharge. Hydraulic rating curves can be interpreted as the availability of habitat based on the channel dimensions and its relation to flow in the stream. Wetted perimeter is the one most commonly used, as it is an indicator of the availability of aquatic habitat. Generally, measurements should be taken in riffles, as they are more rectangular and shallower, which makes them more sensitive to lower flows and disturbance, then other habitat types (PPWB, 1999).

For the Carroll Creek pilot reach, many cross sections were taken along the entire stretch, and the hydraulic parameters were related to flows from 0 to 5m^3/s (see Appendix D-10). Inflection points were extracted from plots of wetted perimeter to flow, and of topwidth to flow to see if there were differences in inflection points from the most upstream to the outlet of Carroll Creek.

The wetted perimeter inflection points were analyzed first. The most upstream group of reaches (1 to 4) has a wider range of inflection points that are spread out between 0-3 m^3/s. The further downstream reaches have inflection points that are more contained to the lower flows (under 1.5m^3/s).

This suggests that perhaps the upstream reaches are first to be affected by diminishing flows, but aren't any more sensitive at the very low flows than reaches 5-10. These reaches further downstream do have more inflection points at the lower reaches, and are all affected by low flows. The first common low flow that generates inflection points are:

- Reaches 1-4: 0.75-0.9 m3/s (upstream reaches)
- Reaches 5-9: 0.6-0.7 m3/s (middle reaches)
- Reaches 10-13: 0.55-0.65 m3/s (low reaches)

There is little change in the lower range of inflection points in the middle reaches from 6 to 10, despite the change in drainage area. Figure 7.75 shows the different reaches (1-13) and the flows that are derived from the wetted perimeter inflection points.

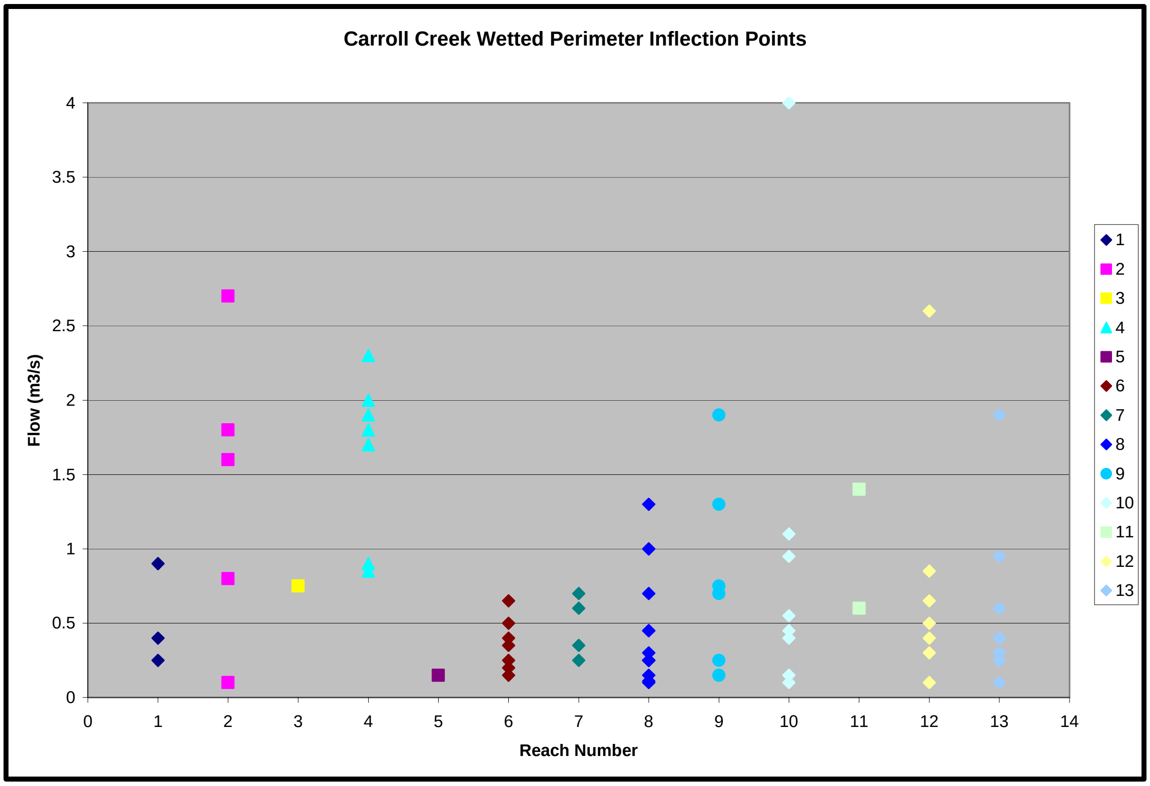


Figure 7.75 Carroll Creek wetted perimeter inflection points by reach

With respect to topwidth hydraulic inflection points, there are slight differences seen from upstream to downstream of the tributary. The upstream reaches (1-7) have inflection points that are consistently more spread throughout the flow range, and begin at a higher flow magnitude then the inflection points in the downstream (8-13) reaches. The downstream reaches tended to have more inflection points in the lower flow range of between 0.1 m^3/s and 1.5m^3/s (see Figure 7.76).

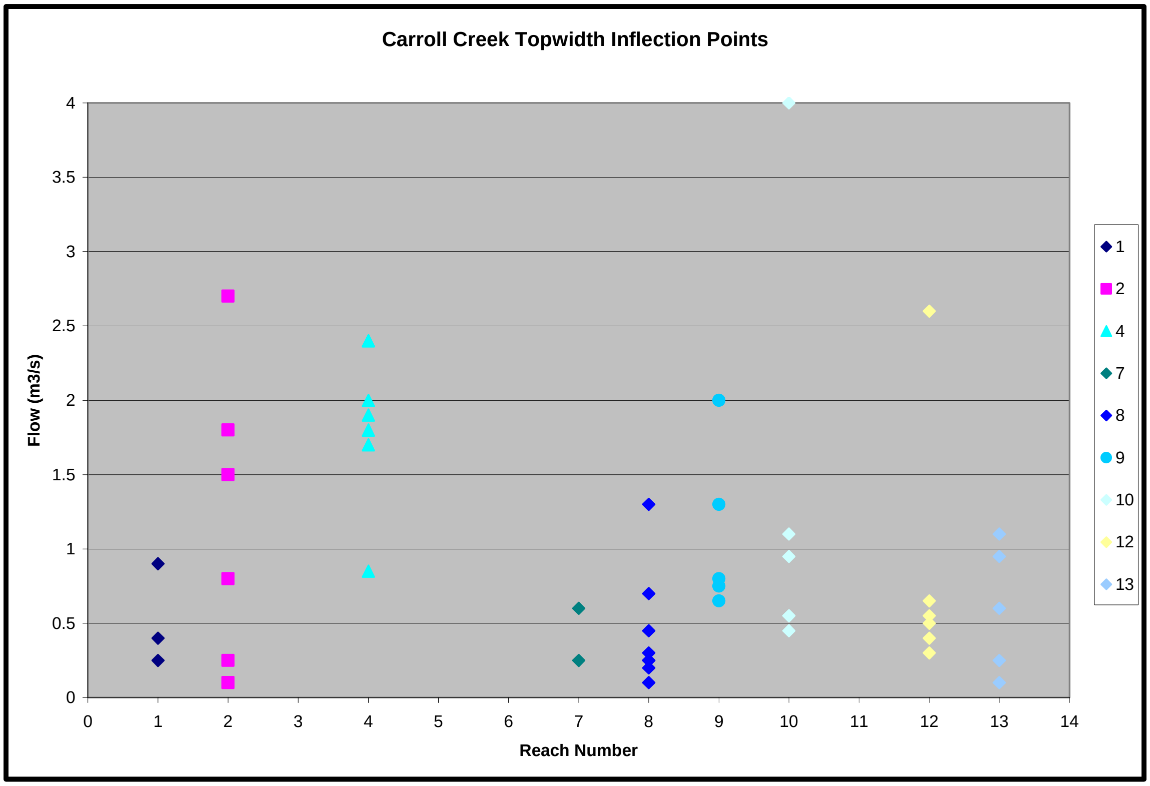


Figure 7.76 Carroll Creek topwidth hydraulic inflection points

The results seem to imply that the inflection points are more related to channel shape and slope, particularly the topwidth parameter. As the channel slope flattens out, the flow velocity diminishes and topwidth increases to convey the same flow. Results for Carroll Creek, which is a smaller creek, are more sensitive to changes in slope than tributary drainage. Sensitivity to changing drainage area contributions to streams will vary depending on geology and watershed characteristics. For the case of Carroll Creek, it implies there may not a linear relationship between instream flow hydraulic thresholds and drainage area.

The Ministry of Natural Resources collected spot flow surveys for Carroll Creek on three occasions during 1997 and 1998 (see Figure 7.77). This information provides additional insight into low flow variations along Carroll Creek. Figure 7.78 illustrates the spot flow variations along Carroll Creek from the outlet through to the headwaters. This figure illustrates some very important points; first the flow in the creek during very low flows is at the low extreme of the hydraulics model results presented in previous figures. This illustrates the importance of matching the details in the hydraulics models to the flow range being analyzed. The hydraulic model developed for Carroll Creek would not have sufficient detail to properly reflect small flow changes expected in the lower flow range of Carroll Creek. The hydraulic model for Carroll was constructed from cross sections collected as part of the Carroll Creek study completed by MNR, while this information was collected for a different purpose than low-flow hydraulic modelling.

The second important aspect of the information presented by Figure 7.76 is the variation in low-flows along Carroll Creek. This variation illustrates the stream can be gaining and losing through different reaches and these gains and losses can vary with the condition of the shallow groundwater table. This illustrates how complex assessing impacts of potential takings could be on low order tributaries (order 1, 2 etc., small streams). A groundwater taking on a small stream has the potential to completely change the gain and loss locations.

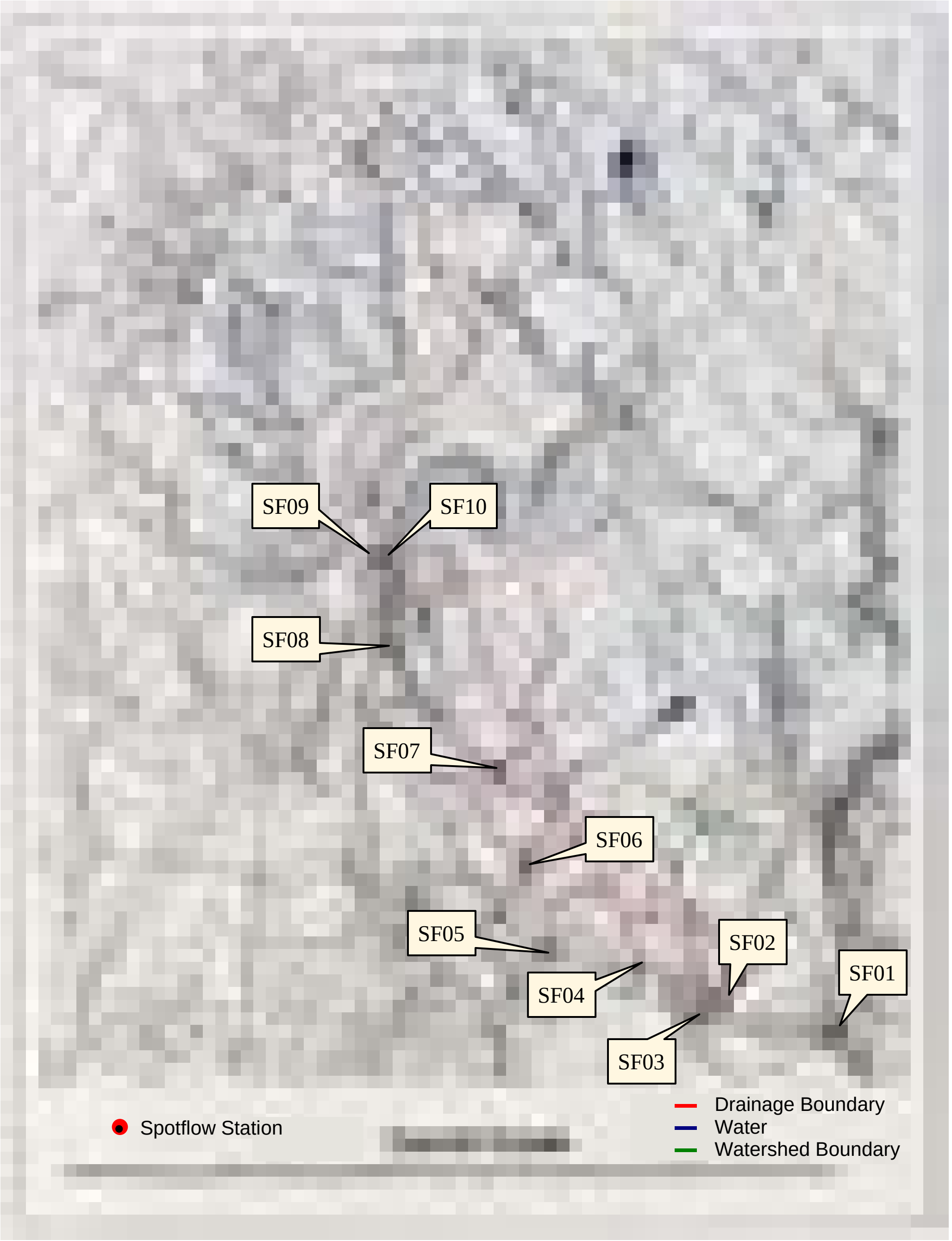


Figure 7.77 Spotflow stations on Carroll Creek.

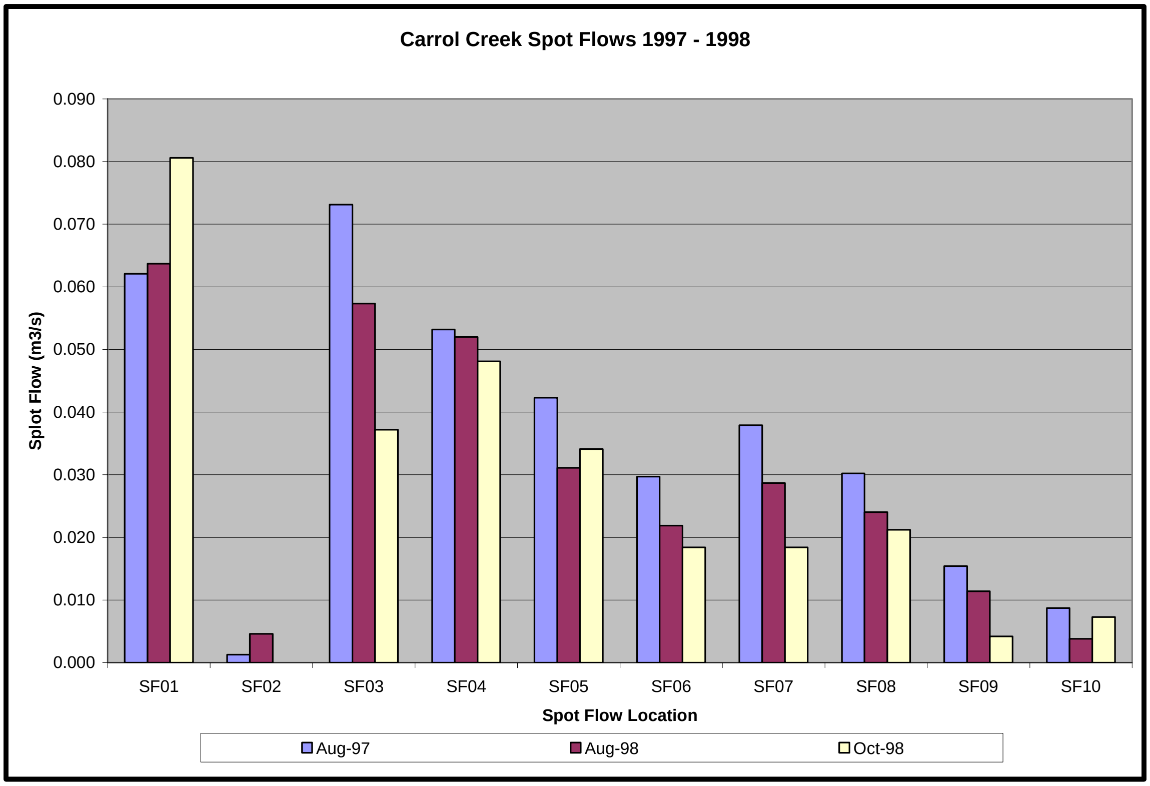


Figure 7.78 Spot flows in Carroll Creek on three occasions from 1997 to 1998.

The spot flow readings at station SF02 illustrate how low flows in some stream reaches can virtually disappear into the substrate and reappear further downstream. This type of situation can create a significant barrier to migration and forms another threshold to consider in a given stream.

The spot flows provide insight into the lowflow regime of Carrol Creek. The detailed Hec-Ras hydraulic model created for Carrol Creek was based on cross sections that were collected for other purposes. Additional detail in the low flow portion of each cross section would produce an improve flow hydraulic relationship for this stream. This highlights the importance's of standards for collection of stream hydraulic information to allow the use of this information to serve several different uses or applications.

8.0 MONITORING ECOLOGICAL RESPONSE TO LOW FLOWS

8.1 Introduction

Monitoring ecological response is needed to validate some of the simple desktop methods such as Tennant and Tessmann. It is difficult to monitor the ecological response because of several compensating factors and the lagged response to environmental stresses. Three methods of biological monitoring are tested in this chapter, with results that are quite varied. Biomass index and survivorship was tested in three reaches in Whitemans Creek, and stable isotope analysis was tested at various reaches in the Grand River watershed.

8.2 Defining a Conceptual Model for Determining the Ecological Effects of Water-Takings

There are a number of important points that need to be considered when designing a sampling program for determining the potential effects of water removals on stream and river ecology. Some of these points were highlighted in the previous sections and include:

(i) well-developed stream/river hydrology-based modelling methods (i.e. standard-setting and incremental) are insufficient for the task of determining ecologically-based guidelines for water-takings;

(ii) ecological issues will complicate both the measurement and interpretation of results and require that spatial and temporal variability be accounted for in the conduct of water taking effects studies;

(iii) field-based methods for demonstrating stressor-related effects exist, but are compromised by dynamic lags, environmental variability and biotic complexity;

(iv) the consequent accumulation of impacts within stream/river environments caused by hydraulic changes suggests foodchain-related rather than populations-specific endpoint measurements ought to be included in the determination of consequent water-taking effects (Power *et al.*, 1995);

(v) existing stressor measurement frameworks should be adapted to the problem of determining the potential effects of water-takings.

Evans *et al.* (1990) suggested a generalized model for ecosystem response to stress distinguished by three stages, which may be adapted to the problem of monitoring and determining when water takings have significantly degraded a stream/river ecosystem. The first phase, alarm, is dominated by signs of changes in species dispersal rates and distribution and production/biomass changes within the affected system. Presence/absence, relative frequency of occurrence and individual growth rate (biomass) and density studies are appropriate for determining the existence of alarm-related stressor effects.

In the second, or resistance, phase natural population-level regulating processes are triggered, leading directly to expected changes in species' abundance, mortality and survivorship. Decreases in numerical abundance and changes in survivorship (% survival), and increases in total mortality are expected in dominant taxa and will yield systematic changes in sampled population characteristics which are diagnostic of stress in general. Population estimation, statistically-based survivorship/mortality and the sequential sampling of routine biologic characteristics of dominant taxa for paired comparisons with non-affected reference sites are sufficient for establishing the existence of persistence-related stressor effects.

In the final, or extinction, phase population abundances declines rapidly to zero. Population-related projection studies using data collected from studies aimed at establishing the existence of resistance phase stress, may help prevent aquatic ecosystems from degrading to this stage by predicting the time frame within which local extinction might occur if no remedial actions were taken. However, there are few studies that need to be considered once stress responses in this phase are made clearly evident by local extinction events.

As with any environmental stressor, water-takings are capable of eliciting alarm, resistance and extinction responses. The prevalence of alarm should indicate the need to prevent or reduce future takings. The prevalence of resistance should provide prima facie evidence (sufficient first evidence to establish as true) for immediate remedial intervention, which might take the form of permit moratoriums, enforced reductions in takings or if possible, increased water release from dams and reservoirs. It is unlikely that all stream/river systems will be identical in terms of their response patterns to similar water extraction stresses. Resource limitations preclude studying each and every system individually, a fact which suggests that streams be hydrologically-typed for study (e.g., by stream channel type, geologic/geographic zone, extent of connectivity to ground water, stream order etc.). Once grouped, index sites can be selected for detailed study from which stream/river type specific guidelines may be developed. The method of using index sites is currently being discussed in Europe under the auspices of the development of guidelines for the European Water Framework Directive. Index rivers are also used to effect for managing anadromous fish stocks in Atlantic Canada and Québec (e.g. for Atlantic salmon, *Salmo salar*).

The Evans *et al.* (1990) framework coupled with the use of index sites underpins the choice of sampling sites currently being used in conjunction with studies of the possible effects of water abstraction on headwater brook char (*Salvelinus fontinalis*) populations (CRESTech funded MSc research being carried out at the University of Waterloo) and the GRCA sponsored evaluation of ecological flow assessment techniques. In all instances, studies focus on obtaining data for establishing the existence of alarm and resistance phase stresses. A brief description of sampling methods is given in Section 8.4.3.

8.2 Fish Biomass Index as an Indicator to Biological Response to Low-flows

The biomass index (BMI) is a method that is used to determine the relative amount of biomass, or living organic matter including fish or aquatic insects, contained in a certain region. The BMI was used to assess the quality of the aquatic ecosystem by comparing the level of BMI (measured in kg of biomass per hectare of water surface) to the minimum flows in a river reach. The hypothesis was that there would be a positive correlation between streamflows and biomass. Essentially, the BMI would be used to assess if a correlation existed between biomass and minimum flows to see how fish (ecological needs) are impacted by low-flows and water abstractions. Preliminary conclusions show that a direct correlation cannot be made, since there are too many variables, natural and anthropogenic to consider a good relationship. The procedure to determine BMI in Whitemans Creek is described below.

8.2.1 Study Sites

The fishery biomass data for Whitemans Creek was collected by the Ministry of Natural Resources and the GRCA between 1987 and 1996 to monitor the impacts of changing fishing regulations. Three study reaches in Whitemans Creek were used to collect biomass information to build a biomass index for both brown trout and rainbow trout. The three study reaches were:

- Site #1: Whitemans Creek at Rest Acres Road; upstream site
- Site #2: Whitemans Creek at Apps Mill; mid-stream site
- Site #3: Whitemans Creek at Mill Street, downstream site

Some key human-induced changes occurred in Whitemans Creek during the time period between 1989 and 1995, as well as some climatic and environmental conditions that should be noted. Please see Table 8.1 for further information.

Table 8.1 Notable environmental changes affecting biomass in Whitemans Creek

Year	General Flow Regime	Environmental Conditions	Human-induced Change
1988	Severe Drought conditions		
1989	Dry Year, near drought conditions	Rainbow trout start appearing in Whitemans Creek	Barrier dam downstream in the Grand River at Brantford was removed
1990	Above average flows		Regulated catch-and-release regulation began; reduced harvest of all trout
1991	Dry Year		Substantial water takings directly from stream
1992	Wet Year, very high flows	Decreased spawning success due to high flows in fall	
1993	Average Flows		
1994	Average flows		
1995	Average flows		

8.2.2 Data Collection

Flows

From Table 8.1, it can be seen that there are both dry and wet conditions in the stream, as determined by the statistics on minimum flows taken for each year. Some of the minimum flows calculated included the 7-day, 15-day, 30-day and 60-day minimum flows for Whitemans Creek. Flow data was collected from the stream gauge on Whitemans Creek at Mount Vernon.

The calculation of minimum flows describes the lowest mean daily discharge that occurs over a given number of consecutive days (n-days) such as the *7-day minimum flow* (Armstrong *et al*., 2004). This is repeated using different numbers of consecutive days for the average calculation of flows, such as the 15-day minimum flow or the 60-day minimum flow. See Section 5.1.2 for more information on these flows and their importance.

Biomass

The trout biomass data that was collected was solely based on fish numbers and area. Each study reach was sectioned off and the reach was subjected to standard mark-recapture electro-fishing protocol. Each fish collected was weighed (in kg) to determine the total mass of all fish in the reach. Other information collected on the fish included species (rainbow or brown trout), and age category, in yearly time steps from less than a year (symbolized as 0 or 0+) to greater than 3 years (3+) in age. The cross-sectional area and the surface area (in hectares) of the stream were measured to determine the BMI of kilograms of fish per hectare of water surface of the study reach.

8.2.3 Results

To determine if there was a correlation between low-flows and the BMI, these 2 parameters were plotted for each reach for rainbow and brown trout. Figures 8.1 to 8.6 show the results of the biomass study.

Rainbow Trout

Figures 8.1 to 8.3 show the data for rainbow trout. The dominant biomass age category is the 0+ or year-of-the-young (YOY) trout, with some abundance of 1+ (yearlings) trout. The BMI seems to have a year to 2-year delay of increase in biomass after a wetter year, and showing decreases in biomass with a reactionary delay of a year after low flow. The delayed reactionary period could be attributed to the spawning patterns of rainbow trout, which spawn in early spring. When low-flows occur, such as in 1989, Figures 8.1 and 8.2 show that the amount of biomass in the 0+ and 1+ decrease dramatically in the year following the drought. Conversely, high flows, such as those in 1992 show a sharp increase the following year for 1+ fish.

There is a general trend of an increase in rainbow trout numbers after 1991, which could be attributed to human-induced changes. As seen in Table 8.1, a regulation of catch-and-release was put into place in 1990 for all trout in Whitemans Creek at Apps Mill (Site #2). Since fish are now being put back into the stream instead of being removed by fishermen, the increase in biomass could also be attributed to the regulation, especially for the older fish. If unaware of this anthropogenic influence, it could be interpreted that the high biomass in 1993 could be linked to the high flow periods during the wet fall of 1992 and the wet spring of 1993. However, the likelihood is the migrating rainbow trout first appeared in Whitemans Creek at this time, with the removal of the dam.

Within-year comparisons (reading vertically in linear columns in the figures 8.1, 8.2 and 8.3) are inconclusive, as higher biomass can occur during low-flows or high flows, and lower biomass can also occur during both high and low-flows. The condition of high BMI during low-flows may be attributed to the increase in efficiency of catch. The volume of the creek during low-flow is much less than the volume at high flows, which creates a situation whereby the fish are easier to catch. The efficiency of the equipment increases with a lower volume, and the visibility of fish is higher due to shallower depths. Higher biomass during low-flows is also hypothesized to occur because of a reduced stream area may result in a concentration of fish in a confined area.

Since the first appearance of rainbow trout occurred in 1989 and 1990, the large increase in the 0+ biomass in 1993 at Rest Acres Road (Site #1) could be attributed to the hatching of the first generation of fish spawned in Whitemans Creek. The large jump in 0+ seen in 1994 for Sites #2 and #3, could be a response to better hatching success due to stable conditions of flow, temperature and food. However, the larger number of 0+ could also be attributed to a greater number of spawning adults finding Whitemans Creek.

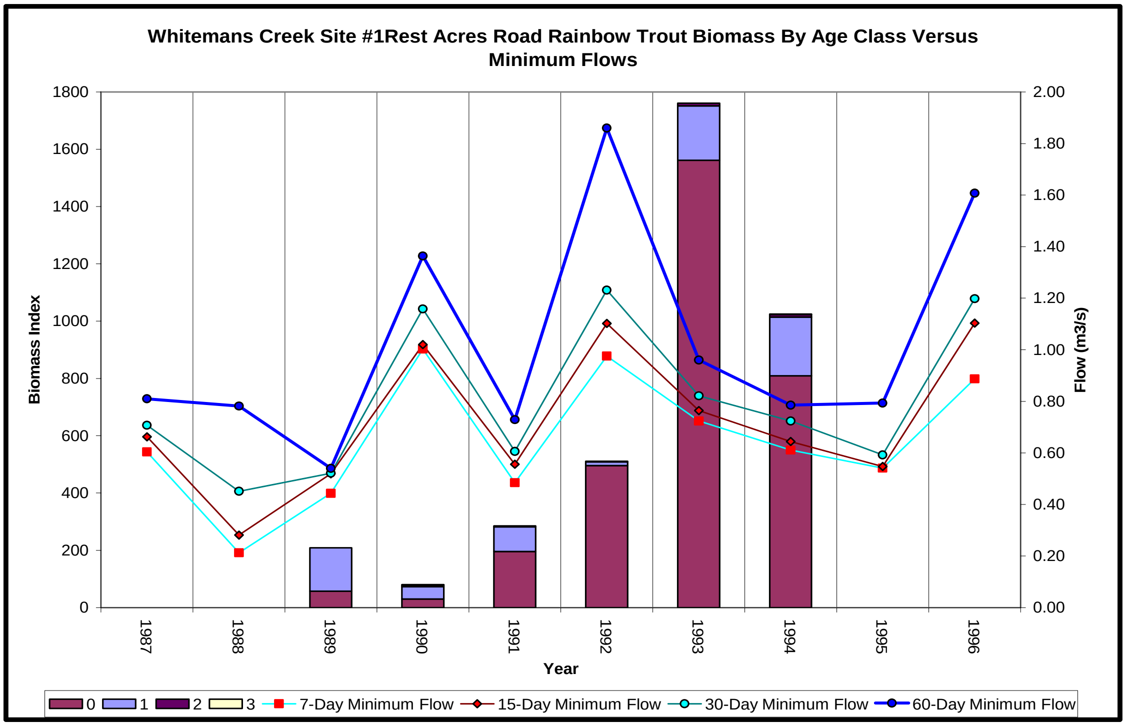


Figure 8.1 Biomass for Rainbow trout by age category and level of minimum flows in Whitemans Creek at Rest Acres Road.

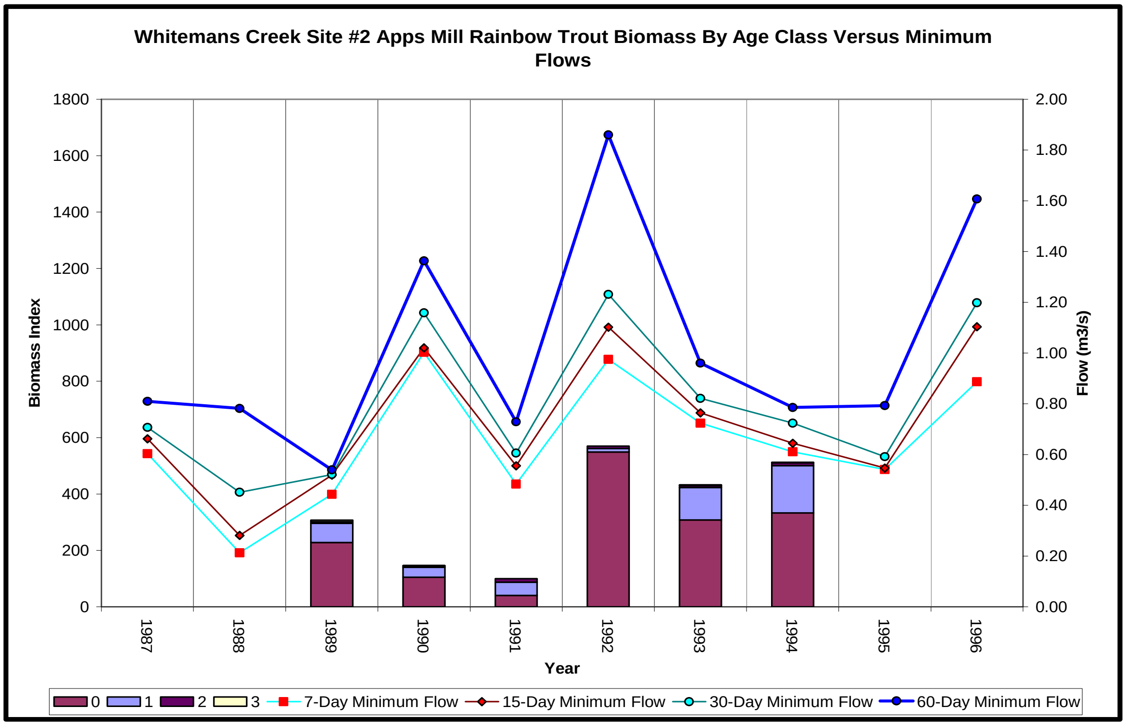


Figure 8.2 Biomass Index for Rainbow trout by age category and level of minimum flows in Whitemans Creek at Apps Mill

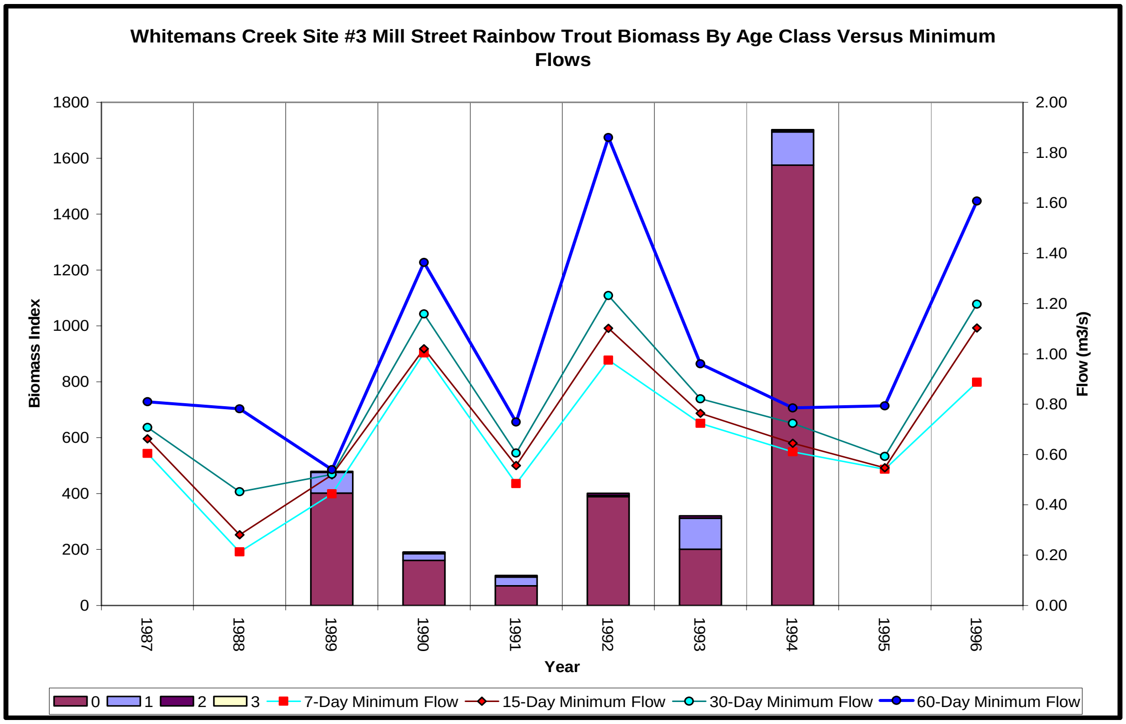


Figure 8.3 BMI for Rainbow trout by age category and level of minimum flows in Whitemans Creek at Mill Road

Brown Trout

Figures 8.4 to 8.6 show the results of the BMI comparison to minimum flows for brown trout in Whitemans Creek. The BMI values for brown trout are in general much lower than the values seen for rainbow trout. Notice that the BMI axis values for rainbow trout (Figures 8.1 to 8.3) range from 0 to 1800, whereas the brown trout BMI ranges from 0 to 600. The brown trout BMI values are more homogenous than the rainbow trout, showing less variability throughout the years of data collection.

The age distribution of brown trout is more varied than the rainbow trout, indicating the longevity of that species in the creek as compared to rainbow trout. The younger trout still dominate, with 0+ and 1+ alternating for the dominant biomass age class. This could be attributed to the habits of the brown trout, which do not migrate out to Lake Erie, while the rainbow trout smolt out at 2+ years and return to spawn when they reach 3+ or 4+ years. Thus, it is possible that the rainbow trout are more resilient to low flows since they don't reside in the stream for their entire life cycle.

As with the rainbow trout, it seems there are a few instances of a delayed reactionary period that positively correlates low-flows with lower biomass, or high flows and high biomass. This delayed reactionary period may have some relationship to the spawning habits of the brown trout, who spawn in the fall and have an incubation period over-winter to spring. Thus, adult spawning trout need sufficient flows to reach spawning grounds during the fall, and adequate connectivity between pools is necessary for them to swim to upstream reaches. Thus, a low-flow period later in the fall affects the population and BMI of the 0+ fish of the next spring. Also affecting numbers is the condition of the river over winter. If a winter flood occurs, then scour and ice movement could disturb, or destroy, the eggs, or a very cold winter could cause anchor ice to smother eggs. However, a stable, cold winter when the ice does not move until spring thaw has a higher success rate for hatching of brown trout. Although there are some instances that a 1-year reactionary period correlates low-flows to biomass can be seen, it is uncertain that a direct relationship exists. The instances of a direct positive low-flow correlation with low biomass for brown trout are inconclusive.

Higher flows show a stronger relationship with a more considerable change in the BMI after a high flow year, especially at Site #1 (Rest Acres Road) after 1992. The reactionary period for higher total BMI after the wet year of 1992, is 1-2 years for brown trout. However, in the upper and middle reaches (Mill Street and Apps Mill), there is a decrease in the 0+ biomass after the 1992 wet year. Thus, the correlation is also inconclusive for high flows and high biomass. There is no direct relationship between high flows and high BMI for brown trout.

The concept of connectivity between pools is especially important for brown trout. As young, brown trout prefer cover and refuge areas in the stream, which are usually located in pools. However, if connectivity is minimal, meaning there is little flow over riffle areas, then the larger brown trout are unable to move between the pools in search of food. Thus, the smaller, younger fish sharing the same disconnected pool with larger fish will encounter competition as well as predators. The refuge areas will already be occupied by larger fish that will prey on the smaller fish. As a consequence, the populations and biomass of 0+ and 1+ fish should decrease the year after low-flows break the connectivity between pools. After the dry year of 1989, the biomass decreases minimally at Sites #1 and #2, and relatively more at Site #3. However, this is not explicit in the figures on BMI for brown trout after another dry year in 1991, and actually the biomass increases in most cases. Diminished connectivity also could have long-term effects on the older fish, who have to use more energy to push their way through the lower flows in the riffle sections, creating stress. The quality of the water instream also could have effects on the trout populations; they may be subjected to poorer water quality conditions such as increased stream temperatures or lower dissolved oxygen content.

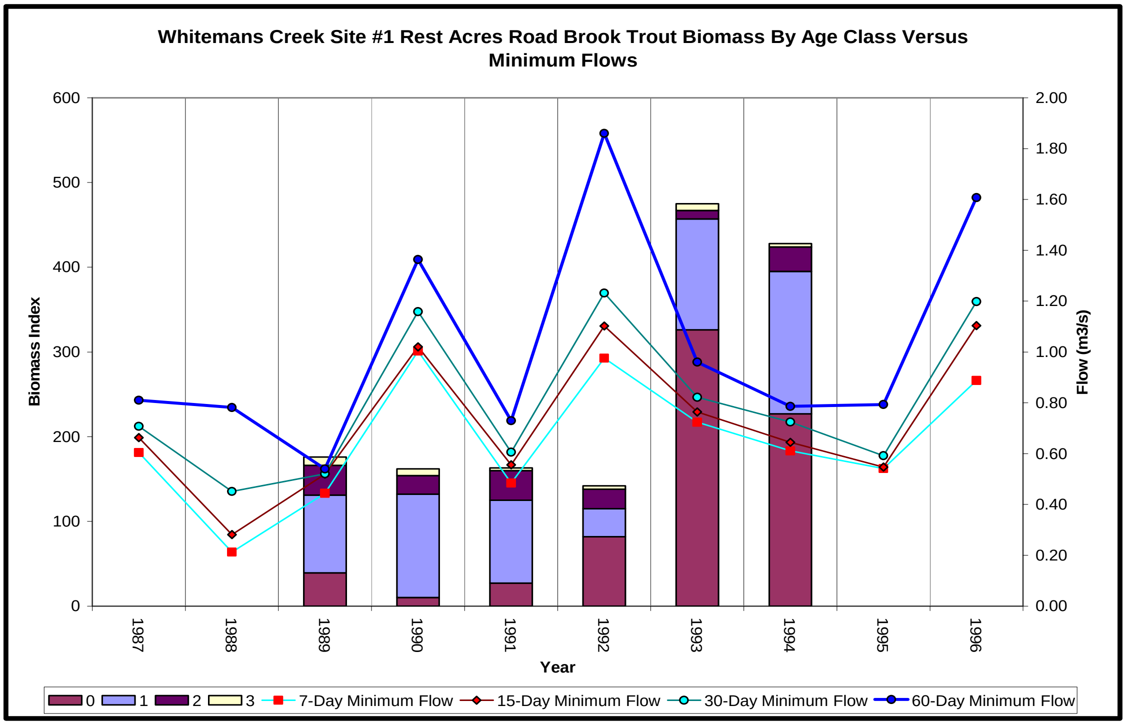


Figure 8.4 BMI for Brown trout by age category and level of minimum flows in Whitemans Creek at Rest Acres Road

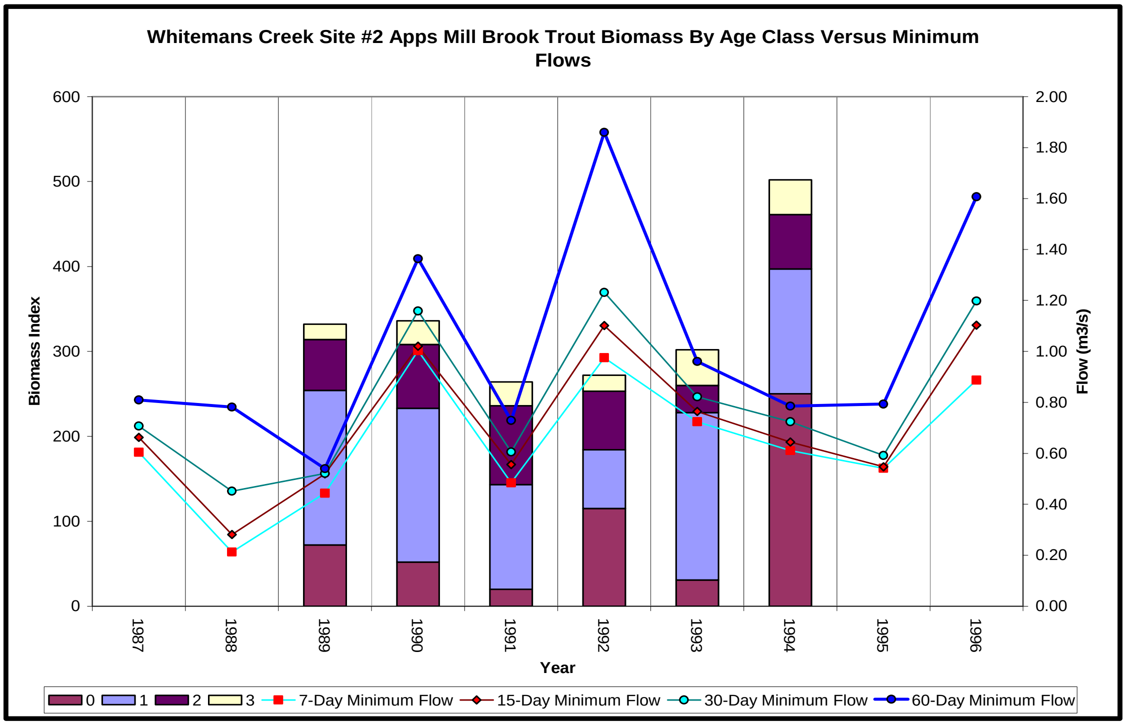


Figure 8.5 BMI for Brown trout by age category and level of minimum flows in Whitemans Creek at Apps Mill

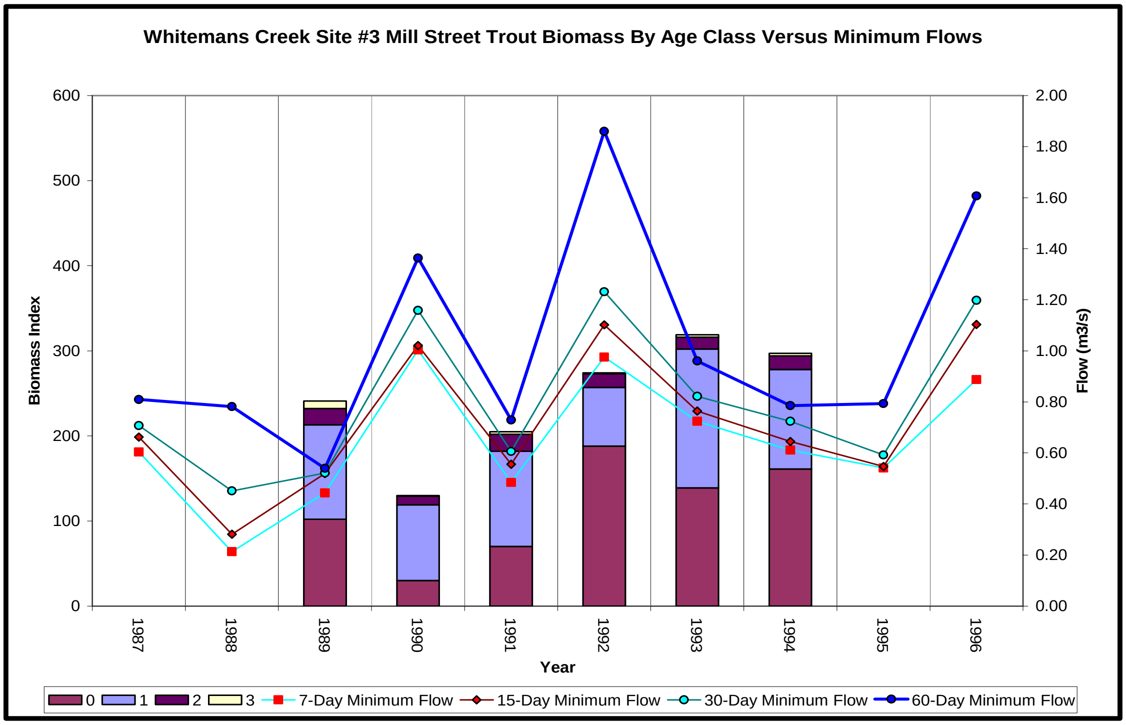


Figure 8.6 BMI for Brown trout by age category and level of minimum flows in Whitemans Creek at Mill Street

8.2.4 Problems with Correlating Minimum Flows to Fish Biomass Index

Analysis of the BMI information could not show a good correlation with flows in Whitemans Creek. The result was not unexpected as biomass is an integrative measure of fish community performance that will incorporate the effects of changes in all environmental conditions on stream resident fish age-classes and species. Biomass will, therefore, include both the positive and negative effects of environmental change on component age-classes and species and does not uniquely recognize the effects of water-taking impacts alone. In addition, biomass responds with a lag to environmental changes as a result of variations in the growth or survival conditions of affected species. There were several other problems that were encountered when trying to correlate minimum flows and BMI.

First, as previously mentioned, the catch efficiency of fish is higher during low-flows due to the decrease in volume of the study reach. The ability to catch fish is higher with less water volume and the breadth and intensity of the electrical field will be greater at the outer edges of the study reach. Thus, it is easier to catch fish during lower flows, which would result in an uncharacteristically high BMI.

Second, measurement of the cross-sectional area and the area of the entire water surface of the study reach is required for reliable estimates of the volume of living space, but was not provided. A slight miscalculation of the surface area of the stream or cross section changes the value of the denominator in the calculation of the BMI. Since BMI is calculated as kg/ha of water surface, a change in the area of the water surface will change the BMI, while the biomass weight stays constant. For instance, although the cross-sectional area of the edges of the study reaches were measured each time sampling was done, the cross-sectional area in between these limits can change dramatically as flows increase or decrease, thus gaining or losing surface area respectively.

Third, although it was previously thought that trout were relatively stationary as they reach the rivers, fish have the capacity to move great distances over the course of any time period. In the very short-term scale, fish can avoid capture during the biomass collecting exercise, and when a large fish moves out of the study reach, it could eliminate a large percentage of the biomass in that reach since it is proportionally much larger than the younger fish. In the longer-term scale, fish move day by day to find ideal conditions for themselves, with respect to temperature, competition, food sources and external stresses.

Fourth, direct correlations of minimum flows and BMI are falsely accurate, as there are many other variables affecting both fish populations and environmental conditions in and around the river reach. For instance, the catch-and-release regulation has a considerable impact of the populations of trout, as fish are returned to the river instead of being removed or eaten. Predators such as raccoons and other terrestrial predators have fluctuating populations external to the conditions within the stream that will affect the fish populations instream. Climatic conditions (extreme weather conditions such as floods and droughts, as well as seasonal fluctuations in temperature and precipitation) also affect the populations. Human-induced impacts affecting populations including: pollution, irrigation diversions, fishing, agricultural runoff, instream recreational activities, dams and other engineered structures, and land-use stress in riparian areas are among the more direct influences, with many other less direct and indirect influences impacting fish populations.

8.2.5 Possible Suggestions for Improving BMI Testing

The measurement of BMI uses the mass of fish found per area of the water surface. However, this is somewhat misleading as the profile of the water column and the actual volume of living space is not accounted for. A very shallow but wide stream will dramatically alter the fish populations from a stream that is deep and narrow. BMI could be more accurately calculated as mass per volume of living space in the stream. This could be calculated by doing a few more cross-sections of the stream and using flow rates to determine the volume of water in the study reach.

In general, the correlation between minimum flows and BMI is not a surrogate indicator of the ecological integrity of a river reach. There are too many other variables that affect both the biomass, the BMI and the minimum flow statistics to make direct links between these two parameters. Thus, BMI is a poor indicator to monitor biological response to low-flows due to water abstraction.

However, the use of BMI is not completely obsolete; the methods can be used in conjunction with other biological response methods and monitoring as a comparison. Further studies are required for establishing these relationships at a lower trophic level within the stream – or across the trophic levels – in the aquatic stream community. The use of the stable isotope analysis method, for example, is a method receiving recognition as an indicator of the quality of ecological habitats instream. The BMI could be a supplement to the SIA and other methods to monitor biological response, but cannot be used alone as a reliable monitoring or assessment tool. Survivorship has been suggested as another indicator of the ecological response to low-flows, and this is discussed below.

8.3 Survivorship of Fish Species in a River Reach

The survivorship metric is another calculation that can be made to determine the status of fish in a reach. Survivorship is defined as the "number of animals alive after a specified time interval, divided by the initial number." This metric is usually calculated on a yearly basis and is useful for tracking populations over time. It has been suggested that survivorship could be a good metric to determine the potential impact of poor environmental conditions on fish populations. To determine survival of fish, the following equation is used:

$$\text{Survival} = \frac{\text{fish of age class n in year x}}{\text{fish of class n+1 in year x+1}}$$

Survival is essentially calculated as the ratio of fish that return to a specific region that are a year older. The data collected in Whitemans Creek during 1989 to 1994, which was also used in the BMI calculation, was applied to the survivorship metric to possibly better explain the change in fish populations in a river reach. Mark and recapture were completed each year to determine the survivorship in the reaches. For this study on survivorship, the calculation of survival was categorized based on age class. When recapture was unavailable, the catchability was used based on data from other years as the population estimate; this occurred in 1992.

Jim Bowlby of the Ontario Ministry of Natural Resources calculated the data for survivorship, based on age class of brown trout in Whitemans Creek. As with the BMI study, three reaches were compared, including Apps Mill; this reach was changed to a regulated catch-and-release fishing area in 1990. Hence, it would be assumed that survivorship would be higher in this reach than the other two reaches, at Rest Acres Road and at Mill Street.

The survival of Age 1 brown trout is seen in Figure 8.7. The 1+ age group decreases in survival when competition from 2+ fish increases, meaning that the larger fish are out-competing the smaller fish, a scenario that would be expected. There is an increase in 2+ fish in 1993, which could indicate a movement of this age class into the reach.
Compared to other locations, within the special regulations area of App's Mill, it can be seen that there is a higher survival rate for brown trout of 3 years or younger.

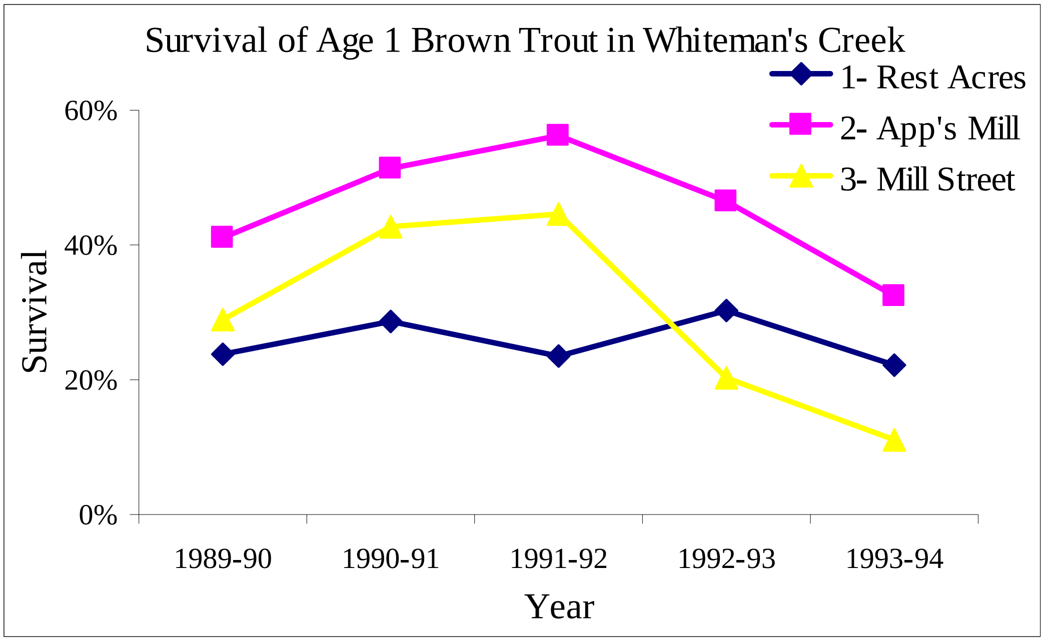


Figure 8.7 Survival of Age 1 Brown Trout in Whitemans Creek

Age 2 brown trout survival is seen in Figure 8.8. The unusually high survival of the Age 2 brown trout in 1994 is likely due to the movement of fish from upstream areas that sometimes suffer from high summer temperatures.

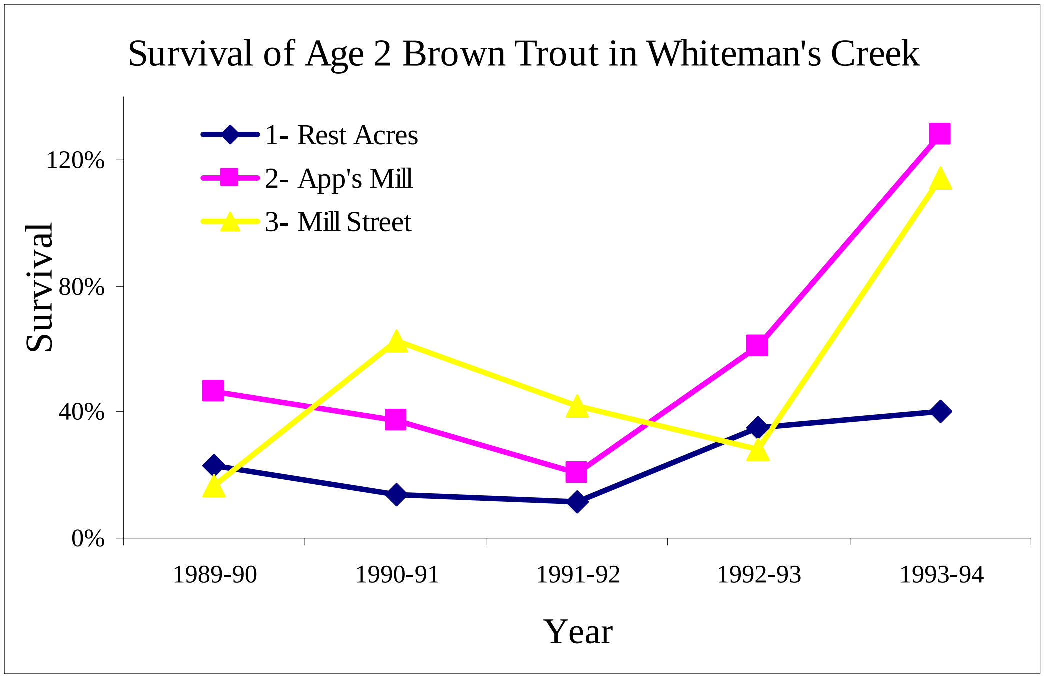


Figure 8.8 Survival of Age 2 Brown trout in Whitemans Creek

From the interpretation of the data, it was concluded that neither species of brown or rainbow trout was having a limiting effect on the other. The variation in population throughout the years was dependent on the strength of the age class to survive the younger life stages. The assumption that the community structure did not change was not correct for this study, as there was the regulation and the movement of rainbow trout into the reaches.

It can be interpreted that the fish regulation is changing the survivorship of the reach. This metric, as similar to many other metrics, assumes implicitly that the community structure is stable. This is not the case in Whitemans Creek with the regulation in place, and catch-and-release returning fish that would have previously been removed still inhabiting the reach. Thus, the use of the survivorship metric does show some slight effects of low-flows on the populations of trout in Whitemans Creek, however it is not conclusive for a direct correlation between the two parameters.

8.4 Stable Isotope Analysis Method for Determining Ecological Response to Low-flows

The use of the BMI and the survivorship metric showed no clear or direct correlation to lower flows instream and is inconclusive in the results produced in Whitemans Creek. There were too many indirect anthropogenic and natural influences to make clear linkages between flows and ecological response. Hence, another method was needed that would better characterize the response of biota instream. A monitoring program developed to determine ecological response that has had increased recognition has been the use of the Stable Isotope Analysis (SIA) approach. This approach involves the use of stable isotopes, which trace patterns of energy flow in stream foodwebs. The following section will introduce the SIA approach, fieldwork completed to test this approach and results of the study for 3 reaches in the Grand River watershed. The work on SIA was overseen by Mike Powers of the University of Waterloo.

8.4.1 The Theory Behind the Stable Isotope Analysis Method

Predator-prey relationships in streams are a way to characterize the movement of nutrients and the linkages between tropic levels, and thus can be an indicator of the quality of the ecology of a stream. Using a foodweb perspective is beneficial, as it characterizes the population dynamics of not just one key species, but of the resources, prey and potential predators, and how they respond to environmental change (Power *et al*., 1995). One method to characterize these relationships is to use the relative abundance of naturally occurring elements, which are consumed by the biota instream. However, these elements must not be reactive in the natural environment and be relatively variable sources of energy for aquatic organisms. Thus, the use of stable isotopes, or the form of an element that will not decay (stable) are preferential. An isotope describes an element’s different varieties based on its weight. For example, the composition of any one element includes protons, neutrons and electrons; of which the number of neutrons is variable creating ‘isotopes’ of the same element. Most elements that have a biological importance, including carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulphur (S), generally have 2 or more stable isotopes.

Heavier isotopes of naturally occurring elements such as carbon and nitrogen are the most useful as biological tracers, and these two elements are ubiquitous; found on earth, in the atmosphere and in all living things. For instance, usable nitrogen for biological processes is created when bacteria alter naturally occurring atmospheric nitrogen (a large component of the air) in the soil. This ‘fixed’ nitrogen is only usable by plants as an energy and nutrient source in this form. This fixed nitrogen is the relative content to be compared to the stable isotope. Carbon is a major element in the tissues of plants that is created during the process of photosynthesis.

The heavy isotopes are symbolized 13C for carbon and 15N for nitrogen, with a natural abundance of approximately 1% or less. However, despite their low natural abundance, these stable isotopes are important components in the transfer of energy through foodwebs. Analysis of stable isotopes, or the SIA method provides an indirect assessment of food source origins (Hecky and Hesslein, 1995) and has become increasingly popular as a means of assessing aquatic foodweb structure and the feeding ecology of constituent fish populations (e.g. Peterson *et al.*, 1985; Peterson and Fry, 1987; Kling *et al.*, 1992; Cabana and Rasmussen, 1994; Vander Zanden *et al.*, 1998; Guiguer *et al.*, 2002). SIA provides a time-integrated view of diet and trophic position (the niche held by an organism in the foodweb), which is dependable at least on seasonal scales (Hesslein *et al*., 1993).

Studies of SIA methods rely on the results of laboratory experiments that have demonstrated a rise in the level of the 15N isotope (compared to other N isotopes) as energy is transferred from prey to predator (DeNiro and Epstein, 1981; Minagawa and Wada, 1984). The relative increase in 15N, also called nitrogen enrichment, is a consistent pattern at each level of a food chain (or at each trophic transfer). Thus, a convenient quantitative measure of the relative trophic position of an organism within the foodweb can be calculated (Cabana and Rasmussen, 1994).

The ratio of the carbon isotopes, in contrast, remains relatively unaffected by trophic transfer (DeNiro and Epstein, 1978; Fry and Sherr, 1984). Organic matter such as leaves and other terrestrial plant material instream is a source of carbon. For instance, allochthonous coarse particulate organic matter (CPOM) is the term used to describe the organic carbon that enters the stream from an external source, such as a riparian tree leaf falling into the stream. This CPOM is a major source of food in small headwater streams, providing a large proportion of the fixed carbon in stream ecosystems. The leaf material entering the stream, which is essential for the colonization of microbes, is transported downstream, is shredded and consumed by certain types of ‘shredder’ macroinvertebrates. The preservation of the leaf litter is essential for long-term survivability of the food source. Fine particulate organic matter (FPOM) is also an important food source for filter-feeder macroinvertebrates.

With respect to carbon, algae and terrestrial carbon sources exhibit distinctive carbon signatures due to the process of fixing carbon. This results in the ability differentiate between the relative reliance of higher trophic organisms on foodwebs based on algal or terrestrial origins (Rosenfeld and Roff, 1992; Doucette *et al*., 1996a).

8.4.2 An Alternate Ecological Response Method

Since the analysis of carbon (13C) and nitrogen (15N) are associated with different levels of the food web, SIA methods are a good indicator of the existence of alarm-related stressor effects. The combined use of carbon and nitrogen values, allow connections between predator and prey to be established with reasonable certainty (Wada *et al*., 1991). Analysis of naturally occurring stable isotopes have been increasingly used in ecology to describe trophic relationships between organisms (Peterson, 1999), and the technique has proven useful in defining the nature and extent of many previously hypothesized trophic connections (Wada *et al*., 1991). The development and application of stable isotope analysis in aquatic ecology has improved understanding in trophic relationships among biota (Peterson and Fry, 1987). Stable isotope ratios of carbon (13C/12C) and nitrogen (15N/14N) have been used to provide information about feeding relationships in aquatic environments (e.g. Kling *et al*., 1992; Vander Zanden *et al*., 1998). Unlike other methods of tracing trophic connectivity, stable isotope analysis provides a time-integrated view of diet and trophic position. Recently, stable nitrogen isotopes have been used to trace pathways of anthropogenic impacts in marine and freshwater foodwebs (e.g. Spies *et al*., 1989; Kidd *et al*., 1995; Vander Zanden *et al*., 1999; Murchie and Power, 2004). Accordingly, the use of stable isotopes will be critical to the study of the correlation between water abstractions and change in species abundances. The combined analyses of carbon and nitrogen isotopes may prove important in further understanding of the subtleties of the variability in flow impacts on lotic foodwebs. Thus, Doucette *et al*. (1996b) have concluded that there is considerable utility in the use of carbon stable isotope analysis in understanding anthropogenic alterations in the carbon budget of streams and that stable isotope analysis can be a powerful technique for deciphering food webs and identifying anthropogenic impacts on foodweb structure.

Thus, the application of the stable isotope analysis method was employed in the Grand River watershed. The Evans *et al*. (1990) framework, discussed in Section 8.2, was used for the evaluation of ecological flow assessment techniques to obtain data for establishing the existence of alarm and resistance phase stresses. The study focused on the possible effects of water abstraction on headwater brook char (*Salvelinus fontinalis*) populations. A brief description of the sampling methods is given below.

8.4.3 Study and Field Sampling Methods

The basis of the study design was to test two hypotheses linked to the alarm and resistance phase response expected in stressed aquatic ecosystems. These hypotheses are as follows:

Hypothesis 1:
Water abstraction will be negatively correlated with the relative frequency of biomass occurrence, individual growth rates and densities of dominant stream taxa consistent with alarm phase responses to stress

Hypothesis 2:
Water abstraction will result in a negative correlation to species' abundances and survivorship, and a positive correlation with mortality, consistent with resistance responses to stress that are ultimately reflected in the shortening of lotic foodwebs and the compression of the carbon resource base.

Testing these hypotheses required linked multi-trophic level, multi-site studies, replicated over a number of years using affected and reference (control) sites. The use of control sites - similar stream sites unaffected by water removal activities of any kind - is very important in the study. To stay in the context of studies on fish and invertebrate species, all the study sites are headwater streams where water is being removed from the "source" for commercial and municipal use. All sites were chosen with similar physical attributes, as best as possible, including gradients, substrates, bank side vegetation and cover, and available fish habitat. The selection of similar sites was thought to reduce the possibility of confounding effects due to stream size and place along the length of the watershed, or to minimize variables in the comparisons.

To be most effective, the study sites should be categorized using an impact gradient of differing levels of water removal. A spatially-based gradient based on water removal rates, expressed as a percentage of baseflow, may be used across all study sites. A temporally-based gradient may be included by selecting a site where water abstraction rates may be controlled. However, to eliminate the effects of inter-annual differences, replication is needed across the years.

There are a number of parameters that need to be tested, including physical and chemical, shown in Table 8.2 and biological parameters, described in Table 8.3. Physical parameter measurements should be made prior to the initiation of any biological sampling.

Table 8.2 Physical and chemical parameters needed for studies into ecological flow requirements

Parameter	Measurement	Frequency
Physical	Baseflow	Continuously
	Discharge	Continuously
	Variability in Discharge	Continuously
	Energy	
	Slope	
	Temperature	Continuously
Chemical	pH	
	Conductivity	
	Dissolved oxygen	

Biological sampling should occur at multiple trophic levels, and be conducted using stratified random sampling of available habitat types within each study site. Prior to the completion of the biological surveys, stream reaches should be inventoried for habitat type based on substrate, flow and cover characteristics (Stanfield *et al*., 1997). Several cross sections of the stream should be measured to get an accurate account of the sample area of the reach. If studies are carried out over a number of years, habitat inventories must be repeated annually to ensure consistency between years. All captured fish should be returned alive to the sampled habitat segment upon completion of the survey.

Table 8.3. Biological parameters needed for SIA method

Type	Parameter	Collection Method	Description
Fish	Length (mm)	• Electro-fishing • Mark and re-capture • Peterson population estimators • Zippen removal method (Zippen, 1958)	Measurement in spring, mid-summer and autumn to capture seasonal dynamics is ideal; mid-summer sampling minimum requirement Triple pass sampling recommended Multi-year if possible Live capture and release
	Mass (g)		
	Species density (no/m^2)		
	Species biomass (g/m^3)		
	Average species condition		
	Age-specific growth rates (mm/day)		

Macroinvertebrates	Feeder classification	- D-frame and kick sampling - Drift net sampling over 24h period	Community structure estimates (foodweb structure) Drift density can be multiplied by discharge to estimate quantity of drift items available as a forage resource to stream resident fish
	Diversity		
	Eveness		
	Richness		
	Dominance indices		
	CPOM transport and storage		
	FPOM transport and storage		

Drift density is the number of organisms found per $100m^3$ of water, when multiplied by discharge allows for the estimation of the quantity of drift items available as a forage resource for stream resident fish. Some of the classifications of macroinvertebrate feeders include grazers, diatoms, filter feeders, shredders and predatory insects. Leaf detritus can include both CPOM and FPOM.

Adult mortality and juvenile over-winter survival measurements can be obtained from mark-recapture experiments conducted in the fall and spring using Peterson population estimators, if studies span a number of years. Such studies are recommended for establishing resistance phase stress responses to water abstraction activities. Energy flows can be traced to create stream/river foodwebs by clipping one of the fins (adipose fins have no bones) and using it in stable isotope analysis, once baseline comparative analysis of fish flesh/fish fin studies have been completed.

Statistical testing was completed on the study reach data, for the comparison of the affected and non-affected site gradients. The gradient data suggests the use of linear regression to establish the extent and significance of any correlation between water abstraction rates and measured biological response. Means were compared to determine if there is a significant difference between affected and non-affected sites, for two samples and for multiple comparisons of means (using 2-sample T-tests and Tukey's post hoc HSD tests, respectively). The variance within each class was also verified with F-tests and Shapiro-Wilks tests, to determine homogeneity and normality.

8.4.4 On-Site Sampling for Macroinvertebrates

After site inspections of numerous sites for which flow and temperature information were available, three creeks, Bechtel, Blair and Mill Creeks, were selected for the sampling. These three creeks were preferred over larger, mainstream river sites, due to their similarity in headwater impacts, proximity to one another and ease of land access, as arranged by the GRCA. Sampling was conducted on a monthly basis throughout the summer of 2003. Sampling consisted of random selection of upstream and downstream substrate types and undercut bank habitats. Standardized kick sampling methods were used on all upstream and downstream substrate sampling sites. Standardized disturbance sampling of undercut bank habitats was accomplished by inserting a dip-net into the undercut bank and prodding the net gently back and forth to free any attached macroinvertebrates. Standardized filtering of stream water for dissolved organic carbon

(DOC) analysis and retention of water samples for dissolved inorganic carbon (DIC) analysis were also conducted on each initial sampling trip. The sampling schedule is given below in Table 8.4. Sampling was restricted at Bechtel due to construction of new fencing, restricting site access as originally selected.

Table 8.4: Study Site sampling schedule for SIA.

Site	Sample Dates
Blair Creek	August 06, September 11, October 10, March 17
Bechtel Creek	September 12, October 16
Mill Creek	August 08, September 10, October 19, March 18

The samples were roughly sorted in the field and were processed in the laboratory for proper identification and processing for stable isotope analysis. This included allowing sufficient time (24h) for gut evacuation by the macroinvertebrates to improve the measurement; identification of the specimens while in alcohol; and a drying period in the oven prior to grinding the biomass for the carbon and nitrogen stable isotope analysis. The Environmental Isotope Laboratory processed the analytical portion of the isotope analysis, using a mass spectrometer and elemental analyzer. See Appendix A (Table A.8) for the list of taxa that were identified at each study site and a more descriptive procedure.

Stable isotope ratios (symbolized δ15N and δ13C) are measured as a difference in parts per thousand (‰) and compared to the international standard, and expressed as a delta (δ) value. If the sample is enriched in the heavier isotope, it will have a higher delta value, and a depleted sample will have a lower delta value.

8.4.5 Results of Study

The comparative plot of stable isotope measurements obtained to date, of the three study sites, shows good separation on both the nitrogen and carbon axes (Figure 8.9). Samples from Mill Creek tend to be the most nitrogen enriched and carbon depleted, probably reflecting the relative importance of anthropogenic nitrogen inputs (e.g. sewage seepage and agricultural runoff) and allochthonous carbon in the Mill Creek foodweb. Conversely, Blair Creek is the most carbon enriched as a result of a lower percentage of bankside riparian vegetation upstream of the study site and consequent lower percentage reliance of the foodweb on allochthonous carbon (Doucette *et al.*, 1996). By contrast, Bechtel Creek is the lowest in nitrogen, reflecting the lower anthropogenic nitrogen inputs, but intermediate in terms of the importance for allochthonous carbon in the foodweb. All study sites differed significantly (Tukey's HSD $P < 0.05$) on the carbon and nitrogen axes, indicating unique positioning of the sites.

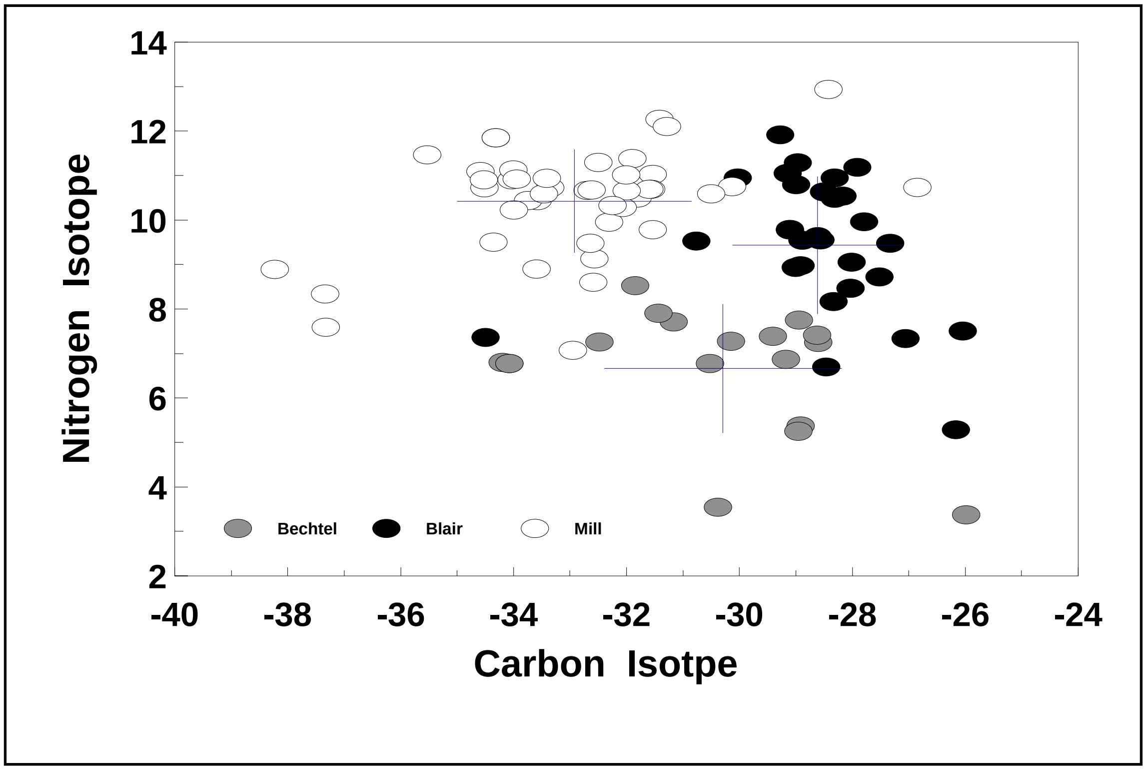


Figure 8.9: Carbon (δ13C) and nitrogen (δ15N) cross-plot of the invertebrate stable isotope analytical results for Blair, Bechtel and Mill Creeks.

Findings here accord with those of Hicks (1997), who noted from stream community studies in the Waikato region of New Zealand, that mean foodweb isotope signatures differed between shaded forest and unshaded pasture streams based on the importance of allochthonous material (conditioned leaf litter and terrestrial invertebrates). Autotrophs in forest streams were not a significant C source for food webs whereas the C source of food webs in the unshaded pasture streams was a mixture of allochthonous and autochthonous material.

With the preliminary data, there is some suggestion of varying foodchain lengths by stream site. For example, the range of the nitrogen ratios (δ15N) in Mill Creek is 5.8‰ while in Bechtel the range is more limited (5.1‰). There is also some suggestion in the preliminary data that variability in foodweb carbon signatures are correlated with discharge, with the higher discharge Mill Creek sites being more depleted than the lower discharge Blair Creek site. Direct comparisons to Bechtel Creek are currently not possible owing to differences in riparian vegetation and the probable importance of groundwater inputs for flow maintenance. Comparisons between Mill and Blair Creeks, however, echo the findings of Hicks (1997) who found the δ13C of Cladophora in New Zealand streams was related to water velocity, with more δ13C enriched values in pools than in runs.

Results suggest significant impacts in energy pathways occur as a function of changes in flow regimes. Flow related impacts on the isotopic signatures of taxa have been reported elsewhere in the literature. Sheldon and Walker (1997) suggested that flow stabilization in the lower Murray River, Australia, promoted the growth of filamentous algae, perhaps at the expense of bacteria. Evidence from gut and faecal pellet analysis, and from analysis of carbon stable-isotopes of snails, suggested that resident gastropod taxa were detritivores, feeding mainly on amorphous organic detritus. Because algae have a relatively high C:N ratio (low nutritional value) they may provide inadequate energy sources to maintain female growth and reproduction, thereby explaining the correlation between increased algal biomass and declining snail abundances associated with stabilized flows.

McArthur *et al.* (1996), have documented both seasonal change at a given site and differences between study streams, noting that temporal changes in isotopic composition of riparian species and aquatic macrophytes are site-specific. Discriminant analysis dissimilarity plots of isotopic results demonstrated that the contribution of species to the detrital pool depended on the site and season. Findings at the Blair, Bechtel and Mill Creek study sites parallel those reported by McArthur *et al.* (1996) with distinctive site-specific results in evidence for those data that have been analysed (see Figure 8.9). In Blair and Mill Creeks (see Figure 8.9) there is no difference between the isotope signatures of the upstream and downstream samples (two-sample t-test P-value 0.668), suggesting within site variability is low. Samples obtained from Bechtel Creek show an apparent difference between upstream and downstream samples. However statistical testing indicated the differences were not statistically significant (two-sample t-test P-value = 0.615) when samples were tested as a group or on a taxon-specific basis (i.e. caddis fly t-test P-value > 0.05).

Mean study site carbon (δ13C) and nitrogen (δ15N) isotope values were further assessed with significant analysis of variance followed by multiple comparisons of means using the conservative Tukey's HSD post hoc test (Cox, 1987) to determine the significance of observed differences in mean study site isotope values. Testing results are presented in Table 8.5 along with coefficients of variation for each isotope at each study site. All study site δ13C and δ15N tested as significantly different from one another using Tukey's HSD test (P<0.05).

Table 8.5 Mean study site isotope signatures and isotope coefficients of variation (CV)

Site	**δ13C**	**δ15N**	**δ13C CV (%)**	**δ15N CV (%)**
Blair Creek	- 28.61	9.44	5.25	16.36
Bechtel Creek	- 30.28	6.67	6.94	21.78
Mill Creek	- 32.92	10.43	6.32	11.11

Carbon variability within each study site is similar, although lowest in Blair Creek. Nitrogen variability differs between sites and may correlate with either discharge or flow variability, although flow data have not been collated in a form suitable for comparative testings.

8.4.6 Summary

A comparison of fish biomass monitoring in the Whitemans Creek Watershed in response to observed minimum flows was completed to show that there are no real obvious correlations; illustrating the difficulty in observing the ecosystem response to low-flows. An alternative method was needed for characterizing the ecological response to water abstractions.

The difficulties associated with using aggregate fish community response measures (e.g. biomass) for determining the potential biological effects of water-takings led to a study to investigate alternative monitoring approaches aimed at measuring responses at the base of stream foodwebs that will ultimately trigger measurable biomass responses. The work completed by Mike Power (University of Waterloo) with respect to monitoring the Carbon-Phosphorous-Nitrogen balance offers some options with respect to monitoring the response of the environment to water taking. Mike Power's suggested monitoring program may be one means of monitoring ecosystem response. Stable isotope monitoring may be made taxon-specific and may be used to monitor flow-induced changes in nutrient dynamics important for triggering changes in fish biomass. Stable isotope monitoring is relatively cheap, may be twinned with standardized invertebrate abundance/biomass surveys and is capable of being expanded to include fish species. Long-term research sites could be set up to carry out this monitoring.

Additional scientific study is needed to relate cause and effects to changes in isotopic composition, however this method has the potential to indicate change at a very base level offering early warning to changes occurring in a stream that will manifest themselves in top level organisms and water quality observed in a stream.

9.0 WATERSHED CONTEXT

The following chapter explains how the existing work completed in the pilot reaches would be scaled up into a watershed strategy. This watershed strategy is Component B of the initial study.

The logistics of a full watershed study is often impossible for larger watersheds at every area of concern, and thus scaling up a pilot study such as this is suggested. The methodology includes the need to scope other potential reaches for study and determine if there is enough concern to warrant full studies on those reaches. With the use of modeling and the techniques used in the IFN report, several gauged and ungauged sites could be assessed for ecological flow requirements. The methodology as described in this chapter was considered in a scoping exercise to scale up the IFN issues into a full Grand River watershed study.

First, a general description is given on how to determine areas within the watershed that could be in need of an assessment of ecological flow requirements. Next, the process is outlined in stages of the work that needs to be completed to assess reaches that are of concern; this is done for both gauged and ungauged sites. Finally, some additional reaches in the Grand River Watershed are characterized using the methodology of scaling up to a watershed process to provide examples for other CA's to follow and also to assess the applicability of the process.

Items to consider for a Watershed Study:

- full studies are impossible for larger watersheds at every area of concern, thus we need to scope other potential reaches for study and determine if there is enough concern to warrant a full study on that reach
- using modeling and the techniques used in this report, several other gauged sites were considered in a scoping exercise to scale up the IFN issues into a full Grand River watershed study.
- OFAT was one of the models used to quickly determine some subwatershed parameters
- Comparison of the OFAT parameters were done with monthly mean flow data obtained from the Water Survey of Canada archived hydrometric data.

9.1 Methodology for Upscaling Instream Flow Project to Other Reaches

The expansion of the Instream Flows Project to a watershed scale requires the selection of a number of other reaches across the watershed. Sites that may have potential issues with regards to water takings and the subsequent degradation of the ecological habitats within those reaches are subject to various levels of study. Three stages of study are proposed: to determine whether a serious issue exists in the selected reach, characterization of the water uses, and if human extractions are seen to pose a serious threat to the ecological integrity of the reach, to determine the ecological flow requirements.

The levels for the study are thus a scoping stage, a detailed scoping stage and a full study. Each level of the assessment is detailed below.

9.1.1 Stage 1: Scoping

The first stage of the process is an initial scoping to determine where potential water takings may exceed the ecological threshold for that reach. Scoping is a basic assessment of the water available and the water currently being taken and the characterization of the prospects for future takings. This step focuses on finding several reaches within the watershed that may have potential water management issues.

Tasks in the Scoping stage include:

1. Organizing and characterizing water use from unadjusted PTTW information
2. Organizing summary flow information using OFAT
3. Comparing water use to flow instream, using a few parameters such as mean annual or average summer flows

The first task in the Scoping stage involves obtaining PTTW database information from the MOE. The database provides information on the maximum permitted water takings in a region or subwatershed. The second task utilizes OFAT modeling software to provide a base for generating summary flow statistics in a subwatershed. The PTTW and OFAT information can then be compared to determine the demand (PTTW information) and supply (OFAT results) within a watershed. Further OFAT information from subwatersheds in the Grand River watershed are described in Section 9.5.

The goal of these tasks is to determine whether an issue exists in this reach. The tasks try to establish if the water takings exceed the available water in the reach, and if the takings are above certain threshold value. This threshold value could be a percentage (i.e. 50%) of the mean annual flow, or perhaps on a seasonal basis for summer flow parameters or low-flow parameters.

If no significant difference or exceedance is found between the available water and the water takings in the reach, then the study can be completed here and no further work needs to be completed at this point. There is no threat to the ecological integrity of this reach from a water taking perspective. There is enough water in the reach to fulfill the needs of both human and ecological needs. Ultimately, this implies that the MOE is able to continue granting PTTW in this type of reach.

If, however, the water takings begin to exceed the available water, then the study needs to move to the next stage of the process, to Stage 2: Detailed Scoping. There is a potential issue of the degradation of the ecology of the reach based on current water takings.

9.1.2 Stage 2: Detailed Scoping

The second stage of the process further refines the values calculated in Stage 1 for a more detailed scoping of the water use and availability in the reach. The goal of this stage is to get a better, more realistic estimate of the actual water takings, to determine whether an issue will arise with the degradation of the river ecology due to over-takings and to better define the linkages between takings and the natural environment.

Tasks in the Detailed Scoping stage include:

1. Organizing or characterizing the water use by adjusting the PTTW information to better reflect actual takings
2. Organizing summary flow information
3. Comparing water use to flow instream
4. Simulation modelling

As the PTTW information from the database is fairly crude, further research is needed to detail the actual water takings and assess the takings more accurately. This may include looking at seasonality, calling municipalities for actual water takings and researching other water users for metering or reporting of actual water extraction from groundwater and surfacewater sources. Information on flow could be gathered from any WSC or other stream gauges in place to characterize the long-term flow record. Further modelling could be completed with other tools where the data permits. Once these tasks are completed, the decision needs to be made whether an issue of overtaking exists in the reach.

If no overtakings of water are seen in the Detailed Scoping stage, then it may be possible for the MOE to grant more PTTW permits.

If there is a significant exceedance of water takings when compared to the instream flow, based on critical threshold values, then there is a potential threat to the ecological integrity of the reach. The water takings could pose a threat to the ecological needs of the reach, and so the reach is declared a high-use or sensitive area to consider for establishing a detailed instream flow program.

Note that there is reason to distinguish between potential high impact areas and sensitive areas. For example, a water bottler may want to establish an operation close to a spring that has a direct linkage to the natural environment, possibly a coldwater stream. The total use in the given area may not be high, however the ecology of the coldwater stream system may be sensitive, and therefore a more detailed study may be warranted. Depending on the situation such as this coldwater water stream, takings may not be permitted.

Options for follow-up for this stage of Detailed Scoping could include:

- Developing detailed reach instream flow estimates, to be completed by either the CA or MOE
- Suggesting the implementation of staff gauges in the reach
- Implementing rules for water takings, based on staff gauge heights for example
- Applying conservation measures along the reach based on levels of water

9.1.3 Stage 3: Full Ecological Flow Assessment Study

The final stage of the process would be the implementation of a full assessment of the reach to determine instream flow requirements. This stage would determine how much can be taken and what needs to remain instream for the maintenance of ecological flow needs.

To define how much can be taken, the IHA software would be run to determine the point at which a standard deviation of change had occurred. This would be simulated by continuously removing a unit of water and observing the change in the parameters until a standard deviation of change (either positive or negative) from the original values has been reached.

The full assessment, including fieldwork, data analysis and interpretation would be completed for this stage to determine the ecological flow requirements for this reach. A series of stages are presented in the next section for establishing instream flow requirements where stream gauges are present on a reach.

9.2 Staged Approach to Establishing Instream Flow Requirements

Establishing instream flow requirements should use a staged approach geared to issues in a specific area. In areas where the number of water takings are small relative to the source, simple desktop assessments are likely to be adequate. However, in potential high impact areas such as Whitemans Creek or the Norfolk sand plain, a more detailed approach is required. The following are the tasks for establishing the Instream Flow Requirements, with reference to the GRCA study methods and results in parentheses:

1. Assessment of the current water takings, such locating areas of concern and looking at the discrete and cumulative impacts over time and space.
2. Streamflow Analysis including a comprehensive analysis and development of low-flow statistics, high flow statistics and percentile statistics. Percentile statistics are important to reflect the variability of the source when developing or assessing a taking strategy (see 7.1).
3. Geomorphic Survey with cross sections and information sufficient to construct and calibrate a HEC-RAS model and estimate geomorphic thresholds (see 7.2.2).
4. Detailed hydraulics model of reach based on HEC-RAS modeling (see 7.2).
5. Development of geomorphic thresholds for reach such as bankfull flows, flushing flows, bed mobilizing flows and residual pool flows (see 7.3).
6. Development of a naturalized flow series reflecting pre-development conditions and of a post-development condition with takings both cumulative and discrete included ().
7. Application of the IHA and RVA software to analyze the implications of the water takings on specific aspects of the flow regime (see 7.5.1.3 to 7.5.1.8).
8. Expected impacts to physical hydraulic habitat estimated by relating the results from the IHA and RVA analysis with hydraulic modeling results (see 7.5.1.9).
9. Expected impacts to sediment transport and channel morphology estimated by relating change in flows to exceedance of geomorphic thresholds (see 7.5.1.10).
10. Establishment of hydraulic threshold such as flows needed to maintain connectivity.
11. Qualitative assessment of potential impacts based on life cycle requirements of specific species (see 8.4).
12. Assessment of above information to formulate a water taking strategy.

It is expected the above investigation would be completed on indicator reaches in areas of concern.

9.3 Components of Scaling Up to a Watershed Strategy

The components of the pilot study need a method for scaling up to a watershed strategy. Information that was retrieved for the pilot study is often difficult to obtain or time consuming to process. The following section will detail the process to generalize the components from a pilot study to apply ecological flow requirement techniques across an entire watershed.

9.3.1 Water Takings

First, the watershed strategy needs to recognize two types of concerns that can arise from takings:

1. Site specific or reach specific impacts often associated with large takings;
2. Cumulative impacts that can arise from cumulative takings in a reach or sub-watershed or an adjacent subwatershed.

Both concerns need to be considered when assessing a water taking. Assessing cumulative taking impacts is more difficult than the assessment of single discrete takings. Additional information needs to be included in the PTTW database to facilitate the assessment of cumulative takings. The additional information required includes the following:

1. Actual taking
2. Time frame or time series of actual taking or takings
3. Sources of actual takings beyond just groundwater and surfacewater.
4. Groundwater sources need to be linked to regional groundwater aquifers that are classified as either a deep, intermediate or shallow systems. An expected discharge location or area needs to be associated with these regional aquifers. This information is necessary to link the taking to expected points of impact. For example, does the regional aquifer where the taking occurs discharge locally or in the adjacent watershed?
5. There must be sufficient information to construct a time series of actual and potential takings that can be use to create an adjusted streamflow series in reaches of interest or concern. This requires knowledge of the actual water taking, the sources of the water taking and the discharge location of the source that would be affected. A modeling approach may have to be used to simulate flows in some areas as an alternative, until better observed information becomes available.

The above information is needed to create a framework to assess and manage cumulative impacts associated with water takings.

Areas of Concern – Potential High Impact Areas

The level of assessment must be issue driven. A single solution doesn't fit all areas. What this implies is a scoping exercise is needed to identify potential high impact areas where potential for impact is highest. Potential high impact areas would require a higher level of investigation to establish water-taking thresholds.

Another area of concern is regulated reaches of rivers. If takings and assimilative capacity have become dependent on regulation, cumulative takings in the regulated reaches need to be considered to properly assess the required conditions attached to the takings.

To identify areas of concern, it is expected the following process would be followed:

1. Plot surfacewater and groundwater maximum permitted takings with proportional size dots. This map will quickly identify where the water used is highest in a watershed. An example of the type of information that is now available across Ontario is seen in Figure 6.1, as the PTTW database is in digital format.
2. Some filtering of the PTTW information is needed to weed out specific takings. An example of a single-use taking is the Ducks Unlimited Ponds permits. The document titled "Lifting Ontario's Permit to Take Water Moratorium: A Method for Assessing Water Use in Ontario Watersheds" (AquaResouces Inc., 2005) may be of assistance in this regard. Some work has been completed to filter or refine the PTTW database in this report.
3. Once Permits To Take Water have been further assessed, refine the map to identify the size of the taking and it geographic location. A map is an effective means of completing this exercise. This should allow specific potential high impact areas or areas of concern to be identified in given watersheds.

Areas of Concern – Regulated Reaches

Regulated reaches where reservoirs may provide a high degree of regulation may need to be considered depending on the degree of regulation or objective of the reservoir. Figure 2.6 illustrates the regulated reaches in the Grand River watershed. Two sample questions that can be asked to determine this point are the following;

1. Is flow augmentation or regulation an operating objective of the reservoir?
2. Are certificates of approvals contingent on regulated flows?

Both Certificate of Approvals and municipal surfacewater takings assume a specific degree of flow augmentation from major reservoirs (i.e. minimum low-flow targets). The process to characterize these areas of concern is as follows:

1. Identify regulated reaches.
2. Identify dependencies on regulated reaches.
3. Identify takings along or adjacent to regulated reaches. This is difficult to accomplish with the current PTTW database. A crude estimate can be made by selecting a buffer along the regulated reach (e.g. 1 km), and organizing permits within this buffer. Ultimately, it would be preferable to link PTTWs that affect the regulated reach to the reach where the cumulative impact assessments is being completed.

4. Permits along regulated reaches may need to be organized for the permits that may be part of a large systematic approach such as a watershed plan or environmental assessment.

In the Grand River watershed, an example of Point 4 would be the reservoir takings which were considered as part of the Grand River basin study. These takings along with municipal takings and the Certificate of Approvals attached to sewage treatment plants along the regulated reaches of the Grand River, Speed River and Conestogo River all have interrelated dependencies, and therefore should be viewed differently from other permitted takings along regulated reaches.

Organization of Permit to Take Water Information – Cumulative Analysis

After reviewing and refining the PTTW information above a reach of concern or interest, the PTTW information needs to be organized to facilitate analyzing and managing cumulative impacts. The following steps are required:

1. Where possible, characterize the groundwater takings based on local knowledge as either shallow, intermediate or deep and where the expected impact of the taking would be realized. This is difficult to accomplish at present given the groundwater takings are not linked to the water wells and the water wells are not linked to an aquifer. However, this is needed to properly manage and assess cumulative impacts associated with water takings.

2. Organize surfacewater and groundwater takings to facilitate reached based assessments where upstream cumulative takings can be considered in context with local takings to facilitate completing reach based assessments.

This approach applies equally to regulated and unregulated reaches. Although current information bases limit the approach at the present time, this should be the ultimate goal. Accomplishing the approach requires an overall water framework to organize the necessary information. Some good work to refer to has been completed by the Province of British Columbia (British Columbia Ministry of the Environment 1996). The Watershed Atlas for this province developed a coding system to uniquely identify any point along a watercourse in the context of the overall watershed upstream and downstream. This approach offers a framework to uniquely identify takings for example and relate their dependencies to a source and flow system. This approach would have to be further developed to accommodate the groundwater flow system and permitted takings. This type of approach would require a multi-ministry and agency effort to organize. Given the need for a framework to organize information being developed as part of source water protection, it is timely to consider this approach.

9.3.2 Qualitative Assessment of Impacts Associated with Water Takings

To facilitate a qualitative assessment of potential biological impacts associated with water takings, two charts of life cycle requirements of four different fishery species have been developed (see Figures 4.2 and 4.3). These charts are intended to aid in conducting qualitative assessments of potential impacts by indicating the life cycle requirements at different times of the year. Charts could be developed for other aquatic organisms or considerations that could be used to scope potential impacts associated with water takings. The qualitative scoping could be used to assess the need for more detailed investigation.

The appendix discussing the effects of channel shape and hydraulic characteristics (Appendix C) is also intended to support qualitative assessments by inferring what sensitivities a particular channel shape may have with respect to changing water levels.

9.4 Transferring Instream Flow Requirements to Ungauged Locations

Transferring instream flow requirements or flow information to ungauged locations requires careful consideration of the underlying physical characteristics that influence flow and sediment transport in a given area.

A summary of key factors affecting water taking sensitivity are shown in Figure 9.1.

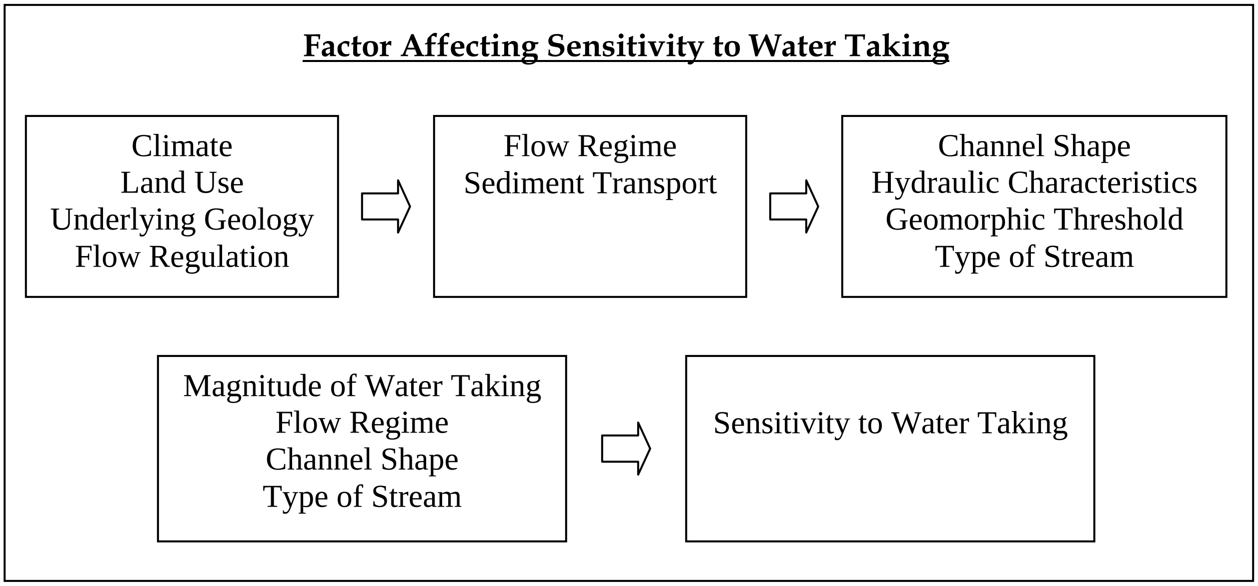


Figure 9.1 Factors affecting water taking sensitivity

Physiographic Units

Based on underlying geology, climate, land use and flow regulation, a watershed can be classified into areas with similar characteristics, called physiographic units. Selected indicator gauges can be picked to represent these classified areas that could be used to transpose flow characteristic or gauged information to ungauged locations. Ideally detailed analysis would be completed at indicator gauges, which should include geomorphic and detailed hydraulic investigations. Detailed information such as flow statistics, geomorphic thresholds and reach level instream flow thresholds at the indicator gauge could be transposed to ungauged locations, using drainage area to normalize the information. It is expected that there should be a good correlation between the flow regime response and the local geology/physiography. If there is good correlation, general unit area streamflow statistics could be related to dominate geologic/physiographic units. The transposed information could then be used to scope the magnitude of issues at ungauged locations. Scoping the magnitude of the issue at the ungauged location would determine the need for additional site-specific investigation.

The streamflow statistics would be used to complete a desktop scoping of the available flow in given areas, with Tessmann being the expected method to be used at this level of scoping to estimate the instream flow needs and the amount of water that may be available. Monthly normalized statistics will be needed to support this effort. Depending on the extent of single taking or cumulative use in a given area the level of detail for further investigations would be scoped. In potential high impact areas, it is expected that detailed hydraulic surveys would be completed to estimate thresholds to partition flows needed for the environment and flows available for human use. Staff gauges would be located on these reaches to assist takers; monitors could be established at staff gauge (Solist Loggers) to monitor compliance/effectiveness of water taking strategy.

Some programs exist to estimate flow characteristics at ungauged location; the *Ontario Flow Assessment Techniques* is one example. The OFAT program is a GIS-based tool that allows efficient estimates of watershed characteristics upstream of a user-defined point of interest. This tool allows the user to estimate flow characteristics/statistics at a user-defined point of interest. The flow statistics generated by OFAT are based on regional empirical models.

Caution must be used when applying the OFAT program to generate flow statistics. Regionally based empirical flows statistics may vary by orders of magnitude from actual observed statistics. Several of the regional models were developed prior to the availability of GIS and the information layers currently available and need to be revisited. Regional empirical models may also neglect the effects of regulation by large reservoirs. The OFAT tools appear to be able to estimate mean annual flow with some degree of accuracy, however this would have to be confirmed for different areas.

A more reliable approach would be to use the indicator gauges selected to represent different areas of the watershed in combination with OFAT to estimate physical watershed characteristics at the indicator gauge and the ungauged location. Information at the indicator gauge site could be transposed to the ungauged site using drainage area or a combination of drainage area and other physical characteristics to prorate information between the indicator site and the prorated site (as in Figure 9.2).

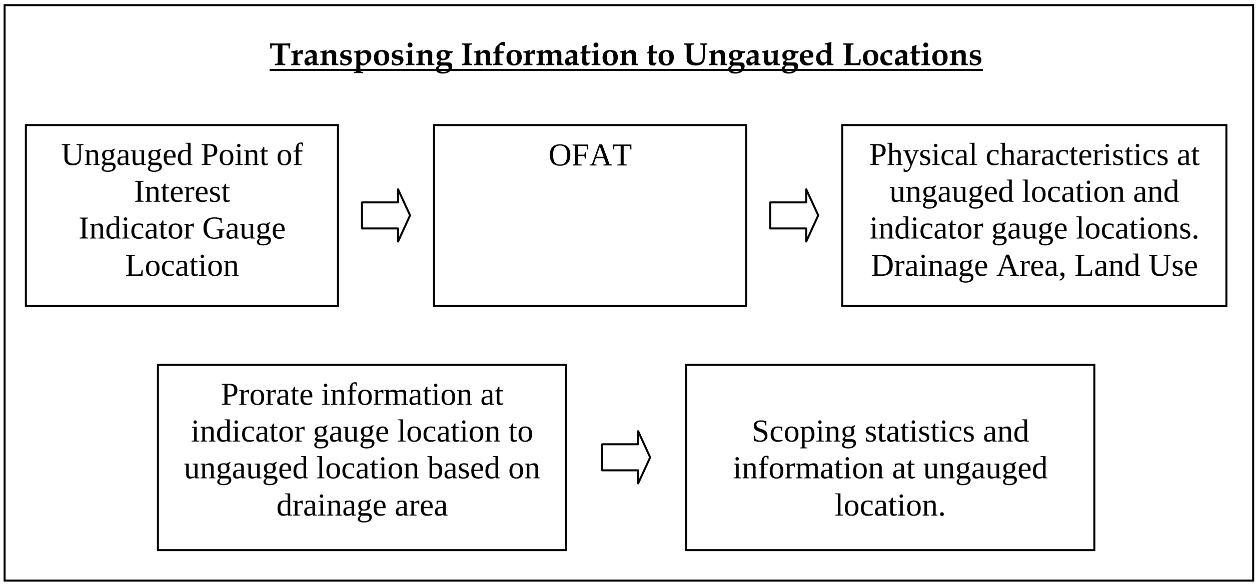


Figure 9.2 Factors affecting water taking sensitivity: ungauged locations

To facilitate development of information at stream gauge sites, Water Survey of Canada should be approached. Developing detailed hydraulic models and geomorphic relationships at selected gauge stations operated by WSC would help leverage flow information collected at WSC sites and help confirm reliability of rating curves at these sites. There is general interest from WSC managers. The MOE may wish to pursue discussions with WSC to investigate opportunities to develop geomorphic and hydraulic models in an effort to expanded/develop the information base used to establish instream flow thresholds. Gauge sites should be selected strategically to cover off discrete physiographic units and areas of concern.

9.5 OFAT Results

The *Ontario Flow Assessment Techniques* is an automated tool for estimating flow information for watersheds in Ontario. It is currently used by both the MNR and MOE to support their projects and programs. With OFAT, any location along a watershed can be computed in the interactive GIS-based software to determine low and high flow statistics with a number of existing hydrologic models automated into the software. OFAT can also compute mean annual flows, Tennant minimum instream flow requirements and bankfull flows for any subwatershed in Ontario. The software delineates a watershed for any outlet point selected by the user, and watershed parameters are calculated including a summary of watershed information, and flow information such as low-flow, high flow and bankfull parameters. These OFAT-generated values are used to compare to the values taken at the gauged sites to determine the accuracy of the model. This accuracy can then be used as a baseline for determining whether this model can be used at other, ungauged sites in the watershed. For instance, some parameters that OFAT calculates are good estimates of the watershed conditions, however other estimates are not as reliable. Water Survey of Canada gauges were selected as the outlet of a subwatershed across the Grand River watershed to determine the various streamflow data for the Grand River and its tributaries.

9.5.1 Flood Flow Estimates

OFAT calculations for flood flows include a variety of different return period flood values. The flood estimates from OFAT are generated from a number of different flood prediction models (see Appendix H), which were compared to values calculated from actual observed data from stream gauges in the study reaches. The maximum and minimum values from the OFAT flood prediction models are given in Table 9.1.

For the higher flood flow estimates, the OFAT models are reasonably similar to the GRCA estimates. However, the range of values is quite wide and extreme values are often significantly different from the GRCA estimate. For the lower half of flood estimates, OFAT values are much higher than the GRCA estimates.

9.5.2 Low-flow Estimates

Low flow estimates for the pilot reaches use the 7Q statistics for comparison. There are several different low-flow prediction models generated in OFAT. The maximum and minimum flows are listed in Table 9.2. Please see Appendix H for more detailed information.

The regulated reaches values have substantially higher OFAT estimates, while the other smaller reaches have higher but less prominent differences in the GRCA versus OFAT estimates. The significantly higher estimates in the regulated reaches are due to the moderating effect of dams that retain a minimum flow requirement during the low-flow season.

9.5.3 Instream Flow Needs Estimates

The Tennant Method (Tennant, 1976) estimates were the calculations given by OFAT for instream flow needs. The values of the different categories are shown in Table 9.3, along with the GRCA calculated values, based on the mean annual flow. The OFAT numbers are very reasonable estimates of the actual values as the mean annual flow estimates are very similar.

The final two columns were a check of the Tennant flushing flow estimated by OFAT, and the comparison to the D_{50} bed mobilizing flow as estimated by Parish Geomorphic during their fieldwork.

Table 9.1 Flood flow calculations in comparison with OFAT estimate ranges

Return Period (Years) Flow in m^3/s	1.25		2		5		10		20		50		100	
	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT
Grand at Blair	249	478.33 486.84	387	309.21 1084.5	597	441.86 1590.6	747	531.4 1897.6	899	617.24 2179.4	1110	644.53 2535.6	1270	728.92 2794.4
Exceptional Waters Upstream	417	792.97 807.07	610.56	489.42 1798.3	912.96	699.38 2645.2	1132.8	841.11 3161.9	1353.6	976.98 3634.1	1660.8	1020.2 4229.3	1910.4	1153.7 4659.8
Exceptional Waters Downstream	434	853.83 869.01	636	523.43 1922.6	951	747.97 2820.5	1180	899.55 3368.9	1410	1044.9 3868.8	1730	1091.1 4497.6	1990	1233.9 4952.1
Nith River at Canning	142	217.5 221.36	209	151.12 422.63	295	215.94 609.89	350	259.7 723.42	401	301.65 826.63	465	314.99 955.02	513	356.23 1048.1
Eramosa River	15.2	64.92 66.08	25.9	42.35 72.14	36.6	63.02 98.34	41.3	75.73 120.47	44.5	87.31 142.07	47.2	101.96 167.94	48.6	112.41 193.15
Blair Creek	1.04	6.199 6.309	1.61	4.977 6.888	2.31	8.451 10.51	2.73	10.251 13.26	3.11	11.116 15.904	3.57	12.434 19.385	3.91	14.062 22.012
Whitemans Creek	33.4	98.89 100.65	49.2	73.85 112.02	64.6	105.53 159.05	72.6	126.92 188.12	79.1	147.42 244.96	86.4	153.93 249.09	91.2	174.09 331.96
Mill Creek	3.76	26.27 29.19	5.29	15.44 39	7.26	23.82 46.24	8.49	29.94 52.93	9.62	36.05 62.39	11.00	41.62 69.07	12.00	46.88 76.87
Carroll Creek		15.8 16.1		13.3 26.1		20 37		24 43.3		27.9 48.9		29.1 55.8		32.9 60.6

Table 9.2 Low-flow comparison with OFAT estimates

Statistic	7Q2		7Q5		7Q10		7Q20		7Q50		7Q100	
Flow in m^3/s	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT
Grand at Blair	10.05	2.9 3.32	6.93	1.77 2.3	5.34	1.36 1.9	4.461	1.16 1.62	3.715	0.97 1.37	3.35	0.9 1.24
Exceptional Waters Upstream	17.57	5.24 6.22	13.51	3.21 4.27	11.77	2.46 3.52	10.51	2.1 2.99	9.25	1.75 2.54	8.49	1.63 2.31
Exceptional Waters Downstream	17.98	5.72 9.36	15.47	3.5 6.63	14.3	2.68 4.51	13.4	2.29 3.69	12.45	1.91 3.13	11.86	1.78 2.64
Nith at Canning	2.103	0.88 0.88	1.676	0.56 0.71	1.494	0.44 0.55	1.37	0.35 0.47	1.26	0.28 0.39	1.203	0.25 0.36
Eramosa River	0.49	0.312 0.621	0.32	0.191 0.48	0.24	0.146 0.424	0.18	0.125 0.383	0.12	0.104 0.351	0.08	0.097 0.333
Blair Creek	0.13	0.02 0.06		0.014 0.04		0.01 0.03		0.009 0.025		0.008 0.021	0.08	0.007 0.019
Whitemans Creek	0.609	0.4 0.49	0.37	0.23 0.3	0.268	0.17 0.23	0.198	0.13 0.19	0.135	0.1 0.16	0.103	0.09 0.15
Mill Creek	0.27	0.14 0.17	0.19	0.08 0.12	0.13	0.06 0.09	0.16	0.06 0.1	0.11	0.05 0.08	0.09	0.04 0.08
Carroll Creek		0.056 0.096		0.04 0.059		0.034 0.045		0.029 0.038		0.025 0.032		0.022 0.03

Table 9.3 OFAT comparison of Instream Flow Needs based on Tennant method

Instream Flow Need (m^3/s)	Outstanding		Excellent		Good		Fair		Fair to Poor		Poor		Mean Annual Flow		Flushing Flow	
	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT	GRCA	OFAT
Grand at Blair	19.40	17.47	16.17	14.56	12.94	11.65	9.70	8.74	3.23	2.91	3.23	2.91	32.34	32.34	187.00	58.24
Exceptional Waters Upstream	35.08	31.375	29.24	26.146	23.39	20.917	17.54	15.69	5.85	5.229	5.85	5.229	58.47	52.29	161.00	104.58
Exceptional Waters Downstrm	37.28	34.30	31.06	28.59	24.85	22.87	18.64	17.15	6.21	5.72	6.21	5.72	62.13	57.17	161.00	
Nith at Canning	6.80	6.79	5.67	5.66	4.54	4.53	3.40	3.40	1.13	1.132	1.13	1.132	11.34	11.32	18.30	22.64
Eramosa River	1.49	1.55	1.24	1.29	0.99	1.04	0.74	0.78	0.25	0.26	0.25	0.26	2.48	2.59	21.83	5.178
Blair Creek	0.144	0.089	0.12	0.074	0.096	0.059	0.072	0.045	0.024	0.015	0.024	0.015	0.24	0.297	0.32	0.297
Whitemans Creek	2.62	2.634	2.19	2.20	1.75	1.756	1.31	1.317	0.44	0.44	0.44	0.439	4.37		3.06	8.78
Mill Creek	0.54	0.53	0.45	0.44	0.36	0.35	0.27	0.26	0.09	0.09	0.09	0.09	0.90	0.8795	1.05	1.74
Carroll Creek		0.279		0.232		0.186		0.139		0.046		0.046		0.465		0.93

Note: Tennant Flushing flow is compared to the *Parish Geomorphic* D_{50} bed mobilizing flow

Table 9.4 Comparison of OFAT mean annual flows to actual data

Flows (m^3/s)	Mean Annual Flow	
	GRCA	OFAT
Grand at Blair	32.34	32.34
Exceptional Waters Upstream	58.47	52.29
Exceptional Waters Downstrm	62.13	57.17
Nith at Canning	11.34	11.32
Eramosa River	2.48	2.59
Blair Creek	0.24	0.297
Whitemans Creek	4.37	4.39
Mill Creek	0.90	0.8795
Carroll Creek		0.465

9.5.4 Summary of OFAT Results

The OFAT tool appears to do a reasonable job of estimating mean annual flow. Given that the mean annual flow is used to estimate the Tennant and Tessmann statistics, OFAT does a reasonable job of estimating these statistics. High flow, low flow and bankfull flow statistics estimated using OFAT show a great deal more variability. This not a limitation of OFAT, but is a limitation of the underlying regional models OFAT uses to estimate these statistics. The Province should give consideration to updating the regional models used in estimating flow statistics. Several of these regional models were developed prior to modern day GIS technology and could benefit from current day technologies.

9.6 Monitoring

The need for monitoring at sites where stream gauges are in place is strongly recommended. Detailed geomorphic cross sectional profiles should be completed to monitor the site for changes in the hydraulics of the reach. The geomorphic cross sections are also then available for updated information input to hydraulic models such as HEC-RAS to estimate instream flow relationships. Monitoring on a regular basis will allow for more accurate hydraulic modeling results and allow for further understanding and calibration to the changing hydraulic parameters in the study reach. Geomorphic studies such as the process taken by *Parish Geomorphic*, which consider the instream flow requirements of the system, should be undertaken. This would involve a minimum of 3 cross sections per study reach, collecting bankfull measurements, substrate data and bank characteristics (vegetation and shear stress). Generally, ten cross sections were taken per study reach for this pilot study. With the field data, thresholds that should be calculated include the bankfull flow, bed mobilizing flow (D_{50}), flushing flow, and residual pool flow thresholds. Please refer to the *Parish Geomorphic* reports (under separate cover) for further detail on collection and processing of data for geomorphic thresholds.

10.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter lists the conclusions from the pilot study on instream flow requirements in the Grand River watershed. Recommendations to further ecological flow assessment in the Grand River Watershed and the Province of Ontario immediately follow the conclusions from which they arise. Conclusions and recommendations are categorized into three topics: instream flow approaches, hydraulic and geomorphic studies, and biological monitoring, for a more focused summary of the results. The Ministry of the Environment should be complimented for demonstrating leadership in this area by initiating these studies. This will likely be looked back on as a key turning point in environmental management in Ontario.

10.1 Conclusions and Recommendations from the Grand River Study

Instream Flow Approaches

1. A range of approaches, from simple to sophisticated, were tested for instream or ecological flow assessment in 8 pilot reaches in the Grand River watershed. In some cases, these approaches gave results that were in agreement with each other, but in other cases different approaches yielded different results and threshold values. Simple approaches to establishing or estimating instream flow needs were not found to be suitable for all types of reaches. For instance, groundwater driven reaches have dampened flow variability and methods such as the Tessmann method yield estimates which do not make sense.

Recommendation: The level of investigation, and the approaches used, should be geared to the issues, or potential issue, and characteristics of the stream system. An inter-disciplinary approach and application of multiple tools can provide converging lines of evidence and reduce uncertainties.

2. Simple approaches that exist from the USA infer ecological needs from flows, however these methods have not been validated in Ontario. They may be used as a starting point; however commitments should be made to monitor their hydrological and biological efficacy. For instance, simple hydrologic methods such as the Tessmann and Tennant methods are used to specify instream flow needs, but have not been validated in Ontario, particularly with respect to long-term biological response.

Recommendation: The MOE should pursue further testing of the Tessmann approach in different southern Ontario watersheds. When considering test sites for these methods, they should ideally be sited in distinct physiographic areas with the view to potentially regionalize these methods. Different orders of streams should be investigated in each physiographic area. This work is best completed through research at university institutions. Studies should be inter-disciplinary and at a minimum must include direct assessment of flow regimes, invertebrate and fish communities and the connectivity between the three, for a period of several life cycles.

Also, the Tessmann method is a relatively simple desktop procedure and therefore should only be used to scope issues or used as a guide to indicate where further investigation is required. It should not be used as the sole determining basis for instream flow requirements or with respect to the issuance or denial of a PTTW.

Recommendation: Specifying minimum flows for a reach requires a nested approach. This approach should include the following:

a. A check with high-level scoping or for orders of magnitude difference should constitute the initial assessment step, with specific emphasis placed on the completion of a cumulative takings assessment.
b. When observed streamflow is not available everywhere; pro-rating streamflow based on common physiographic units is one level of verification. This level of verification should include a characterization of the flow regime and flow characteristics in the area of the proposed taking (i.e. is it a baseflow driven system, runoff driven system or other flow regime)
c. The taking should be related to the flow regime and how the taking is expected to affect the flow regime (considerations include baseflow period, high flow period, intermediate flow period). The taking should also be related to knowledge of the flow requirements of resident biota where such knowledge, at a minimum, should include minimum depths required to maintain habitat connectivity and flows required to maintain non-stressing thermal regimes and sufficient redd oxygenation.
d. Reach-level investigations should be an expectation based on the magnitude of the taking, with respect to the source and cumulative nature of takings in a given reach.
e. Where a large number of takings exist in a given reach, there may be economies of scale to consider when having the reach level investigation completed (Whitemans Creek as an example).
f. Where there are a large number of takings, the cumulative biological effect of those taking should be assessed on an ongoing basis to ensure the maintenance of aquatic ecosystem integrity.

3. Long-term monitoring is the underpinning of good defensible science. The completion of some of the work in this report would have been unattainable without good long-term flow data sets. However, biological monitoring and good research data into aquatic ecosystems are still lacking.

Recommendation: The commitment to maintaining good flow records, stream gauges and hydraulic measurements needs to be continued for streams in different physiographic regions of the Province of Ontario. The collection of this data is the basis for many different projects and studies, not just for instream flow studies and should be maintained for the commitments to proper water management. Long-term biological monitoring data sets are needed to complement flow and hydraulic information.

4. A single minimum flow is not sufficient to adequately describe the natural environment’s water needs. Water supplies are dynamic; streamflows vary within the

year and between years. Focusing solely on summer low-flow needs may overlook the implications of takings during the early spring period. For example, the frequency of out-of-bank flows is important to riparian zone replenishment, and may be triggers for certain life stages of fish. In a given stream, it may also recharge shallow aquifers adjacent to the stream and redistribute riparian material such as woody debris, which is needed to create instream habitat.

Recommendation: The MOE should consider the entire natural flow range requirements of the environment when attaching conditions to Permits to Take Water. A range of flows and thresholds is needed to properly describe the environmental flow requirements. Takings need to consider the variability of supply and the associated variability of flow required by biota to complete their life cycles in affected streams and rivers. This implies that water taking conditions attached to Permits to Take Water must be variable and scaled to the availability of supply and the needs of the environment. The MOE should consider specifying variable takings linked to both the availability of supply and variability of the natural environment's flow requirements.

5. There are two good examples given in the report of how to integrate instream flow requirements into the conditions attached to the Permits to Take Water. The City of Guelph Arkell water taking and the Region of Waterloo surfacewater taking (see Section 7.5.6.4) are good examples of permits that contain conditions that link the taking to the availability of the source. The City of Guelph permit contains a cut-off flow below which takings are not permitted.

Recommendation: The conditions and temporal aspect of the Permits to Take Water for the Guelph Arkell and Region of Waterloo permits should be used as models to set conditions for future PTTW applications. Consideration should be made to the timing and seasonal requirements of the aquatic ecosystem when issuing permits.

6. A major barrier to analyzing the potential impacts of water takings is the structure and information content of the PTTW database. The current database does not include sufficient information to link groundwater takings to particular aquifers and discharge locations and does not include sufficient information regarding actual takings. This information is necessary to properly consider the potential impacts of cumulative takings above a given reach of interest.

Recommendation: The structure and organization of information in the PTTW database needs to be refined to link takings to discrete sources and link the sources to the discrete discharge points they impact (refer to Section 9.3.1 for method). In addition, the PTTW database needs to be reviewed and revised to include additional information needed to support cumulative impacts and better reflect actual takings during the course of the year.

7. Potential high impact watersheds and cumulative impacts of water takings are a concern in some areas of Ontario. A framework is needed to organize Permit to Take Water information with physical watershed information to facilitate cumulative impact assessment.

Recommendation: Requirements for instream flow recommendations should be harmonized with current initiatives by the MOE to identify potential high impact watersheds. The MOE should consider completing a pilot study to test existing models such as the DHI MIKE BASINS software (DHI Water and Environment, 2002), on a selected potential high impact area in southern Ontario, to investigate its ability to assess cumulative water takings above a given reach of interest. The DHI MIKE BASINS software may offer the necessary framework to organize taking information to facilitate cumulative impact analysis.

8. In studies completed in the United States, communication has been identified as an important component of an instream flow program. In Ontario, the existence of multiple, distinct water conservation programs hinders effective communication. There is a need for better integration of Ontario's various water management programs.

Recommendation: The MOE and MNR should hold discussions to investigate integrating instream flow requirements into the Ontario Low Water Response Program. The OLWRP could fulfill the communication role and more integrated consideration of Ontario Low Water levels, PTTW conditions and instream flow requirements could be achieved. Other options that could be explored are integrating instream flows with land use initiatives such as land use planning and stormwater management.

9. In areas where historical water takings are established in a watershed, and a full range of management options have been explored, it may be necessary to accept some degree of ecosystem degradation. For example, the Whitemans Creek watershed is a region where takings are already impacting the natural flow regime. Two key approaches are typically used that consider an acceptable level of degradation (i.e. social and economic considerations): the increment needs and the building block method. These methods suggest a balance between human and ecological needs, to limit the degree of alteration from the natural flow regime. For instance, maintenance of the connectivity between pools could be the minimum objective to achieve initially in Whitemans Creek

Recommendation: The MOE should develop a process or guidelines for potential high impact areas, indicating the components of detailed local instream flow studies and the process for establishing the minimum flows that must be maintained. Both methods need to be considered, and in areas where historical takings are in place, a level of degradation may need to be selected as the minimum objective that should be achieved in these cases and takings managed to that end. More detailed study will be required to assess options that may be used to raise the minimum objectives over time, while balancing social and economic considerations.

10. There is a wealth of knowledge already established with regard to instream flow needs including a variety of methods, models and thresholds for calculation. Understanding and synthesizing all the information is difficult and it can be a daunting task to decide where to begin. The quality of an instream flow study is dependent on the careful selection of approaches and models to suit watershed conditions, issues and data available.

Recommendation: The MOE should consider holding workshops or training sessions on the topic of instream flow needs and its related components. This would facilitate the incorporation of instream flow needs into subwatershed studies and other surfacewater management studies for a complete assessment of the ecological effects from water takings. A forum could be held gathering all interested parties and the research community on ecological flow requirements to facilitate the introduction and training for new studies across the province.

Hydraulic and Geomorphic Studies

11. Geomorphic analysis is often completed independent of detailed hydraulic modelling or detailed flow analysis. Both flow and geomorphic thresholds were considered in this study when establishing environmental flow needs, in order to respect sediment transport processes that maintain stream form, habitat and riparian zone replenishment. Investigation of the changes in hydraulic parameters due to changes in flow was completed with the HEC-RAS hydraulic model. This model proved its ability to recreate the surveyed water surface profile once calibrated with geomorphic fieldwork. The HEC-RAS model provides a reliable representation of the actual conditions and the suite of hydraulic variables that can be generated in the model are also thus more reliable. This suggests that hydraulic models could be a means of estimating critical flow ranges in the absence of long-term flow data.

Recommendation: Integrating information from calibrated hydraulic models and streamflow analysis with traditional approaches used to estimate geomorphic thresholds offers the ability to develop more robust, defensible geomorphic thresholds and helps integrate hydraulic and geomorphic processes. A full range of flow, geomorphic, hydraulic and biotic requirements is needed to be specified over an appropriate time scale for specific instream flow requirements. Hydraulic models such as the HEC-RAS model can be constructed and calibrated from cross sections and water profile information collected as part of geomorphic surveys.

12. The initial collection of geomorphic cross sections for this study was often supplemented with additional cross sections in the same reach to ensure that the full range of flows could be represented. It became apparent during the study that properly capturing riffle hydraulics is challenging, as riffles can often be diagonal or curvilinear in shape during low flows and slowly inundated as flows increase. To complicate the issue, established geomorphic protocols for gathering cross sections often focus on the high flow parameters. However, low flow information also needs to be collected in riffle sections of the reach to fully understand the hydraulic tendencies.

Recommendation: Special attention must be paid to properly representing riffles in low-flow hydraulic models. To properly represent the hydraulics of a riffle, cross sections are needed upstream and downstream of riffles as well as a cross section that follows the crest of the riffle. Conversely, overwhelming a reach with cross sections does not necessarily add additional value or knowledge to a study; a finite number of carefully selected cross sections can yield the same level of information as blanketing an area with cross sections. Provincial standards and protocols should be established regarding the collection of geomorphic and low-flow hydraulic model information to facilitate the calculation of geomorphic thresholds and hydraulic instream flow thresholds.

13. Observed streamflow information may not exist where takings are desired. Results of this study suggest hydraulic investigations, conducted in a proper manner, can yield useful information to make decisions for a given reach.

Recommendation: Hydraulic information must be supplemented with streamflow observations and hydraulic checks to confirm the reliability of the hydraulic model estimates over the range of flows at which the taking may be active.

14. The *Indicators of Hydrologic Alteration* software, distributed by the Nature Conservancy in the USA, is a useful diagnostic tool. It provides a framework to analyse the impacts water takings may have on flow or hydraulic habitat variables.

Recommendation: The abilities of the IHA software should be utilized in other instream flow studies as a diagnostic tool. The MOE should consider holding a workshop to demonstrate the IHA software and RVA method to interested parties. Model authors should be brought in from the USA and a workshop held to build local capacity in southern Ontario for applying the IHA software and RVA method.

15. The *Ontario Flow Assessment Techniques* software gives reasonable estimates of mean annual flow, yet gives quite a bit of variability on high flow, low flow and bankfull statistics. The limitation of the OFAT tool is that the regional models pre-date the current capabilities of GIS technology.

Recommendation: The MOE and MNR should discuss updating and refining the regional flow models in the OFAT tool. The possibility of improving estimates from these regional models using modern GIS capabilities should be investigated. Also, it is suggested that the DEM in the OFAT tool be updated to ensure the most recent data is available for analysis.

16. To facilitate incorporating geomorphic thresholds into OFAT, or potentially regionalizing geomorphic threshold information, additional geomorphic investigations should be completed at stream gauge sites throughout Ontario. Sites should be selected strategically in unique physiographic regions. Completing geomorphic assessments at existing stream gauge sites would leverage the Province’s investment in these sites.

Recommendation: Additional geomorphic analysis at selected stream gauge sites throughout Ontario should be completed to with the goal to investigate regionalizing geomorphic thresholds for unique physiographic areas throughout the province. This should be done through the MOE and discussions with the MNR and Environment Canada.

17. Channel shape can play an important role in the sensitivity of a river reach to water taking. Flows may be a conservative indicator for change in hydraulic habitat, and it is expected that this change may be dependent on channel shape. For instance, certain

channel shapes, such as an E-type channel, may hydraulically exhibit less of a response to changes in flow and potentially water takings, than a C-type channel.

Recommendation: Channel shape could be used at a scoping stage to qualitatively assess sensitivity to water taking. MOE should pursue further research into the relationship of channel shape to water taking sensitivity. This may be accomplished as a research topic through a university institution.

18. As illustrated in the discussion of channel shape in Appendix C (see especially Table C.1), depending on the shape of the channel, hydraulic inflection points may indicate flows that are below the water level needed to sustain flows in the littoral zone present in some channels, which provides suitable aquatic habitat locations.

Recommendation: The interpretation of hydraulic inflection points should also include the consideration of the shape of the channel. The littoral zone flow requirements for aquatic habitats should be a consideration in determining the low-flow thresholds in a reach.

Ecological Monitoring

19. Ecological responses to any kind of ecosystem perturbation are complex and influenced by numerous subtle compensating factors. Therefore, monitoring the response of the environment to takings is complex.

Recommendation: Monitoring will require an extended period of years to decades before adequate information exists to reliably characterize probable effects. Monitoring that spans several life cycles to cover the range of species present in Ontario streams is required to properly assess techniques and set scientifically defensible guidelines. Partnerships between the MOE and university researches should be established to continue research into means of monitoring biological response to low flows.

20. There was limited biological response information available for the study reaches in the Grand River watershed, other than at Whitemans Creek. Results of analyzing the biological response information for Whitemans Creek showed very poor correlation between low-flow periods or periods of heavy water taking and biological response.

Recommendation: Biological monitoring should be done using the stable isotope analysis method at select indicator monitoring sites to monitor biological response to low flows and water takings. Ideally, these sites should be nested with other water quality monitoring, benthic and flow monitoring information. Protocols should be set for monitoring using the stable isotope analysis or using another accepted approach of ecological response to water abstractions.

21. Aquatic organisms such as fish species have differing and variable requirements for flows over their life cycle. The hydrological life cycle requirements for certain fish species were illustrated in Figures 4.2 and 4.3. These figures were useful as a qualitative assessment of the variable needs of aquatic organisms for flow throughout the year.

Recommendation: For instances where an absence of biological response monitoring information exists, mapping out the life cycle requirements of different species found in Ontario streams, similar to Figures 4.2 and 4.3, should be produced by MOE and used as a qualitative tool to assess potential implications of takings on different species. Life cycle requirements of different fish species found in Ontario streams visualized in this manner could be used as a qualitative tool to assess potential implications of takings on different species. While the higher profile sport fish have been researched more intensively, there is a need for more research into other fish species that are found in Ontario watercourses, as they will have different requirements at different times of the year and are an important part of the ecology of these streams. This information may be best organized in an artificial intelligence type of software.

22. Although beyond the scope of the current study, habitat based modelling has its place. Where water takings are stressing a sensitive environmental reach or feature and trade-offs have to be considered, habitat based modelling is an approach that may be considered.

Recommendation: It may be useful to consider setting up a research reach in southern Ontario where a habitat-based modelling approach could be applied, such as PHABSIM, and expertise with its application could be developed.

23. Monitoring biological response is a complicated task requiring the incorporation of physical, non-biological aspects into the biological response. However, the collection of physical parameters such as temperature and chemical properties of water are often collected for a variety of reasons (i.e. water quality) and do not provide sufficient information for monitoring biological response to stress. Temperature, for example, varies considerably from site to site, throughout the water column and across any reach.

Recommendation: Temperature is a parameter that needs to be monitored at different locations throughout the watercourse, to account for various thermal habitats and aquatic requirements. There needs to be protocols set for where to collect temperature information instream, and how to correlate this to biological response to stress.

Need for Monitoring and Multiple Sampling

25. There are serious theoretical difficulties associated with attempting to determine critical thresholds for water abstraction or any stress-response relationship. Multi-site and multi-year studies have the potential to elucidate response patterns in index systems and to provide critical factual information that will aid managers in determining appropriate flow levels for varying stream/river types. One identifiable shortfall in the completion of hydrology and ecology studies to date is that there has yet to be a study that has specifically coupled hydrological control with measurements of biological response, yet the information from such a study is precisely what is require to adequately manage surface waters for ecological sustainability.

Recommendation: It is doubtful that anything but a concerted multi-year study will yield the information necessary for making informed water management choices given the complexities of intra- and inter-annual variability and taxonomic diversity. Accordingly, it is recommended that hydrologically controlled experimental studies, conducted over multiple years and at multiple sites, be used to appropriately determine ecological thresholds for water abstraction.

10.2 Summary of Recommendations

10.2.1 Future and Continuing Studies

Future studies on instream flow requirements may want to consider these following recommendations:

1. The level of investigation should be geared to the issue or potential issue. Instream flow studies will require inter-disciplinary approaches and at a minimum, must include direct assessment of flow regimes, invertebrate and fish communities and the connectivity between the three, for a period of several life cycles.
2. Specifying minimum flows for a reach requires a nested approach. This approach should include the following:
    g. A check with high-level scoping or for orders of magnitude difference should constitute the initial assessment step, with specific emphasis placed on the completion of a cumulative takings assessment.
    h. When observed streamflow is not available everywhere; pro-rating streamflow based on common physiographic units is one level of verification. This level of verification should include a characterization of the flow regime and flow characteristics in the area of the proposed taking (i.e. is it a baseflow driven system, runoff driven system or other flow regime)
    i. The taking should be related to the flow regime and how the taking expected to affect the flow regime (considerations include baseflow period, high flow period, intermediate flow period). The taking should also be related to knowledge of the flow requirements of resident biota where such knowledge, at a minimum, should include minimum depths required to maintain habitat connectivity and flows required to maintain non-stressing thermal regimes and sufficient redd oxygenation.
    j. Reach-level investigations should be an expectation based on the magnitude of the taking, with respect to the source and cumulative nature of takings in a given reach.
    k. Where a large number of takings exist in a given reach, there may be economies of scale to consider when having the reach level investigation completed (Whitemans Creek as an example).
    l. Where there are a large number of takings, the cumulative biological effect of those taking should be assessed on an ongoing basis to ensure the maintenance of aquatic ecosystem integrity.
3. Integrating information from calibrated hydraulic models and streamflow analysis with traditional approaches used to estimate geomorphic thresholds offers the ability to develop more robust, defensible geomorphic thresholds and helps integrate hydraulic and geomorphic processes. A full range of flow, geomorphic, hydraulic and

biotic requirements is needed to be specified over an appropriate time scale for specific instream flow requirements. Hydraulic models such as the HEC-RAS model can be constructed and calibrated from cross sections and water profile information collected as part of geomorphic surveys.

4. Special attention must be paid to properly representing riffles in low-flow hydraulic models. To properly represent the hydraulics of a riffle, cross sections are needed upstream and downstream of riffles as well as a cross section that follows the crest of the riffle. Conversely, overwhelming a reach with cross sections does not necessarily add additional value or knowledge to a study; a finite number of carefully selected cross sections can yield the same level of information as blanketing an area with cross sections. Provincial standards and protocols should be established regarding the collection of geomorphic and low-flow hydraulic model information to facilitate the calculation of geomorphic thresholds and hydraulic instream flow thresholds.
5. Hydraulic information must be supplemented with streamflow observations and hydraulic checks to confirm the reliability of the hydraulic model estimates over the range of flows at which the taking may be active.
6. The interpretation of hydraulic inflection points should also include the consideration of the shape of the channel. The littoral zone flow requirements for aquatic habitats should be a consideration in determining the low-flow thresholds in a reach.
7. Biological monitoring should be done using the stable isotope analysis method at select indicator monitoring sites to monitor biological response to low flows and water takings. Ideally, these sites should be nested with other water quality monitoring, benthic and flow monitoring information. Protocols should be set for monitoring using the stable isotope analysis or using another accepted approach of ecological response to water abstractions.
8. For instances where an absence of biological response monitoring information exists, mapping out the life cycle requirements of different species found in Ontario streams, similar to Figures 4.2 and 4.3, should be produced by MOE and used as a qualitative tool to assess potential implications of takings on different species. Life cycle requirements of different fish species found in Ontario streams visualized in this manner could be used as a qualitative tool to assess potential implications of takings on different species. While the higher profile sport fish have been researched more intensively, there is a need for more research into other fish species that are found in Ontario watercourses, as they will have different requirements at different times of the year and are an important part of the ecology of these streams. This information may be best organized in an artificial intelligence type of software.
9. It may be useful to consider setting up a research reach in southern Ontario where a habitat-based modelling approach could be applied, such as PHABSIM, and expertise with its application could be developed.

10.2.2 Recommendations for Regulators and Decision-Makers

10. The MOE should pursue further testing of the Tessmann approach in different southern Ontario watersheds. When considering test sites for these methods, they should ideally be sited in distinct physiographic areas with the view to potentially regionalize these methods. Different orders of streams should be investigated in each physiographic area. This work is best completed through research at university institutions.

11. The MOE should consider the entire natural flow range requirements of the environment when attaching conditions to Permits to Take Water. A range of flows and thresholds is needed to properly describe the environmental flow requirements. Takings need to consider the variability of supply and the associated variability of flow required by biota to complete their life cycles in affected streams and rivers. This implies that water taking conditions attached to Permits to Take Water must be variable and scaled to the availability of supply and the needs of the environment. The MOE should consider specifying variable takings linked to both the availability of supply and variability of the natural environment's flow requirements.

12. The commitment to maintaining good flow records, stream gauges and hydraulic measurements needs to be continued for streams in different physiographic regions of the Province of Ontario. The collection of this data is the basis for many different projects and studies, not just for instream flow studies and should be maintained for the commitments to proper water management. Long-term biological monitoring data sets are needed to compliment flow and hydraulic information.

13. The conditions and temporal aspect of the Permits to Take Water for the Guelph Arkell and Region of Waterloo permits should be used as models to set conditions for future PTTW applications. Consideration should be made to the timing and seasonal requirements of the aquatic ecosystem when issuing permits.

14. The structure and organization of information in the PTTW database needs to be refined to link takings to discrete sources and link the sources to the discrete discharge points they impact. This information is necessary to properly consider the potential impacts of cumulative takings above a given reach of interest. In addition, the PTTW database needs to be reviewed and revised to include additional information needed to support cumulative impacts and better reflect actual takings during the course of the year.

15. Requirements for instream flow recommendations should be harmonized with current initiatives by the MOE to identify potential high impact watersheds. The MOE should consider completing a pilot study to test existing models such as the DHI MIKE BASINS software (DHI Water and Environment, 2002), on a selected potential high impact area in southern Ontario, to investigate its ability to assess cumulative water takings above a given reach of interest. The DHI MIKE BASINS software may offer the necessary framework to organize taking information to facilitate cumulative impact analysis.

16. The MOE and MNR should hold discussions to investigate integrating instream flow requirements into the Ontario Low Water Response Program. The OLWRP could

fulfill the communication role so that Ontario Low Water levels, PTTW conditions and instream flow requirements are considered in an integrated fashion. Other options that could be explored are integrating instream flows with land use initiatives such as stormwater management and urbanization concerns.

17. The MOE develop a process or guidelines for potential high impact areas, indicating the components of detailed local instream flow studies and the process for establishing minimum flows that must be maintained. Both methods need to be considered, and in areas where historical takings are in place, a level of degradation may need to be selected as the minimum objective that should be achieved in these cases and takings managed to that end. More detailed study will be required to assess options that may be used to raise the minimum objectives over time, while balancing the social and economic considerations.
18. The MOE should consider holding workshops or training sessions on the topic of instream flow needs and its related components. This would facilitate the incorporation of instream flow needs into subwatershed studies and other surfacewater management studies for a complete assessment of the ecological effects from water takings. A forum could be held gathering all interested parties and the research community on ecological flow requirements to facilitate the introduction and training for new studies across the province.
19. The abilities of the IHA software should be utilized in other instream flow studies as a diagnostic tool. The MOE should consider holding a workshop to demonstrate the IHA software and RVA method to interested parties. Model authors should be brought in from the USA and a workshop held to build local capacity in southern Ontario for applying the IHA software and RVA method.
20. The MOE and MNR should discuss updating and refining the regional flow models in the OFAT tool. The possibility of improving estimates from these regional models using modern GIS capabilities should be investigated. Also, it is suggested that the DEM in the OFAT tool be updated to ensure the most recent data is available for analysis.
21. Additional geomorphic analysis at selected stream gauge sites throughout Ontario should be completed to with the goal to investigate regionalizing geomorphic thresholds for unique physiographic areas throughout the province. This should be done through the MOE and discussions with the MNR and Environment Canada.
22. Channel shape could be used at a scoping stage to qualitatively assess sensitivity to water taking. MOE should pursue further research into the relationship of channel shape to water taking sensitivity. This may be accomplished as a research topic through a university institution.
23. Monitoring will require an extended period of years to decades before adequate information exists to reliably characterize probable effects. Monitoring that spans several life cycles to cover the range of species present in Ontario streams is required to properly assess techniques and set scientifically defensible guidelines. Partnerships between the MOE and university researches should be established to continue research into means of monitoring biological response to low flows.

24. Temperature is a parameter that needs to be monitored at different locations throughout the watercourse, to account for various thermal habitats and aquatic requirements. There needs to be protocols set for where to collect temperature information instream, and how to correlate this to biological response to stress.
25. It is doubtful that anything but a concerted multi-year study will yield the information necessary for making informed water management choices given the complexities of intra- and inter-annual variability and taxonomic diversity. Accordingly, it is recommended that hydrologically controlled experimental studies, conducted over multiple years and at multiple sites, be used to appropriately determine ecological thresholds for water abstraction.

10.3 Final Summary and Conclusions

This pilot study by the GRCA has provided a process for estimating instream flow requirements in southern Ontario. The incorporation of hydraulic, geomorphic, flow and ecological information combine to synthesize a very complex study on the ecological needs for water in streams. Eight pilot reaches were selected in the Grand River watershed to display the many different characteristics in the components of balancing the needs of both the human and natural environment. The pilot reaches were examined using a case study approach, which developed a different process for each location for studying ecological flow requirements, which supported other research that there cannot be one single method for determining instream flow requirements. A multi-disciplinary and staged approach is stressed to adequately characterize the dynamic nature and needs of aquatic environments.

The Grand River Conservation Authority plans to implement some of the findings from this study into daily operations, including flow targets through the regulated reaches. Further study and monitoring of many components of ecological flow requirements, including the physical, chemical and biological aspects of aquatic ecosystems will continue to improve the refinement of environmental flow needs in the Grand River watershed. Discussions amongst the instream flows team and community will enhance the science and management of instream flows.

The conclusions and recommendations provided above summarize the various findings from the Grand River pilot study, which will hopefully be used as a learning tool for other studies into instream flow requirements. The study team acknowledges the effort that the MOE has taken to attempt to consider instream flow requirements in the management of water resources in the Province of Ontario. Continuing studies into instream flow requirements will be able to adapt the findings of these reports and further the research and verification of instream flow approaches in Ontario.

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12.0 GLOSSARY OF TERMS

1st Order Stream**:** headwater or source stream that does not have any tributaries. Based on the Strahler method of stream ordering or the Shreve method.

Adipose fin: a soft, boneless fin in fish

Aggregate: rock, gravels and other hard inert materials that are extracted from the ground. In reference to the industry of extracting gravels and sands from the ground used for mixing with a cementing material to form concrete, mortar, or plaster.

Allochthonous: material that is found in the stream that has come from an outside source, such as leaves from a tree

Anoxic: greatly deficient in oxygen. A condition that can occur in water bodies when oxygen content is very low.

Aquatic Habitat: the specific type of area including the biological, chemical, hydraulic and physical environment characteristics that are used by aquatic organisms.

Autochthonous**:** constituents that are produced within the stream, such as algae (and their products) and submergent plants.

Bankfull Depth: the water surface elevation required to completely fill the channel to a point above which the water would spill onto the floodplain.

Bankfull Discharge: a high flow measurement; the volume of water that would flow when the surface of the water is at the height of the bankfull elevation.

Baseflow: the portion of streamflow that is provided by groundwater discharge.

Bed mobilizing flow: the flow at which the median (or D_{50}) bed material (substrate) becomes entrained into the flow.

Biomass: the amount of living matter, either plant or animal. Can be used as a measurement such as per unit area or volume.

Biomass Index: the relative amount of biomass or living organic matter, such as fish or aquatic insects, that are contained in a certain region.

Channel Morphology: the study of the shape of stream channels

Connectivity: see hydraulic connectivity.

Consumptive Use: referring to a water taking, a use that completely removes the water from the watershed or water source. An example of consumptive use from a watershed is the taking for water bottling. An example of a consumptive use from a source is the removal by dewatering from groundwater; although it is often returned to the surfacewater source, it is a removal from the original water source.

Cross Section: when referring to watercourses, it is a perpendicular line to the water flow where measurements relating to the river can be taken.

Cross-sectional Area: a measurement of mean depth multiplied by the width.

D_{50}: the median grain size of a sample of sediments

Datum: in physical geography, generally refers to the reference system used to determine a location upon the earth's surface. It can be a reference elevation (vertical) or horizontal system.

Desiccation: to dry up

Desktop Flow Methods: calculations made with streamflow data that are not done *in situ*. They are generally performed using computer software, models or other calculations that can be made to obtain information and statistics on processes in the physical environment.

Detritus: loose organic material found in streams; often organic matter that is in the process of decomposing

Digital Elevation Model (DEM): a graph in computer software of various spot elevations (heights) connected to visualize in 3-dimensional space the profile of landscape features such as a streambed or mountain.

Discharge: the volume of water passing through a cross-sectional area of the stream channel per unit of time (e.g. cubic metres per second, m^3/s)

Downstream: a relative term used to describe a location along the stream that is closer to the outlet of the watershed.

Ecological flow requirements: the flow of water in-stream that is needed to maintain a productive community of plants and animals in and around the watercourse.

Evapotranspiration: the vaporization of water into the atmosphere, occurring from both evaporation off the land surface and transpiration from plants.

Floodplain: the flat land adjacent to a stream channel that is inundated by water during high flow periods.

Flow Duration Curve: a plot of the cumulative frequency that shows the percentage of time that a mean flow is equalled or exceeded during a given period of time in a stream. For example, the 98-percent-duration flow (Q_{98}) is said to be a low-flow, and is equalled or exceeded 98% of the time. These curves are used to pull out frequency statistics (i.e. 50% flow) and can be calculated for total flow or seasonal total flow. The shape of curve is determined by the hydrologic and geologic characteristics of a basin. A curve with a steep slope at the high-flow end indicates a flashy river where flow is largely from direct runoff. A gentle slow at the low-flow end indicates a river that is dominated by baseflow from groundwater discharge or surface storage.

Flow Indices: any important flowrate or flow statistic that could have implications to instream flow requirements or ecological flow needs.

Flushing Flow: a flow which provides sufficient energy to re-entrain (suspend in the water column) finer sediments embedded between coarser substrate material on the riverbed. These finer sediments have potential to negatively impact the quality of aquatic habitat in the riffle sections of the river. As a management tool, flushing flows are used to improve spawning gravel quality, fish reproductive success, increase food production, maintain pool depth and diversity and prevent channel encroachment.

Frazil Ice: the first type of ice to form on the surface of a water body, into needle-like crystals, and can often be a result of below freezing air temperatures that cool the water quickly. Frazil ice can mix with the water column to form slush throughout the column, which can cause ice jams in river systems if slowed down or obstructed.

Froude Number: a dimensionless numeric descriptor of the flow in a stream or open channel. Ranges from 0 to 1, with 0 being a tranquil and slow flow, and as it approaches 1, the flow is characterized by more shallow and fast motions. Used to identify pools versus riffles.

Geodetic: a measurement referenced to the earth’s surface through the use of surveying the land.

Geology: the study of the origin, structure, chemical composition and history of the underlying material of the land, which influences the flow of water to the groundwater table.

Geomorphic Indices: flow thresholds calculated from geomorphological parameters that have implications to ecological flow requirements. Indices include bankfull flow, residual pool flow flow, bed mobilizing flow and flushing flow.

Geomorphology: the science dealing with form and surface configuration of the solid earth. It is the study of the interrelationships between the origin (i.e. material composition) of surface features and the causes of the surface alteration (such as erosion, weather, etc.).

Groundwater: water that is contained in aquifers underneath the surface of the land, and is a source of water for many different water users.

HEC-RAS: (Hydrologic Engineering Centers River Analysis System) a hydraulic modeling software program. The software can model energy gradients of water flow and be used to calculate hydraulic parameters along cross sections of a river.

Headwater Stream: the uppermost portion of a stream's drainage, that can originate from springs or seeps from the groundwater.

Hummocky Topography: areas of land in a watershed that are internally drained, and do not have a connection to a watercourse. They are generally found in rolling and moraine areas. Water that flows in these areas goes into recharge or evaporates.

Hydraulic: operated, moved or effected by water; of or relating to water in motion

Hydraulic Connectivity: streamflows or water levels in streams that maintain sufficient flow depths over riffles to allow for fish passage between pools. Significant loss of hydraulic connectivity indicates interconnectedness is lost between all pools.

Hydraulic Habitat: features of a stream that is related to the living conditions for aquatic organisms. For instance, depth and velocity are directly related to flow; other habitat features such as substrate and cover are indirectly related to flow.

Hydraulic Indices: flowrate magnitudes where hydraulic parameters such as wetted perimeter or flow velocity noticeably change when the flowrate is altered. Generally occurs at a hydraulic inflection point. Measured as a flow (m^3/s). These indices have implications to ecological flow requirements.
2) (sing.) A flowrate at which a noticeable change has occurred in a hydraulic parameter.

Hydraulic Inflection Point: the point on a curve describing the hydrology of a stream where the curve switches from concave to convex curvature.

Hydrograph: a plot of a stream's discharge against time. It shows the characteristics of a stream, such as peak flows, baseflows and change of streamflow over time.

Hydrologic: a science dealing with the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere

Hydrology: the scientific study of the processes related to water and the water cycle.

Infiltration: the ability of the soils to accept water. Dependent on soil texture, organic matter, structure, and application rate of water.

Invertebrate: an animal lacking a backbone. Generally in this report this term represents the macro-invertebrates such as small insects and worms that have an aquatic stage in their life cycle and are found in streams.

Littoral: the region in a watercourse that is adjacent to the edge or bank. It is a submerged portion of the stream that generally provides favourable habitat for aquatic plants and animals.

Lotic: systems of flowing water; habitats such as rivers, streams

Macroinvertebrate: organisms with no backbone that is greater than 2mm in size. Generally refers to benthic organisms such as insects and molluscs.

Manning Coefficient (a.k.a. Manning Roughness Coefficient): a measure of the roughness of a surface over which a fluid (like water) is flowing. Used in the Manning equation to determine the relationship between mean velocity of flow to the channel characteristics.

Methods (for instream flow assessment): procedures or techniques used to measure, describe or predict changes in important physical, chemical or biological variables of the stream environment

Methodologies (for instream flow assessment): collections of several instream flow methods which are arranged into an organized iterative process which can be implemented to produce results.

Minimum Flow: the lowest flow that occurs in a specified time period within a year (or range of years), such as the 7-day minimum flow for 2004.

Mobilizing Flow: a periodic flow event which can move a considerable portion of the streambed. Often associated with the ability of the streamflow to move the median (D_{50}) bed material.

Montana Method: see Tennant Method

Moraine: a glacial deposit on the surface of the land containing a variety of sediments collectively called till.

Natural Flow Regime: the characteristic pattern of a river's flow quantity, timing and variability that has been unaltered by human consumption.

Non-Consumptive Use: a water taking that returns some of the water back into the system or source. For example, runoff from irrigation can be returned to the surfacewater stream adjacent to the field.

Ontario Low Water Response Plan (OLWRP): a program created by ministries in the Province of Ontario that sets a 3-tier system for reacting to lower than average flows and precipitation. The plan uses voluntary conservation to mitigate issues that may arise to a shortage of water in the first 2 tiers and requires conservation of water resources in the third tier by water users.

Periphyton: the community of algae growing on a variety of submerged substrates such as rocks, plants or debris, in lakes and streams.

Permit to Take Water (PTTW): a program set by the Ministry of the Environment to regulate the takings of water from groundwater and surfacewater in Ontario. Under this program, any takings over 50,000 L/day are required to obtain a permit, unless it is for fire fighting or livestock watering.

Physical Habitat: The abiotic factors such as depth, velocity, substrate, cover, temperature and water quality that make up an organism's living space.

Pool: a section of a stream where the water has a reduced velocity, often with water deeper than the surrounding areas. Fish use these areas for resting and cover.

PWQM site: (Provincial Water Quality Monitoring site) a point along a river that has been selected to be tested, on a regular basis, for water quality parameters to meet objectives set by the Province of Ontario.

Rating Curve: a graph of the relationship between stage and discharge of at a cross section of a river. Stage data (height of the water surface) is generally collected at stream gauges.

Reach: a portion of valley and stream that includes a stream length of at least 2 riffle-pool sequences (or two wavelengths of a specific stream type). The reach includes the riparian zone and floodplain of the adjacent valley.

Recharge: (groundwater recharge): the replenishment of groundwater sources from surfacewater.

Redds: spawning grounds or nests where fish lay their eggs

Refugia: any object that provides cover for organisms, such as plants or rocks at the side of the river.

Regulated Reach: a stretch of river that has a specified flow rate that is controlled by one or more dams.

Residual Pool Flow: the low-flow associated with a thalweg channel providing refuge maintenance. It is the flow at which water levels are sufficiently low to isolate the pools because no flow is occurring over riffle substrate. It is calculated as the difference in depth between a pool and the downstream riffle crest.

Reservoir: in water management, a structure used to hold water for storage and release; generally built behind a dam for more control of water supplies.

Riffle: a section of the stream with turbulent flow, usually with gravel, cobble or boulder bed material. Riffle sections are between pools and have faster moving water. They are more sensitive to changes in flow, especially low-flows and serve as an indicator of habitat loss instream.

Riparian zone: the land adjacent to a watercourse that is not normally submerged, which provides an area for vegetation to grow as a buffer to the land-use alongside to the stream. It acts as a transitional area between aquatic and terrestrial environments, and is directly affected and is affected by that body of water.

Stable Isotope Analysis: a method to assess aquatic foodweb structure by giving an indirect assessment of food source origins using both carbon and nitrogen as indicators.

Stochastic: random. A stochastic event is one that occurs only randomly.

Streamflow: the movement of water through a watercourse. Streamflow is a combination of overland flow, interflow and groundwater discharge.

Stream gauge: a tool for measuring the water level in a stream.

Substrate: the riverbed inorganic sediment, including rocks, pebbles, sand, silt and clay.

Surfacewater: (surface water) water that is visible on the surface of the earth, including lakes, rivers, streams and ponds. It is a better indicator of water supply than groundwater as it is more easily measurable based on flows and volumes of the water body.

Subwatershed: a catchment area that is a portion of a larger watershed system.

Tennant Method: (also known as the Montana Method): (a). a qualitative assessment of certain levels of flows and the suitability of the physical habitat for various uses at these flows. Used to determine various levels of environmental quality in the stream. (b). a streamflow based, desktop method used to estimate instream flow requirements, based on a percentage of the annual streamflow at a given location.

***Aquatic-Habitat Condition for Small Streams**	**Percentage of Q_{MA}, April – September %**	**Percentage of Q_{MA}, October – March %**
Flushing Flow	200	200
Optimum Range	60 – 100	60-100
Outstanding	60	40
Excellent	50	30
Good	40	20

Fair	30	10
Poor	10	10
Severe Degradation	<10	<10
Q_{MA} – Mean Annual Flow *****Aquatic habitat relationship needs to be confirmed for Ontario		

Terrestrial: relating to the land surface of the earth

Tessmann Method: a hydraulic calculation to determine low-flow thresholds, based on mean monthly flows. The Tessmann Method is a modified version of the Tennant Method, using a monthly approach instead of a two-season or yearly approach.

Situation	Minimum Monthly Flow %
1. IF $Q_{MM} < 40\% \ Q_{MA}$	USE: Q_{MM}
2. IF $Q_{MM} > 40\% \ Q_{MA}$ & $40\% \ Q_{MM} < 40\% \ Q_{MA}$	USE: $40\% \ Q_{MA}$
3. IF $40\% \ Q_{MM} > 40\% \ Q_{MA}$	USE: $40\% \ Q_{MM}$
Tessmann specified a 14-day period of 200% Q_{MA} during the month of highest runoff for flushing purposes. $\mathbf{Q_{MA}}$- mean annual flow, $\mathbf{Q_{MM}}$- mean monthly flow	

Thalweg: the deepest cross-sectional width of a stream, (line of deepest water in a stream channel, as seen from above) normally the area of greatest velocity of streamflow.

Till: the sediments deposited by a glacier that can include grain sizes from gravel, sand, silt and clay.

Topography: the shape of the land surface.

Topwidth: the length that spans the cross-section of a stream at the surface of the water.

Trophic: a feeding or organization level (i.e. herbivore) in a food chain or foodweb.

Undercut Bank: a section of the river's edge (or bank) that has been eroded underneath the water's surface due to the scouring effect of the streamflow. The portion above this undercut of the bank – that is, above the water surface – maintains the original shape, and looks like it has an overhang or lip above the water surface.

Upstream: a relative term used to describe a point in a stream that is closer to the headwaters or top of the watershed. A slug of water starts upstream and travels downstream. Opposite of downstream.

Velocity: the distance traveled per unit time. Similar to speed, but with a direction of travel.

Water Abstraction: the removal of water from a water body for consumptive or non-consumptive uses.

Water Allocation: the distribution and sharing of water resources among water users

Water Budget: calculations made on the water demand and supply to characterize the availability of water for use.

Water Year: a term used in hydrological modeling to describe a 366-day year starting on October 1st and ending on September 30th of the following year.

Watershed: a topographical drainage basin that channels water over land and into streams that eventually flows to one main outlet channel. Also called a catchment, catchment basin or drainage basin.

Wetted Perimeter: the perimeter of a stream cross-section that coveys flow. The width of the streambed and stream banks in contact with water for an individual cross section. Used as a measure of the availability of aquatic habitat over a range of discharges.

Width-to-Depth Ratio: a dimensionless calculation that divides the channel width by the maximum depth at a given flow. Used to infer large changes in the hydraulic regime. The minimum ratio is used as an indicator of the bankfull stage, or channel-forming stage. This stage is considered to be the point at which flow resistance reaches a minimum and, as a result, the channel operates most efficiently for the transport of water and sediment.

Young-of-the-Year: fish that were hatched in the current year.

13.0 LIST OF APPENDICES

RELATED DOCUMENTS UNDER SEPARATE COVER:

1. GEOMORPHOLOGICAL THRESHOLDS FOR INSTREAM FLOW REQUIREMENTS
   BY: PARISH GEOMORPHIC, JULY 2004
2. GEOMORPHOLOGICAL THRESHOLDS FOR INSTREAM FLOW REQUIREMENTS: PHASE II
   BY: PARISH GEOMORPHIC, FEBRUARY 2005.

3. GEOMORPHOLOGICAL THRESHOLDS FOR INSTREAM FLOW REQUIREMENTS: FOR CARROLL CREEK

4. GEOMORPHIC PROTOCOLS FOR INSTREAM FLOW REQUIREMENTS
   BY: PARISH GEOMORPHIC, MAY 2005.

APPENDIX A: BIOLOGICAL CONCEPTS FOR ECOLOGICAL FLOW NEEDS

Table A.1 A proposed hierarchy for the determination of the scale of measurement for geographic, geomorphic and biotic data collection and analysis within watershed systems based on Imhof *et al.* (1996)

System Level	Linear spatial scale (m)	Areal spatial scale (m^2)	Areal and profile boundaries	Time scale of continuous potential persistence (years)	Time scale of persistence under human disturbance patterns (years)	Biotic Assemblage Scale	Life Activity and scale (variable time)
Watershed	10^5	10^{10}	Drainage divides between tertiary watersheds	10^6-10^5	10^4-10^3	community species (migratory)	life cycle life cycle (<20 yrs.)
Sub-watershed	10^4	10^8	Drainage boundaries of quaternary watersheds within tertiary drainage basins	10^4-10^3	10^2-10^1	community/ species	life cycle (1-8 yrs.)
Reach	10^4-10^1	10^5	Minimum of two full channel wavelengths, and defined by as a specific stream type based on the Rosgen (1994) classification. Active profile boundaries up to 1:20yr flow elevation, passive boundaries to 1:100yr flow elevation.	10^2-10^1	10^1-10^0	Species/ community	life cycle/ life stage (0.1-8 yrs.)
Site	10^1-10^0	10^2	Channel segment comprising either a riffle or pool, profile including bankside riparian vegetation up to bankfull elevation	10^0	10^0-10^{-1}	individual	life stage (0.1-0.4 yrs.)
Habitat element	10^0-10^{-1}	10^1	Zones of variable substrate types or characteristics, water velocity and depth within either a pool, step or riffle.	10^0-10^{-1}	10^{-1}-10^{-2}	individual	activity (10^{-3}-0.1 yrs.)

Table A.2: Watershed characterization (linear scale 10^5; areal scale 10^{10}) matrix providing an information structure to differentiate causal attributes from effects on form and the habitat attributes provided by the form.

Causes		Effects		
State	**Condition**	**Process(es)**	**Response**	**Habitat**
a. Climate	precipitation and snowmelt regimes;	runoff, infiltration, evapotranspiration;	drainage density (recharge:discharge and surface and subsurface runoff);	stability and diversity of habitats is expressed by the regime characteristics of the formative (bankfull) and stress (lowflow) flows;
	Temperature	Heating	stream temperature regime	thermal stress and ranges (e.g. cold or warmwater communities)
b. Landform (Geology: Physiography) modifier - Watershed slope	slope stability	slope and channel erosion	sediment load; entrenchment; valley slope	floodplain width and diversity of features (e.g. terraces, cutoffs, swales, oxbows); potential stream types; controls diversity of channel characteristics and therefore habitat potential
c. Landform (Geology: Physiography) modifier - sediment type	sediment stability and source;	sediment transport;	sediment load, type and size;	ratio of suspended sediment vs bedload volumes (mass per unit mass)provides measure of habitat stability; substrate types measure of potential uses;
	porosity, depression storage;	infiltration; discharge (runoff; high and low regime and yields);	drainage density; downstream channel geometry	flow regime; flow contributing areas; living space
	relative alkalinity	redox and oxidation	pH	productivity
d. Landcover	Infiltrability	runoff:recharge	flow regime	temporal volume of living space
	erosivity	sediment, nutrient and carbon transport	sediment load and bank slope;	floodplain and riparian vegetation;
			productivity	biomass, diversity and growth rates

Table A.3: Reach characterization matrix (linear scale 10^3 - 10^1; areal scale 10^5) providing an information structure to differentiate causal attributes from effects on form and the habitat attributes provided by the form.

Causes		Effects		
State	Condition	Process(es)	Response	Habitat
a.[1]Runoff Flows baseflow- groundwater - magnitude and duration (e.g.$_7Q_5$, $_7Q_{10}$, $_7Q_{20}$)	velocity; living space;	respiration;	metabolic stress;	depth, area, oxygen level, temperature;
bankfull - channel forming (1:0.7yr. to 1:1.7yr.)	velocity, depth;	erosion, deposition;	channel geometry (i.e. width/depth, sinuosity, etc.);	aquatic structural habitat (see Table 5);
riparian flows (1:2yr. to 1:20yr.- organic matter exchange)	velocity, flooding;	erosion, deposition and inundation (durational and depth);	floodplain formation; nutrient exchanges; debris movement; migratory access;	riparian/terrestrial habitat, reproductive space;
floodplain -system reset (1:20yr. to 1:100yr.)	velocity, flooding	erosion, deposition	channel slope, floodplain forms	valley terrestrial habitat
b.[1]Slope - riffle slope	energy gradient;	erosion, deposition (lateral);	channel sinuosity;	relative diversity of living space (riffle:pool or step:pool types); spacing
- pool slope	friction gradient	erosion, deposition (lateral)	width:depth ratio	structural complexity; vertical channel variability
c.[1]Sediment - sediment size range	roughness;	erosion, deposition;	width:depth, channel shape;	habitat structure diversity;
- sediment load	channel stability	erosion, deposition	width:depth, sediment size, sorting	habitat structure stability
d.[1]Vegetation - community	roughness, bank cohesion;	succession; erosion, deposition;	woody debris; width:depth, bank stability;	shelter, nutrients;
- age	roughness, shading;	flooding, erosion, deposition, heat transfer;	width:depth; channel complexity	temperature, refuge;
- density	roughness, cohesion	flow velocity, erosion/deposition	bank slope; bank stability	habitat refuge stability

[1] Refers to previous state indicators (a.- climate; b. - watershed slope; c.- sediment type; d.- landcover)

Table A.4: Site/Cross-section characterization matrix (linear scale 10^1 - 10^0; areal scale 10^2) providing an information structure to differentiate causal attributes from effects on form and the habitat attributes provided by the form.

Cause		Effects		
State	Condition	Process(es)	Response	Habitat
a.[1]Flow velocity & depth (bankfull)	shear stress (in the flow)	erosion; deposition	bed/bank form (planform)	relative amounts of spawning, resting, refuge, and ambush areas of a stream type for a given species
Width:depth	friction	erosion; deposition	channel shape (cross-sectional)	determines volume of living space and relative utility for various life stages
b.[1]Slope (water surface)	shear stress (on the bed)	erosion, deposition	channel forms, substrate characteristics (i.e. riffle:pool or bar)	differentiates life cycle requirements and activities (e.g. high slope -feeding/reproduction; low slope - refuge/ambush)
c.[1]Cohesion (bank)	shear strength	erosion	bank slope	refuge areas, ambush (e.g. undercut banks)
Sediment size (sorting D_5,D_{15},D_{85})	roughness, shear strength	erosion, transport	riffles, pools, bars	benthic habitat, spawning areas, shelter
Boulders	friction	erosion, deposition	channel shape	refuge
d.[1]LWD debris (Large Woody Debris)	friction	erosion, velocity	width/depth, bank slope, deposition, nutrients	refuge, spawning areas; food for invertebrates (productivity)
Vegetation - riparian (succession)	friction, cohesion	erosion, deposition	bank slope, shading	refuge areas, temperature moderation, and nutrients as a food source

[1] Refers to previous state indicators (a.- flows; b.-slope; c.- sediments; d. vegetation)

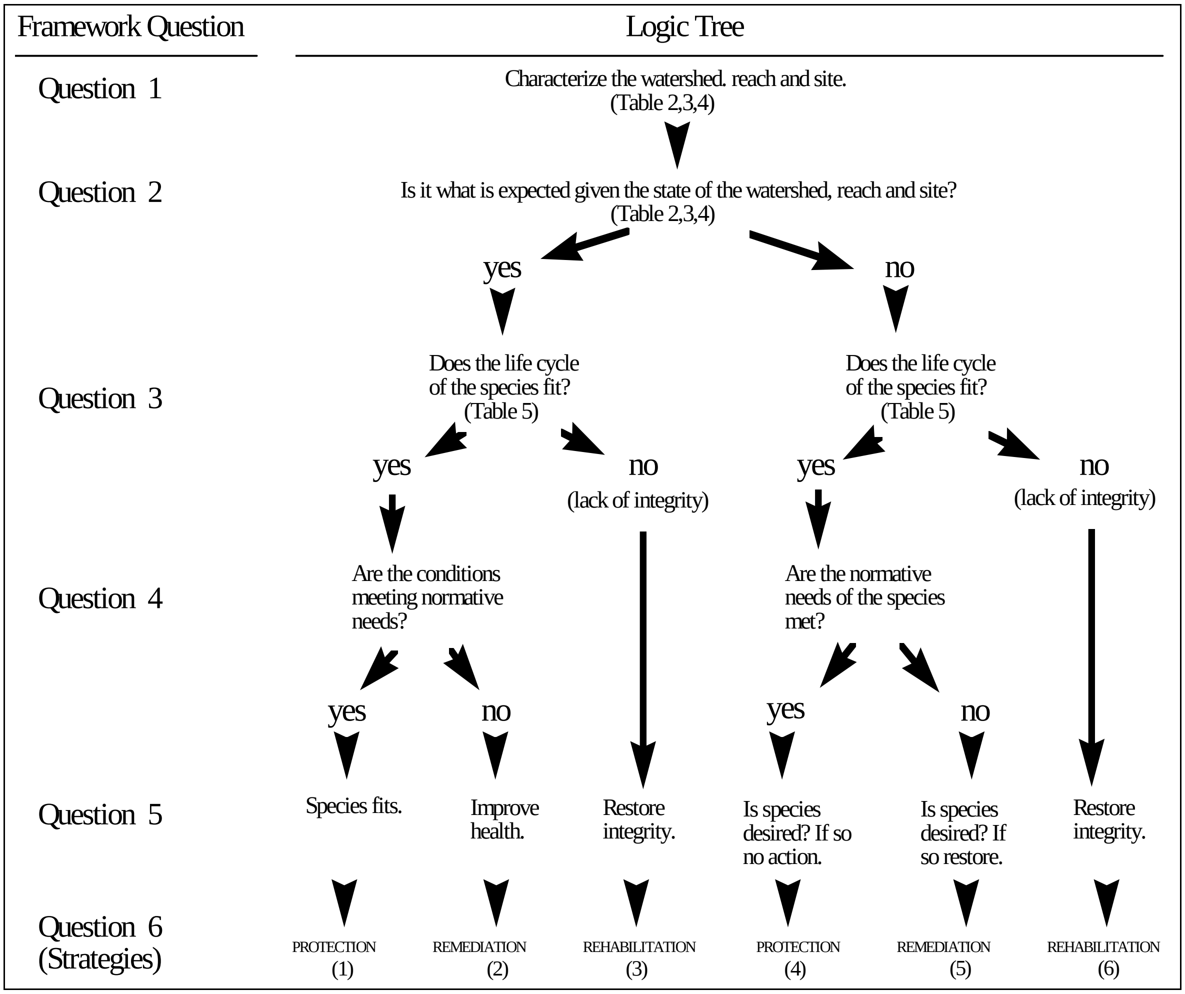


Figure A.1 Logic Tree Demonstrating the Application of a Framework for Physical and Species Habitat Systems Analysis

Table A.5 Life stage/state characterization for brown trout (*Salmo trutta*) in relation to dynamic processes, physical characteristics and required habitat attributes and their interactions.

Life stage/state	Dynamic Conditions	Physical Environment (Static Condition)	Habitat
Reproduction	- erosional zones - fall spawners...October to November v = >30cm.sec^{-1} d = >30 cm - interflow of water through the redd with near saturated O_2 levels through period of incubation - groundwater moderated winter flows	- outwash gravels and sands - gravel moraines - sand and gravel tills - may be limited in bedrock controlled systems - less in till/clay plains - D_{50} = 20mm (coarse gravel substrate) - less spawning in flat dominated riffle:pool systems, evident of active bedrock control	- typical in riffle:pool systems; less in step:pool systems - spawning occurs at head of riffles, often along margins with adjacent cover of logs and overhangs - >400mm depth of substrate necessary for spawning - low % fines in pavement
Nursery	- depositional zones - very low velocities	- sands and silts - shallow depths with high roughness, often with vegetation and/or woody debris and detritus	- shelter and feeding (passive[1]) - riffle margins in the lower half to third of riffles, especially at the tail of riffles - linked to spawning areas
Juvenile	- erosional zones - fast water, shallow to moderate depth	- cobble and boulder - rough bottom with structural diversity that allows good distribution of territory	- feeding and shelter (active[2]) - mid to head of riffles also at the tail out to the pool
Overwinter habitat - juvenile and adult (see also flow requirements)	- depositional zones - continuous low velocities - depth - groundwater flow regime (seepage)	- structural complexity - variable in space -best in physiographic units that allow deep pool formation and active groundwater systems	- refuge and shelter, feeding (passive) - Pools and/or cut banks adjacent to pool area - usually bottom third of pools - undercuts at cut banks, also associated with logjams with one or both cutbank and/or pool
Adult /shelter	- depositional zones (although variable) - stable depths - significant velocity gradients	- medium to high structural complexity - woody debris for shelter - variable in space -best in physiographic units that allow deep pool formation	Spatially variable: - active and passive feeding; shelter - predominantly in pools of 1-4th Order streams - Inhabit riffles with good structure in 3-6th Order streams - High roughness of bed and banks ideal - woody debris is an enhancement factor
Feeding (Active) - environments - food habitats	- erosional zones - feeding areas should support diverse prey assemblage with good biomass - macroinvertebrates major food item during early stages of life	- feeding areas need to be close to shelter - coarse bottom substrates in high gradient areas comprised of gravels, cobbles and boulders	- Feeding is dominant in transitional zones, head of riffles during invertebrate drift or emergence and tail of pools during ovipositing
	- depositional zones for minnow species (important food item in older mature fish)	- substrate variable, depth and volume more important for minnow species	- pool and shallow slow or fast areas used as foraging areas for minnow species
Migration - reproduction	Flow regimes: high and low High flows: - opportunity for movement to reproductive zones and movement of juveniles out of system	- Drainage density an indicator of groundwater vs surface water fed systems	- ideal reproductive/nursery areas in 1-2nd Order streams with good low flows although may range up to 3-4th Order streams
- seasonal habitat use	Low Flows: - control density and survival on an event and regime basis, depends on size/location of stream	- fine soils generate large drainage density/low baseflows compared to low drainage density and large baseflows	- juveniles & adults in 2-4 Order streams - Overwintering areas often confined to 3-5 Order

[1]Active - animal actively seeks and pursues food; [2]Passive - opportunistic feeding only

Table A.6 Life stage/state characterization for smallmouth bass (*Micropterus dolomieui*) in relation to dynamic processes, physical characteristics and required habitat attributes and their interactions.

Life stage/state	**Requirements/Characterization (Dynamic Processes)**	**Physical Characteristics (Static Condition)**	**Physical Habitat Attributes**
Reproduction - habitat	- depositional zones and margins of erosional zones v = < or = 15 cm/sec d = > 30 cm - adult male guards eggs and fry for approx. 1 month - margins need water coverage of approx. 30 cm for period of incubation and yolk sac absorption (approx. 2 wks.) before water levels drop.	- Variable locations, although usually found in units having gravel/cobble bed channels with modest incidence of boulders - Substrate composition variable (fine sand - cobble) - indented shoreline margins with coarse woody debris preferred - also occur along margins of bedrock channels	Usually reproduce in 3-7th Order streams. Occasionally in lower order streams if pool depths are sufficient - margins of pools, usually on upper or lower margin of point bars - can also be found at lower portion of riffle zones - occasionally on outside bend of shallow, poorly defined pools in bedrock controlled systems typically "C_1-C_4" type channels, occasionally "F" types
Reproduction - flows	- sufficient volume and duration to wet channel margins for 3 weeks to one month in late May to mid-June - dampened spring hydrograph	river systems with large drainage area upstream - watersheds within large moraines systems	- Lower order streams are most typical because they exhibit a dampened hydrograph with a long duration
Nursery	- depositional zones and margins of erosional zones - Same locations as spawning - nursery period of approx. 2-3 weeks in water depths from 15-40 cm ideally with some woody debris along margins as well or large boulders - warm temperatures required for optimum growth	- gravel/cobble boulder areas (with boulders) adjacent to depositional zones	- as above
Juvenile/late YOY	- erosional/depositional areas - modest flows adjacent to the main channel - velocity gradients	- substrate from cobble to boulder - Good bottom roughness - woody debris preferred	- edges of pools, bottom of pools in transition to riffles - edges of riffles in mid to lower third of riffle areas
Overwintering - juvenile/adult	- depositional zones - Deep pool areas, near over-summering locations (for YOY) - warm summer conditions for YOY to maximize fitness	- boulder material in channel	- good pool complexity, with boulders and woody debris, typical of "C" type channels; - Deep well defined pools with good complexity comprised of boulders and/or woody material
Adult - Shelter	- lateral velocity gradients	- gravel/cobble, ideally with small to moderate % boulders - depth and structural complexity including pools, runs and ledge rock areas - coarse woody debris a modifier	- Deep and extensive pools and bouldery runs with good structure and roughness in 4-7th Order streams - With extensive woody debris and deep pools, fish will be found in 3rd order streams
Feeding - environment - food habitats	- erosional and depositional features - locations having variable food items - crayfish, macroinvertebrates, amphibians and small fish all important	- substrate of cobbles and boulders ideal for most of the food items - shallow flats and runs adjacent to pools very important	- runs with coarse substrates with boulders - flats with coarse textured substrates - head and tail of pool areas for macroinvertebrates - well sorted pools ideal for minnows
Migration - reproduction and environmental	- main channel edge spawners although some movement will occur from lake to river or larger river to large tributary - movements between pools can occur under lower flows in large rivers, some constraint on movement in smaller streams during low flow periods		- easy access to larger tributaries from river system or lake

Bechtel, Blair and Mill Creek Summer 2003 Sampling

Bechtel, Blair and Mill Creeks were selected for sampling after site inspection of numerous sites for which flow and temperature information were available. In preference to larger, mainstream river sites, Bechtel, Blair and Mill Creeks were selected because of the similarity in headwater impacts, proximity to one another and ease of land access arrangements through the GRCA. Sampling was conducted on a monthly basis. Sampling consisted of random selection of upstream and downstream substrate types and undercut bank habitats. Standardized kick sampling methods were used on all upstream and downstream substrate sampling sites. Standardized disturbance sampling of undercut bank habitats was accomplished by inserting a dip-net into the undercut bank and prodding the net gently back and forth to free any attached macro-invertebrates. Standardized filtering of stream water for DOC analysis and retention of water samples for DIC analysis were also conducted on each initial sampling trip. The sampling scheduling is given below in Table A.7.

Table A.7: Study Site Sampling Schedule. Sampling was restricted a Bechtel due to construction of new fencing, restricting site access as originally selected.

Site	Sample Dates
Blair Creek	August 06, September 11, October 10, March 17
Bechtel Creek	September 12, October 16
Mill Creek	August 08, September 10, October 19, March 18

All samples were rough sorted in the field and returned live to the laboratory where they were kept alive for 24 hours in aerated water. Samples were kept alive for the 24 hour period to allow gut evacuation, so as to improve the resolution of derived isotope measures. Identification specimens were retained in alcohol for verification of field identification and have been archived for possible future use. All samples used for stable isotope analysis were dried at a constant temperature (50^0C) for 24 hours, before being ground to a fine powder with the aid of a mechanical ballmill grinder. Where necessary, invertebrate samples were grouped (i.e. several specimens of the same species) and ground as a group to ensure sufficient sample material was available for analysis. Approximately 1 mg of the resulting powder was then weighed out in laboratory standard micro-analytical tin capsules and submitted to the Environmental Isotope Laboratory for carbon and nitrogen stable isotope analysis. Taxa collected and prepared for stable isotope analysis are identified in Table A.8.

Table A.8: List of Taxa Collected at Each Study Site. Number of isotope samples analysed to date are given below the name of each stream study site.

Taxon	Bechtel n=16	Blair n=29	Mill n=43
Alderfly		✓	✓
Amphipods			✓
Beetles		✓	✓
Caddisfly	✓	✓	✓
Chironomids			✓
Cranefly	✓	✓	✓
Crayfish			✓
Damselfly		✓	✓
Dobsonfly	✓	✓	✓
Dragonfly	✓	✓	✓
Isopods	✓		
Leech			✓
Mayfly	✓	✓	✓
Snails			✓
Stonefly			✓
Waterpenny			✓
Worms			

Stable isotope ratios are expressed as delta values (δ) and measured as parts per thousand differences (‰) between the isotope ratio of the sample and that of a defined international standard according to the formula:

$$\delta R = [(R\text{sample} - R\text{standard}) / R\text{standard}] \times 1000$$

where δR = the carbon (13C/12C) or nitrogen (15N/14N) isotope ratio of the sample or the standard. Samples depleted in the heavier isotope (13C or 15N) in comparison to the standard have lower delta values. Samples that are more enriched in the heavier isotope in comparison to the standard have higher delta values. All international standards are set at 0‰ by convention. Standards used to compute all values reported here included: carbonate rock from the Pee Dee Belemnite formation (Craig 1957) and nitrogen gas in the atmosphere (Mariotti 1983). All stable isotope analyses were performed on a Micromass VG Isochrom continuous-flow isotope ratio mass spectrometer connected to a Carlo Erba elemental analyser at the Environmental Isotope Laboratory, University of Waterloo. The International Atomic Energy Agency CH6 and N1 standards, respectively, were used to determine the accuracy of δ13C and δ15N values measured as the mean difference ± one standard deviation of repeat measures of the standards (δ13C= -0.1‰ (n=20) and δ15N= -

0.1‰ (n=20)). Sample reproducibility was measured by repeat analysis of samples as the mean difference ± one standard deviation of the difference between duplicate analyses of randomly selected samples (δ13C= -0.020±0.09‰ (n=25) and δ15N= -0.01±0.07‰ (n=25)).

Within the preliminary data there is some suggestion of varying foodchain lengths by stream site. For example, the range of δ15N values in Mill Creek is 5.8‰ while in Bechtel the range is more limited (5.1‰). There is also some suggestion in the preliminary data that variability in foodweb carbon signatures are correlated with discharge, with the higher discharge Mill Creek sites being more depleted than the lower discharge Blair Creek site. Direct comparisons to Bechtel Creek are currently not possible owing to differences in riparian vegetation and the probable importance of groundwater inputs for flow maintenance. Comparisons between Mill and Blair Creeks, however, echo the findings of Hicks (1997) who found the δ13C of Cladophora in New Zealand streams was related to water velocity, with more δ13C enriched values in pools than in runs (-23.2‰ in pools with mean velocity 0.12 ms-1 and -28.1‰ in runs, mean velocity 0.24 ms-1). Results suggest significant impacts in energy pathways occur as a function of changes in flow regimes. Flow related impacts on the isotopic signatures of taxa have been reported elsewhere in the literature. Sheldon and Walker (1997) suggested that flow stablization in the lower Murray River, Australia, promoted the growth of filamentous algae, perhaps at the expense of bacteria. Evidence from gut and faecal pellet analysis, and from analysis of carbon stable-isotopes of snails, suggested that resident gastropod taxa were detritivores, feeding mainly on amorphous organic detritus. Because algae have a relatively high C:N ratio (low nutritional value) they may provide inadequate energy sources to maintain female growth and reproduction, therby explaining the correlation between increased algal biomass and declining snail abundances associated with stabilized flows.

To date insufficient results exist to comment on seasonal changes at each of the study sites. Samples have been collected for February and March period and sampling is scheduled for completion in April and May. Late winter samples have been prepared and submitted for isotope analysis, but results are not yet available. McArthur *et al.* (1996), however, have documented both seasonal change at a given site and differences between study streams, noting that temporal changes in isotopic composition of riparian species and aquatic macrophytes are site-specific. Discriminant analysis dissimilarity plots of isotopic results further demonstrated that the contribution of species to the detrital pool depended on the site and season. Findings to date at the Blair, Bechtel and Mill Creek study sites parallel those reported by McArthur *et al.* (1996) with distinctive site-specific results in evidence for those data that have been analysed (see Figure A.2).

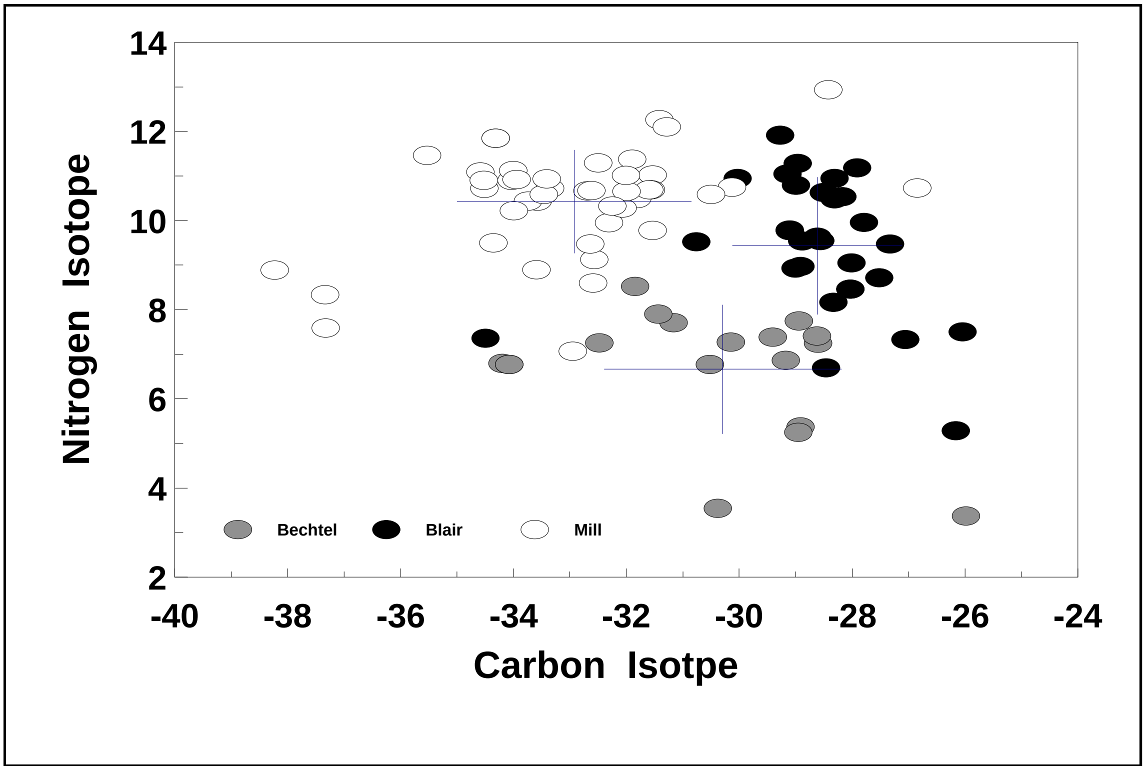


Figure A.2: Carbon (δ13C) and nitrogen (δ15N) cross-plot of the invertebrate stable isotope analytica results for Blair, Bechtel and Mill Creeks. All study sites differed significantly (Tukey's HSD P <0.05) on the carbon and nitrogen axes, indicating unique positioning of the sites.

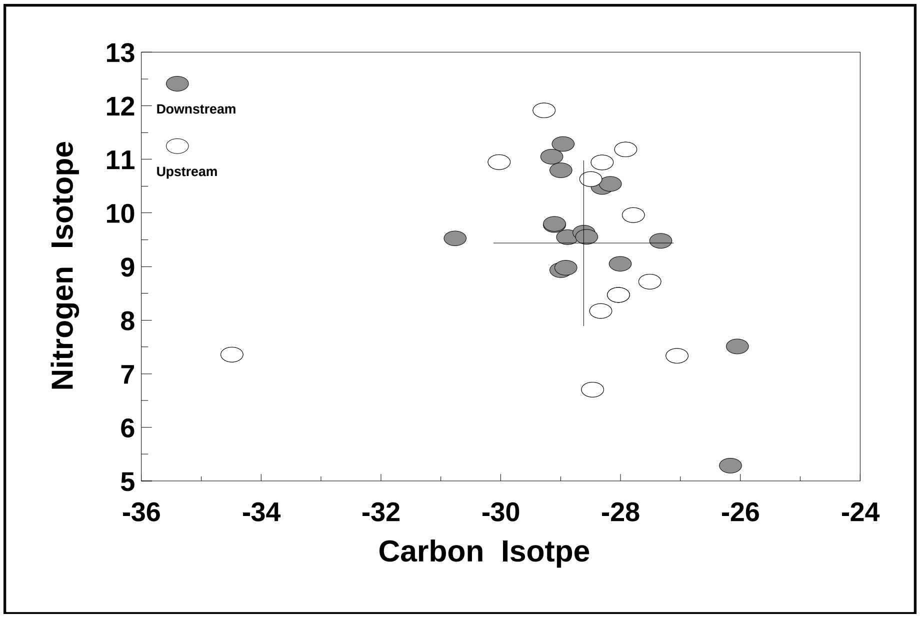


Figure A.3: Carbon (δ13C) and nitrogen (δ 15N) cross-plot of the invertebrate stable isotope analytical results for Blair Creek. Upstream and downstream samples are plotted individually and do not differ significantly (t-test P>0.05) on the carbon or nitrogen axes.

Figures A.3, A.4 and A.5 plot individual results for each stream study site distinguishing between upstream and downstream samples. In Blair and Mill Creeks (Figures A.3 and A.5) there is no difference between the isotope signatures of the upstream and downstream samples (two-sample t-test P-value. 0.668), suggesting within site variability is low.

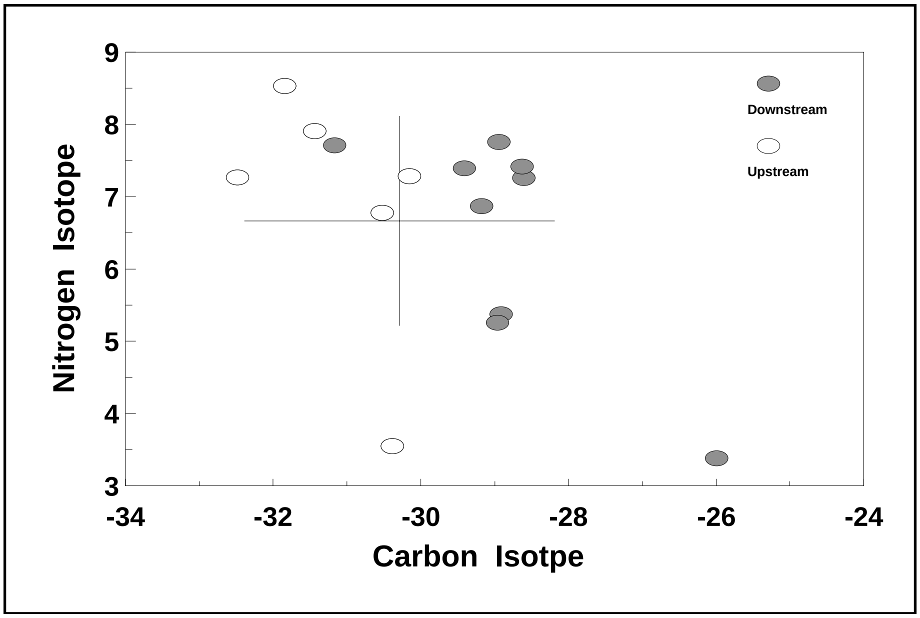


Figure A.4 Carbon (δ13C) and nitrogen (δ15N) cross-plot of the invertebrate stable isotope analytical results for Bechtel Creek. Upstream and downstream samples are plotted individually and do not differ significantly (t-test P>0.05) on the carbon or nitrogen axes.

Samples obtained from Bechtel Creek (Figure A.5) show an apparent difference between upstream and downstream samples. However statistical testing indicated the differences were not statistically significant (two-sample t-test P-value = 0.615) when samples were tested as a group or on a taxon-specific basis (i.e. caddis fly t-test P-value > 0.05).

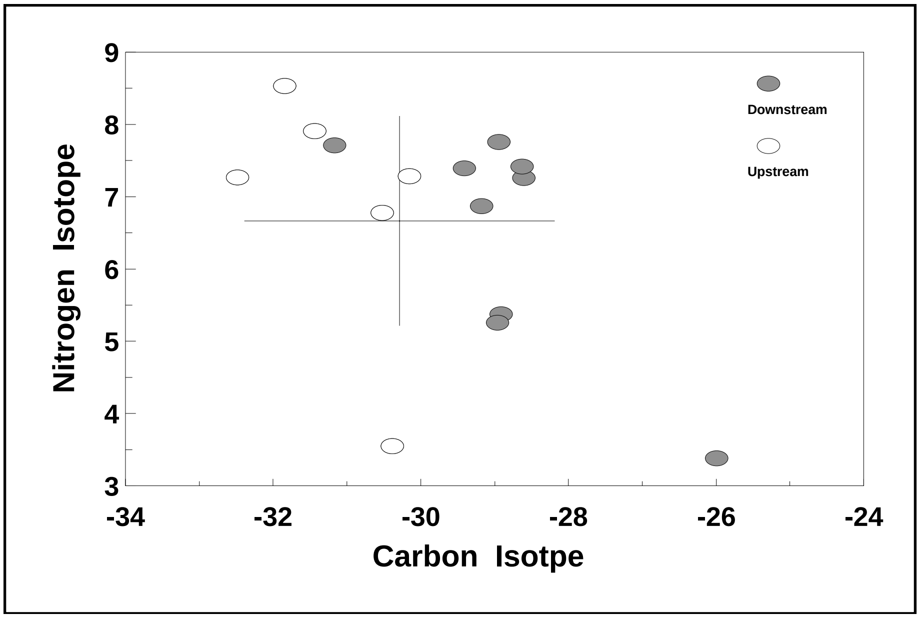


Figure A.5 Carbon (δ13C) and nitrogen (δ15N) cross-plot of the invertebrate Stable Isotopes analytical results for Mill Creek. Upstream and downstream samples are plotted individually and do not differ significantly (t-test P>0.05) on the carbon or nitrogen axes.

Mean study site carbon (δ13C) and nitrogen (δ15N) isotope values were further assessed with significant analysis of variance followed by multiple comparisons of means using the conservative Tukey's HSD post hoc test (Cox, 1987) to determine the significance of observed differences in mean study site isotope values. Testing results are presented in Table A.9 along with coefficients of variation for each isotope at each study site.

Table A.9. Mean study site isotope signatures (δ13C and δ15N) and isotope coefficients of variation (CV). All study site δ13C and δ15N tested as significantly different from one another using Tukey's HSD test (P<0.05). Coefficients of variation for the isotope data are expressed in percent terms.

Site	δ13C	δ15N	δ13C C V	δ15N CV
Blair Creek	- 28.61	9.44	5.25	16.36
Bechtel Creek	- 30.28	6.67	6.94	21.78
Mill Creek	- 32.92	10.43	6.32	11.11

Carbon variability within each study site is similar, although lowest in Blair Creek. Nitrogen variability differs between sites and may correlate with either discharge or flow variablity, although flow data have not been collated in a form suitable for comparative testings.

APPENDIX B: FLOW ANALYSIS RESULTS

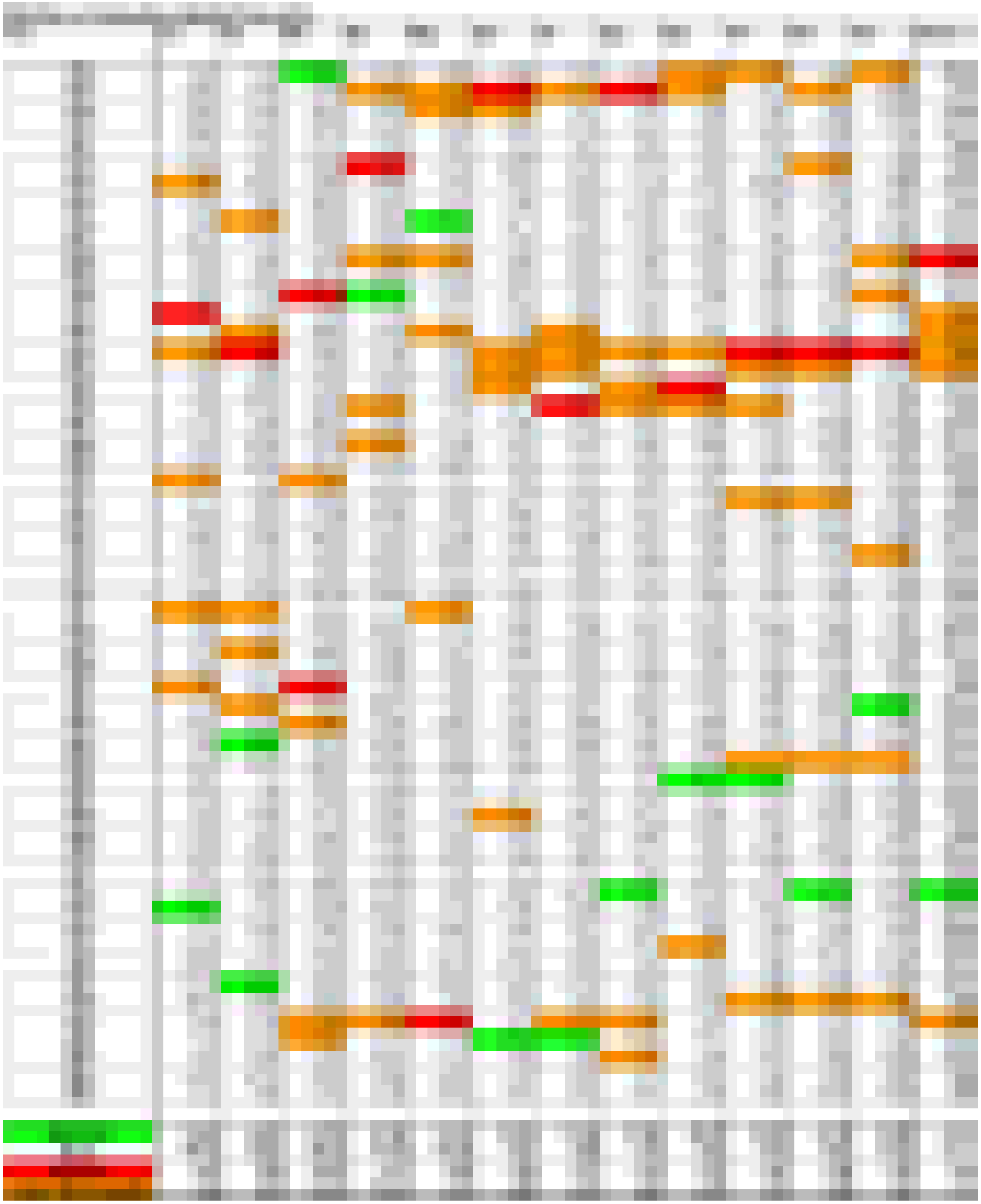
Period of Record:

1.	NITH RIVER AT CANNING	1948-2003
2.	ERAMOSA RIVER REACH	1963-2002
3.	BLAIR CREEK REACH	N/A
4.	MILL CREEK REACH	1991-2002
5.	WHITEMANS CREEK REACH	1962-2002
6.	GRAND RIVER AT BLAIR, DOON AND GALT REACHES	1974-2002
7.	EXCEPTIONAL WATERS REACH	1978-2002
8.	CARROLL CREEK	N/A

Order of Figures and Tables in this appendix are as follows:

1. Mean monthly flow summary table
2. 7-Day low flows summary table
3. 15-Day low flows summary table
4. 30-Day low flow summary table
5. Annual 7-Day Low flows (9 tables, 9 charts)
6. 7-Day Low flow statistics table
7. Running average summary table
8. Running average summary chart
9. Running average ranked summary chart
10. Percentile flow chart: flow by day of year
11. Monthly duration curves chart
12. Annual maximum instantaneous flow chart
13. Annual daily maximum flow chart
14. Maximum daily flows by month chart
15. High flow frequency table

B-1: NITH RIVER AT CANNING REACH



2. Nith River at Canning 7 Day Low Flows (m3/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	19.60	11.94	33.56	19.60	13.17	7.59	5.17	6.67	11.05	8.86	10.58	20.20	3.52	11.10	3.72	6.04	Jan-Apr	May-Sep	Oct-Dec
Average	4.71	4.94	7.63	9.13	5.24	3.51	2.75	2.51	2.78	3.26	4.32	5.84	2.18	3.89	2.27	3.14	7	46	2
Minimum	1.72	1.72	1.83	4.35	2.69	1.74	1.42	1.35	1.38	1.56	1.67	1.71	1.35	1.72	1.35	1.56			
Lower 10 Percentile	2.08	2.46	3.57	5.93	3.19	2.14	1.63	1.63	1.68	2.05	2.42	2.92	1.50	1.99	1.50	2.02			

3. Nith River at Canning 15 Day Low Flows (m3/s)

Maximum	19.60	16.15	48.49	29.24	18.33	14.77	9.91	7.15	14.83	11.69	14.09	16.31	3.78	11.10	4.15	6.49	Sum of occurances by Season		
Average	5.44	5.54	9.22	12.71	6.43	4.17	3.14	2.69	3.10	3.40	4.73	6.78	2.29	4.25	2.41	3.21	Jan-Apr	May-Sep	Oct-Dec
Minimum	1.76	1.73	1.86	4.78	2.87	1.82	1.54	1.49	1.45	1.59	1.67	1.81	1.45	1.73	1.45	1.59	7	46	2
Lower 10 Percentile	2.33	2.58	3.70	6.78	3.79	2.37	1.81	1.65	1.75	2.06	2.47	3.08	1.58	2.08	1.58	2.06			

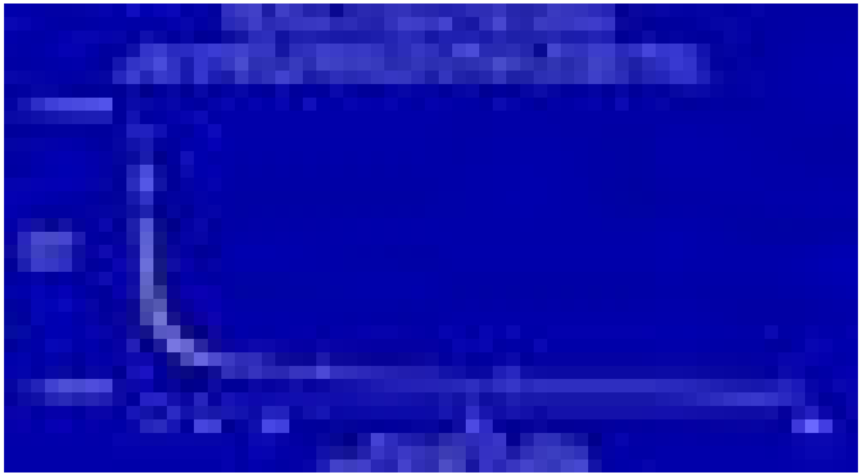
4. Nith River at Canning 30 Day Low Flows (m3/s)

Maximum	21.87	16.76	32.14	40.46	25.47	16.21	11.14	11.84	16.14	23.63	14.49	21.81	4.21	15.71	5.12	11.22	Sum of occurances by Season		
Average	9.24	9.16	13.52	19.06	11.18	6.56	4.25	3.59	3.85	4.39	6.78	9.05	2.54	7.45	2.65	3.99	Jan-Apr	May-Sep	Oct-Dec
Minimum	1.81	1.74	1.88	10.00	3.32	1.99	1.75	1.66	1.49	1.55	1.64	1.94	1.49	1.74	1.49	1.55	5	47	7
Lower 10 Percentile	2.84	2.73	10.06	10.18	10.00	2.77	2.01	1.88	1.89	2.01	2.48	3.16	1.75	2.54	1.80	2.01			

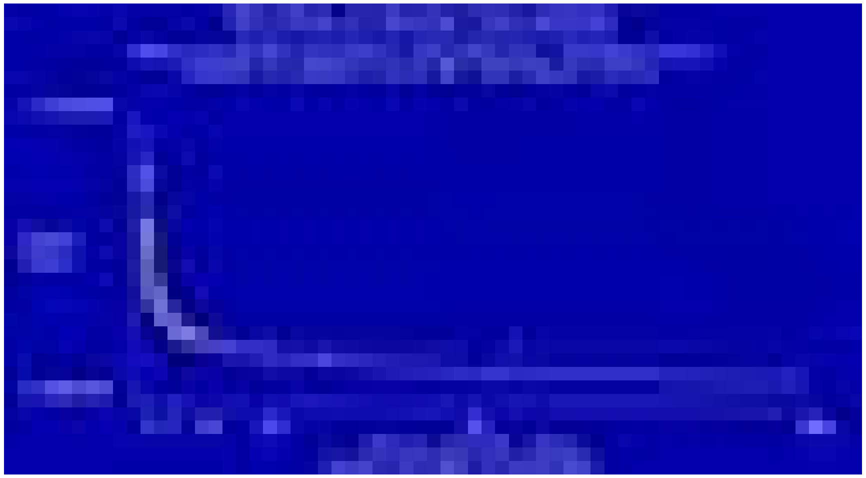
5. Low Flow Frequency Plots

Two Parameter Log Normal Method of Moments				
Mean	2.154			
Variance	0.291			
Coefficient of Skew	0.521			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	2.23	2.09	1.95	0.07
5	1.83	1.70	1.56	0.07
10	1.68	1.52	1.37	0.08
20	1.56	1.39	1.22	0.09
50	1.45	1.26	1.07	0.10
100	1.39	1.18	0.97	0.11

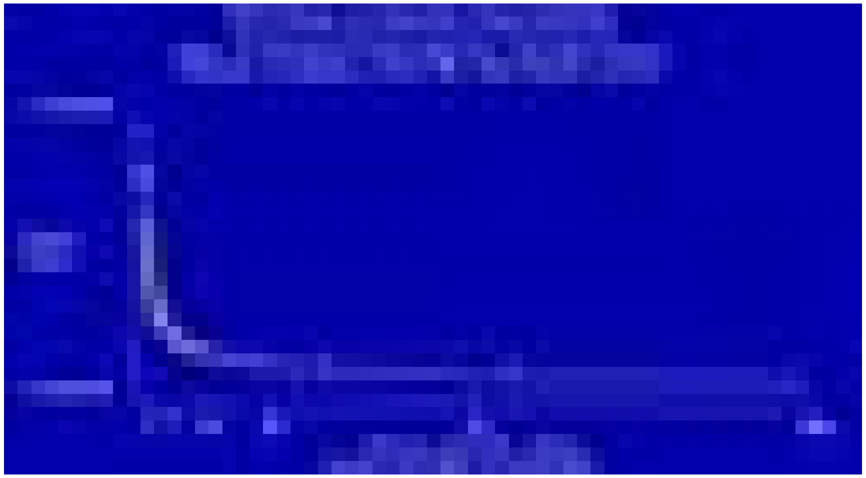
Two Parameter Log Normal Maximum Likelihood				
Mean	0.737			
Variance	0.061			
Coefficient of Skew	0.111			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	2.23	2.09	1.95	0.07
5	1.83	1.70	1.57	0.07
10	1.66	1.52	1.39	0.07
20	1.53	1.39	1.25	0.07
50	1.40	1.26	1.11	0.07
100	1.33	1.18	1.03	0.08



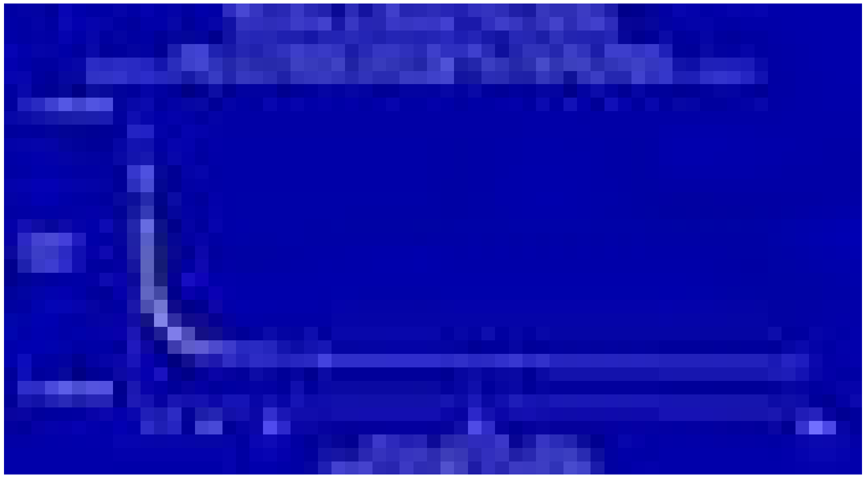
Three Parameter Log Normal Method of Moments				
Mean	2.154			
Variance	0.291			
Coefficient of Skew	0.521			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	2.26	2.11	1.95	0.08
5	1.84	1.70	1.55	0.07
10	1.66	1.50	1.35	0.08
20	1.54	1.35	1.16	0.10
50	1.44	1.19	0.95	0.12
100	1.39	1.10	0.80	0.15



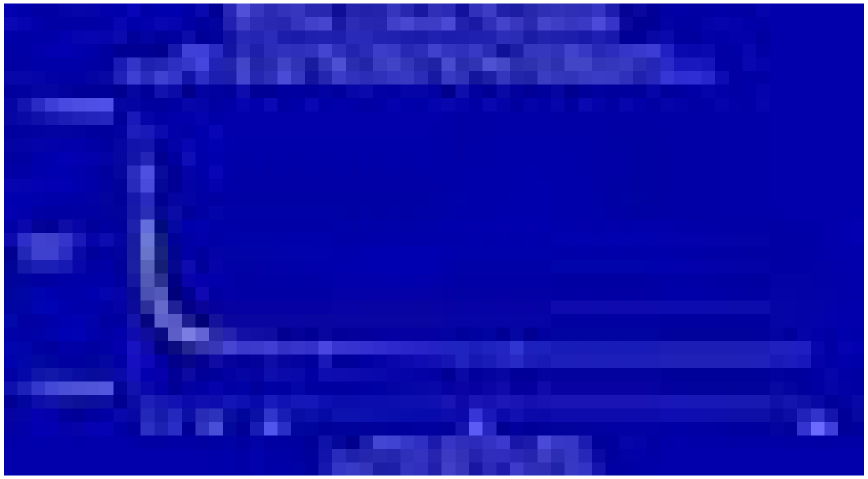
Type III External Distribution Method of Moments				
Mean	2.154	Alpha		2.168
Variance	0.286	Beta		2.296
Coefficient of Skew	0.536	Gamma		1.054
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	2.27	2.10	1.94	0.08
5	1.81	1.68	1.54	0.07
10	1.63	1.49	1.36	0.07
20	1.53	1.37	1.21	0.08
50	1.47	1.26	1.05	0.11
100	1.46	1.20	0.95	0.13



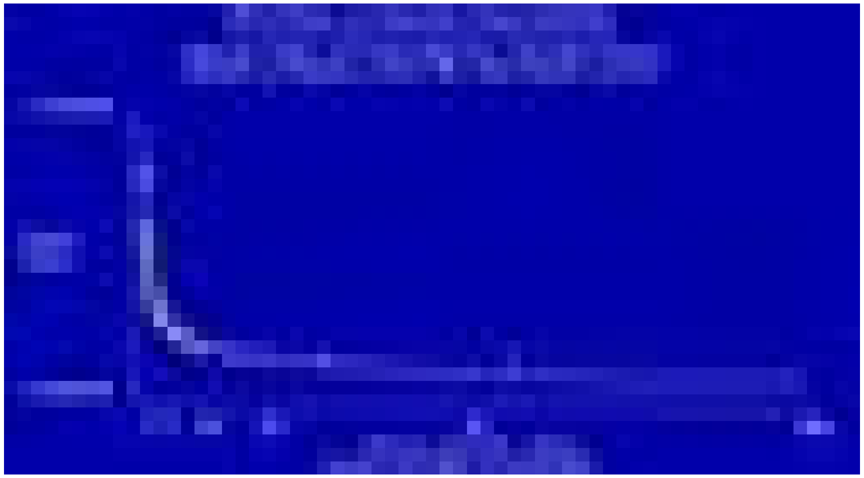
Type III External Distribution Method of Smallest Observed Drought				
Mean	2.154	Alpha		1.716
Variance	0.286	Beta		2.263
Coefficient of Skew	0.851	Gamma		1.26
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	2.11	2.07	2.04	0.02
5	1.75	1.68	1.61	0.04
10	1.69	1.53	1.38	0.08
20	1.68	1.44	1.20	0.12
50	1.72	1.37	1.02	0.18
100	1.76	1.33	0.90	0.22



Type III External Distribution Method of Maximum Likelihood				
Mean	2.151		Alpha	1.716
Variance	0.306		Beta	2.263
Coefficient of Skew	1.020		Gamma	1.264
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	2.09	2.05	2.01	0.02
5	1.75	1.67	1.59	0.04
10	1.71	1.53	1.35	0.09
20	1.73	1.45	1.17	0.14
50	1.80	1.39	0.98	0.21
100	1.88	1.36	0.85	0.26

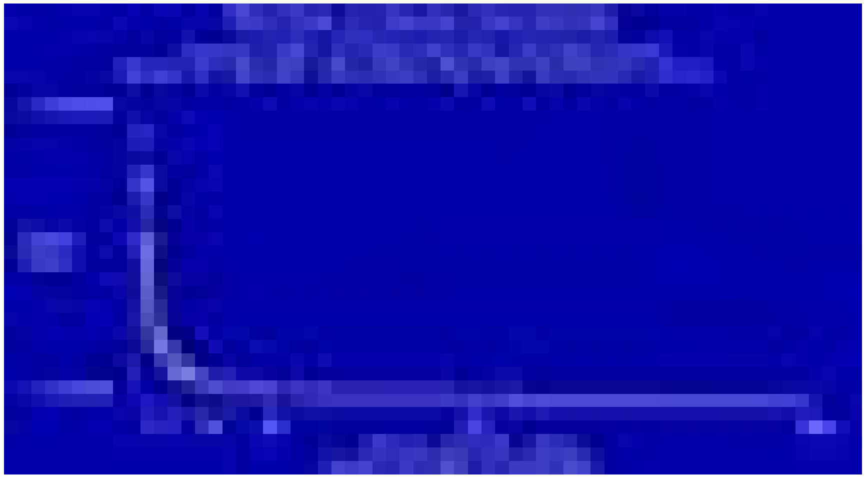


Pearson Type III External Distribution Method of Moments				
Mean	2.154		Alpha	0.172
Variance	0.291		Beta	9.893
Coefficient of Skew	0.636		Gamma	0.457
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	2.17	2.10	2.03	0.04
5	0.00	1.69	0.00	0.00
10	1.54	1.51	1.49	0.01
20	1.48	1.37	1.27	0.05
50	1.43	1.24	1.04	0.10
100	1.42	1.15	0.89	0.14



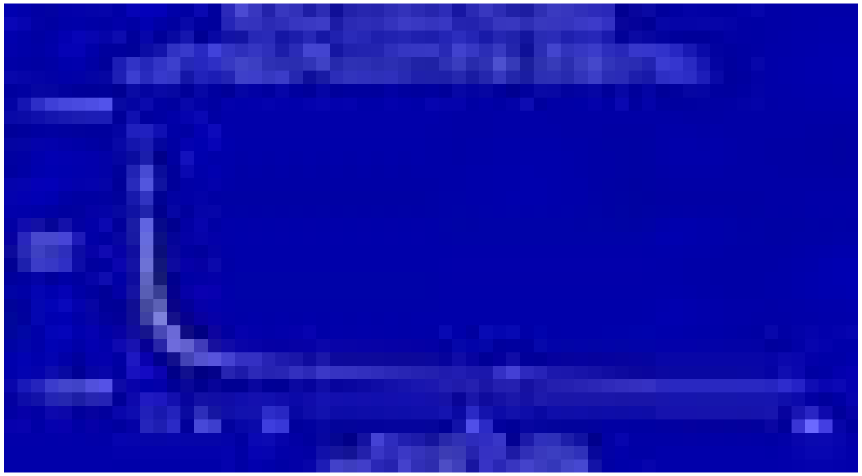
Pearson Type III External Distribution
Method of Maximum Likelihood

Mean	2.154		Alpha	0.382
Variance	0.343		Beta	2.347
Coefficient of Skew	1.306		Gamma	1.257
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	2.17	2.03	1.89	0.07
5	1.77	1.67	1.56	0.05
10	1.63	1.53	1.44	0.05
20	1.53	1.45	1.36	0.04
50	1.44	1.37	1.30	0.04
100	1.40	1.34	1.27	0.03



Pearson Type III External Distribution
Method of Monments (indirect)

Mean	0.737		Alpha	0.017
Variance	0.061		Beta	219.83
Coefficient of Skew	0.135		Gamma	-2.927
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	2.23	2.08	1.93	0.07
5	1.82	1.70	1.57	0.06
10	1.66	1.53	1.40	0.07
20	1.55	1.41	1.26	0.07
50	1.45	1.28	1.11	0.09
100	1.40	1.21	1.01	0.10

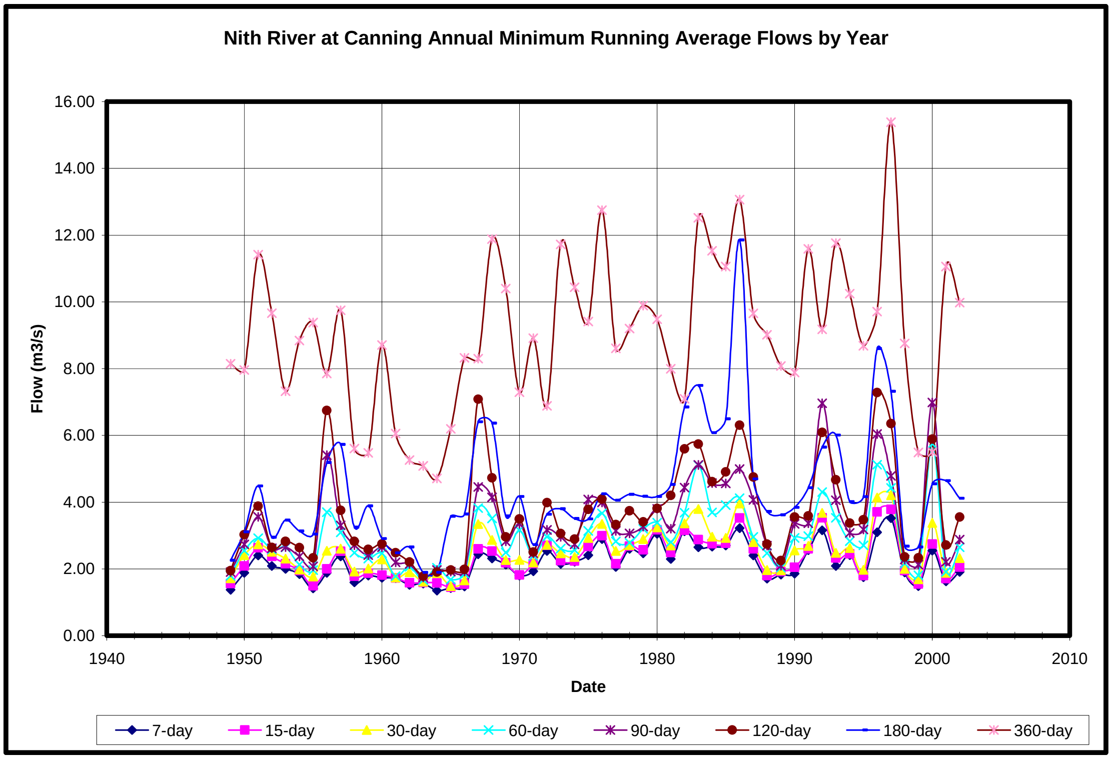


6. 7-DAY LOW FLOW STATISTICS

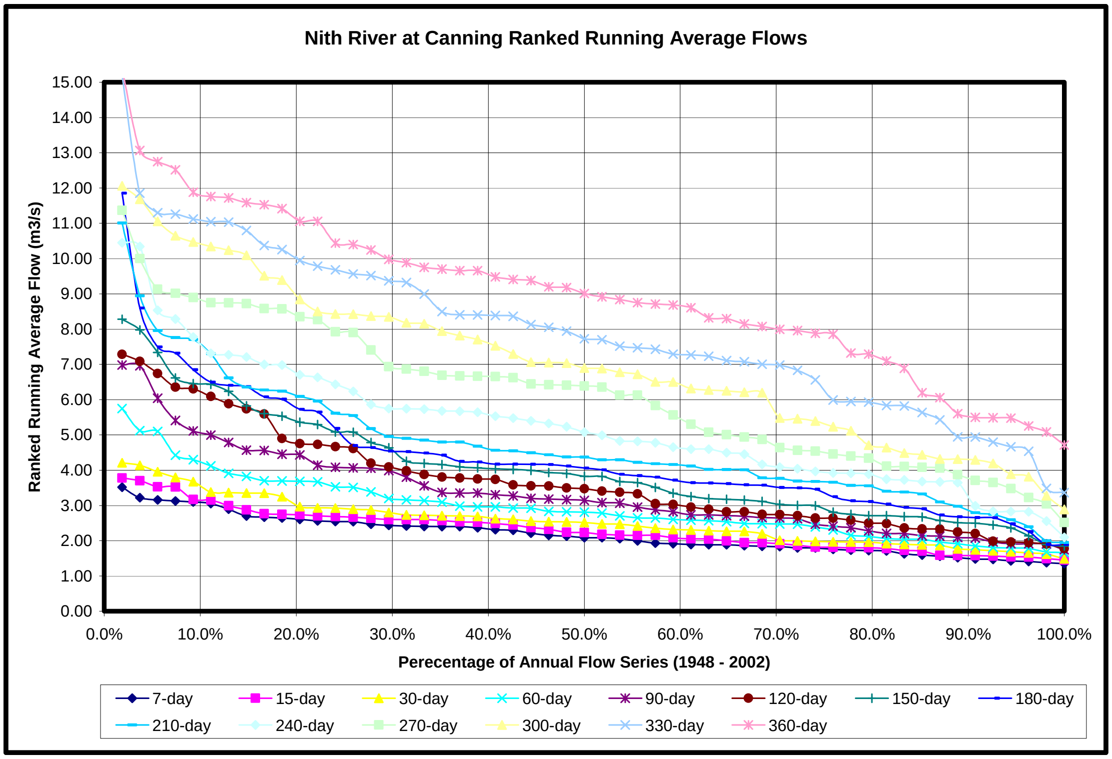
Low Flow Stastics Nith River at Canning 1948 to 2002	**Annual Return Period 7-day Flow (m3/s)**						**Summer Return Period 7-day Flow (m3/s)**					
Statistical Method	**2**	**5**	**10**	**20**	**50**	**100**	**2**	**5**	**10**	**20**	**50**	**100**
Two Parameter Log Normal Method of Moments	2.090	1.698	1.523	1.393	1.259	1.177	2.169	1.733	1.541	1.398	1.254	1.166
Two Parameter Log Normal Maximum Likelihood	2.090	1.698	1.523	1.393	1.259	1.177	2.169	1.733	1.541	1.398	1.254	1.166
Three Parameter Log Normal Method of Moments	2.109	1.695	1.501	1.352	1.194	1.095	2.187	1.729	1.519	1.359	1.192	1.089
Type III External Distribution Method of Moments	**2.103**	**1.676**	**1.494**	**1.370**	**1.260**	**1.203**	**2.178**	**1.707**	**1.514**	**1.386**	**1.276**	**1.222**
Type III External Distribution Method of Smallest Observed Drought	2.070	1.680	1.533	1.441	1.367	1.332	2.149	1.712	1.549	1.448	1.367	1.331
Type III External Distribution Method of Maximum Likelihood	2.048	1.667	1.531	1.450	1.389	1.362	2.124	1.696	1.546	1.458	1.391	1.362
Pearson Type III External Distribution Method of Moments	2.098	1.693	1.510	1.374	1.235	1.151	2.172	1.726	1.532	1.391	1.250	1.167
Pearson Type III External Distribution Method of Maximum Likelihood	2.033	1.666	1.532	1.446	1.373	1.337	2.110	1.698	1.548	1.452	1.371	1.331
Pearson Type III External Distribution Method of Monments (indirect)	2.079	1.695	1.529	1.406	1.281	1.206	2.157	1.731	1.548	1.415	1.280	1.199
Maximum	2.109	1.698	1.533	1.450	1.389	1.362	**2.187**	**1.733**	**1.549**	**1.458**	**1.391**	**1.362**
Average	2.080	1.685	1.520	1.403	1.291	1.227	**2.157**	**1.718**	**1.538**	**1.412**	**1.293**	**1.226**
Minimum	2.033	1.666	1.494	1.352	1.194	1.095	**2.110**	**1.696**	**1.514**	**1.359**	**1.192**	**1.089**

7. Nith River at Canning Minimum Annual Running Average Flows (m3/s)

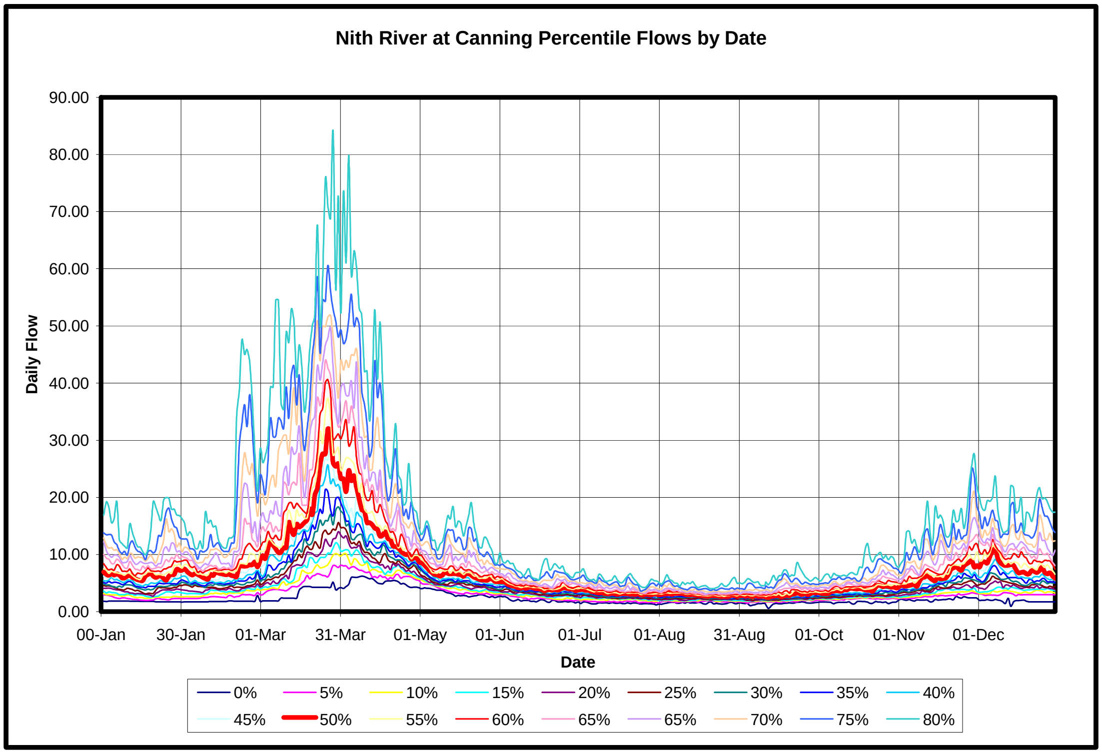
	7-day	**15-day**	**30-day**	**60-day**	**90-day**	**120-day**	**150-day**	**180-day**	**210-day**	**240-day**	**270-day**	**300-day**	**330-day**	**360-day**
Maximum	3.52	3.78	4.21	5.74	6.98	7.28	8.28	11.85	11.01	10.45	11.37	12.07	15.19	15.38
Average	2.16	2.30	2.54	2.93	3.35	3.69	4.05	4.37	4.70	5.26	6.17	7.03	7.95	9.00
Minimum	1.35	1.45	1.49	1.67	1.74	1.77	1.85	1.89	1.95	2.10	2.52	2.89	3.36	4.71
Lower 10 Percentile	1.49	1.58	1.75	1.87	2.08	2.22	2.50	2.66	2.85	3.18	3.76	4.30	4.94	5.53


Nith River at Canning Annual Minimum Running Average Flows by Year
Flow (m3/s)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1940
1950
1960
1970
1980
1990
2000
2010
Date
7-day
15-day
30-day
60-day
90-day
120-day
180-day
360-day

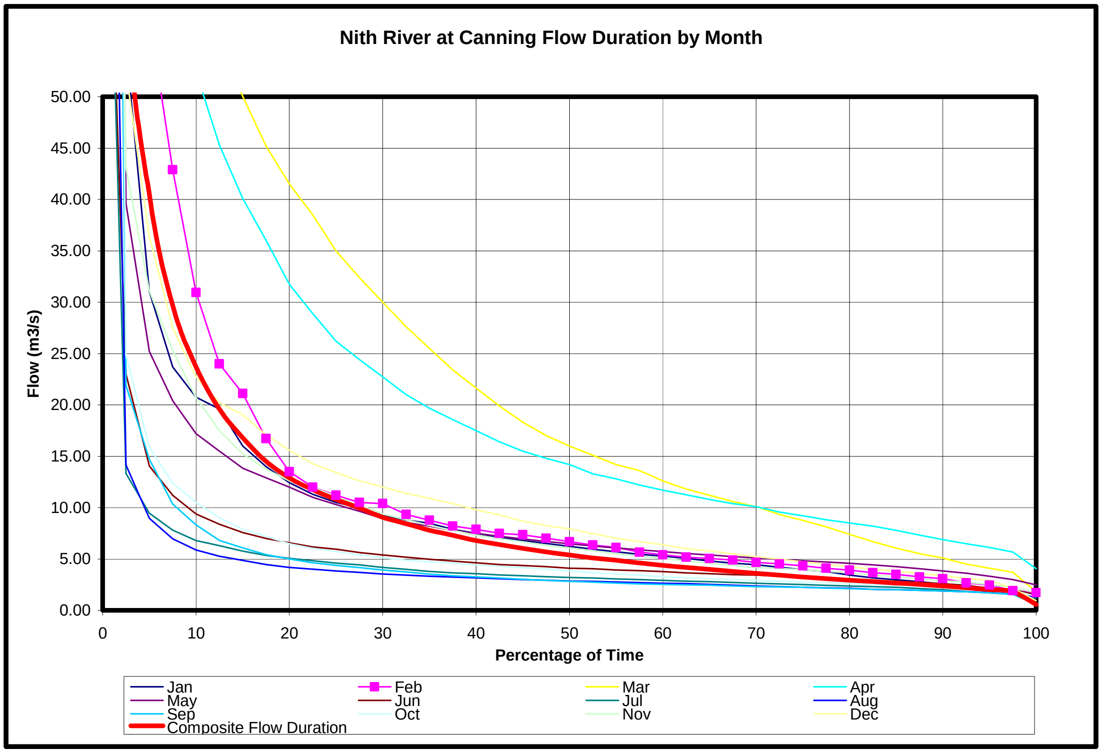
8.


Nith River at Canning Ranked Running Average Flows
Ranked Running Average Flow (m3/s)
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%
Perecentage of Annual Flow Series (1948 - 2002)
7-day
15-day
30-day
60-day
90-day
120-day
150-day
180-day
210-day
240-day
270-day
300-day
330-day
360-day

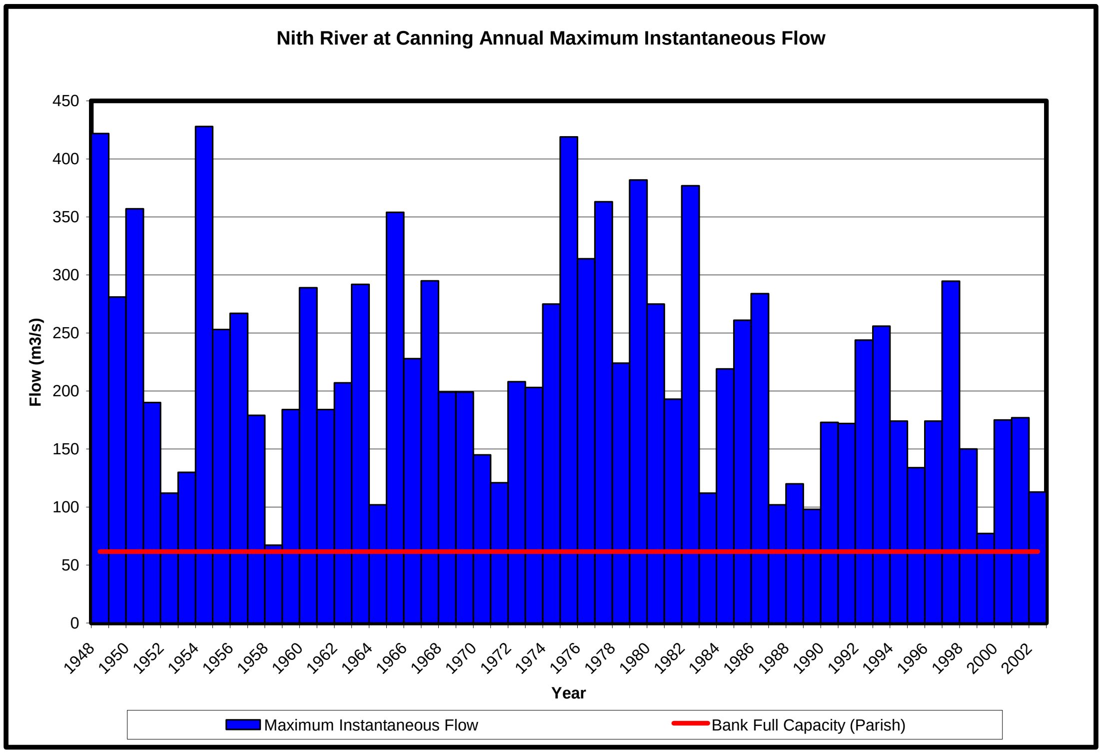
9.


Nith River at Canning Percentile Flows by Date
Daily Flow
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
00-Jan
30-Jan
01-Mar
31-Mar
01-May
01-Jun
01-Jul
01-Aug
31-Aug
01-Oct
01-Nov
01-Dec
Date
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
65%
70%
75%
80%

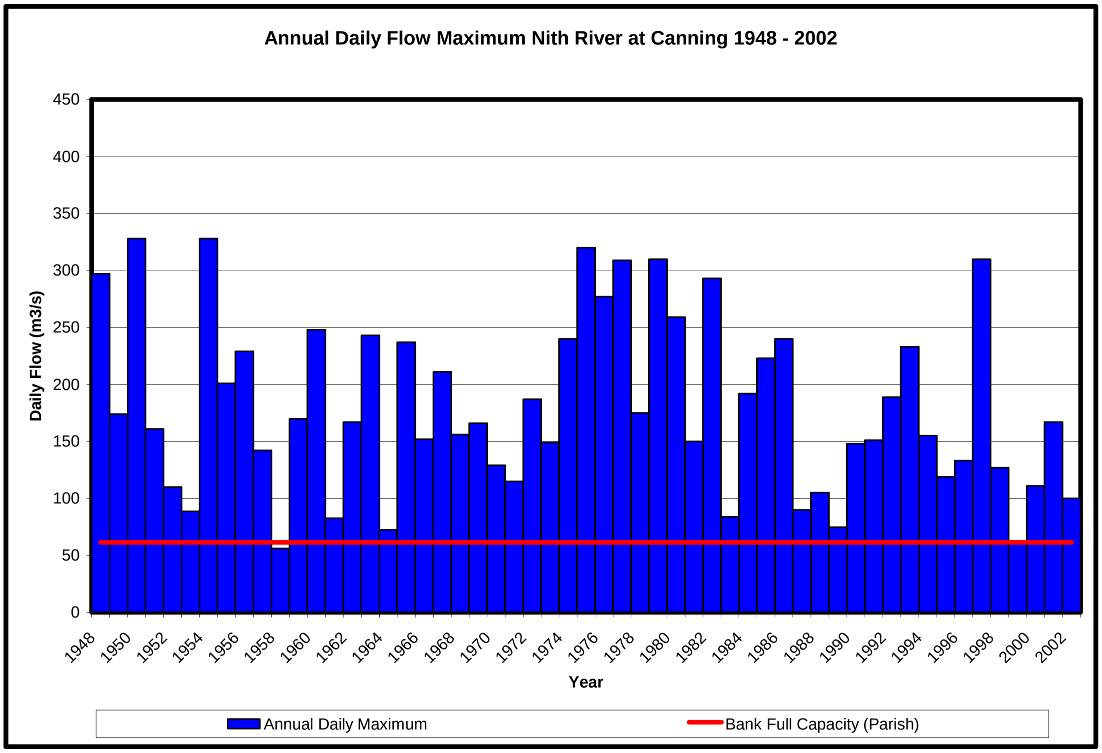
10.


Nith River at Canning Flow Duration by Month
Flow (m3/s)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Percentage of Time
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Composite Flow Duration

11.

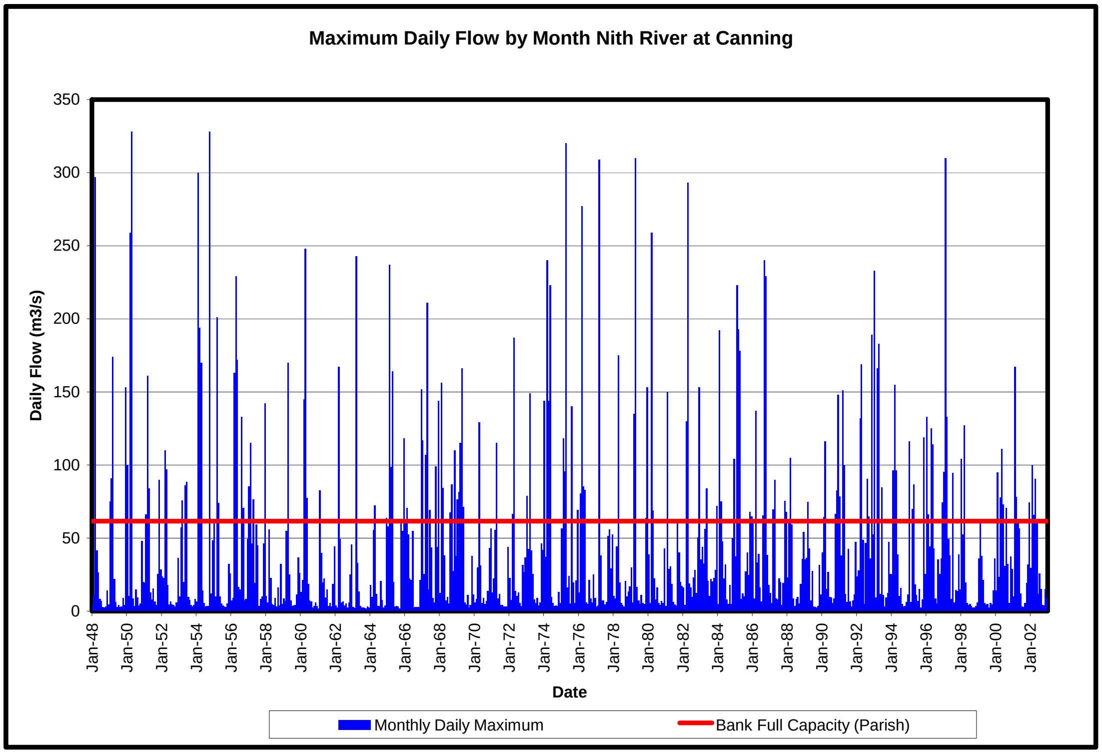

Nith River at Canning Annual Maximum Instantaneous Flow
Flow (m3/s)
450
400
350
300
250
200
150
100
50
0
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year
Maximum Instantaneous Flow
Bank Full Capacity (Parish)

12.


Annual Daily Flow Maximum Nith River at Canning 1948 - 2002
Daily Flow (m3/s)
450
400
350
300
250
200
150
100
50
0
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year
Annual Daily Maximum
Bank Full Capacity (Parish)

13.

14.



15. High Flow Frequency Table (Nith River at Canning 1948 to 2002)

Return Period (Years)	Extreme Value (m3/s)	Log Pearson (m3/s)	Three P Log Normal (m3/s)	Walkby (m3/s)
1.003	27.3	41.4	**41.5**	62.4
1.05	85.8	87.9	**91.2**	85.2
1.25	141	142	**142**	139
2	210	213	**209**	209
5	297	298	**295**	302
10	351	346	**350**	357
20	400	386	**401**	402
50	460	432	**465**	448
100	502	461	**513**	476
200	543	488	**560**	498
500	593	519	**622**	522

B-2: ERAMOSA RIVER REACH

Eramosa River at Watson Road Mean Monthly Flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1963	1.08	0.93	4.59	2.74	2.34	0.87	0.82	0.62	0.52	0.50	0.63	0.51	1.35
1964	1.22	0.78	2.79	3.62	2.09	1.19	1.26	1.44	0.62	0.63	0.72	1.69	1.50
1965	2.12	4.58	2.95	10.47	2.59	0.65	0.85	0.75	0.82	2.04	2.54	3.62	2.83
1966	2.35	2.82	5.23	3.41	2.19	1.46	0.52	0.52	0.42	0.50	1.39	2.54	1.95
1967	2.07	2.15	3.16	8.57	2.58	3.26	2.94	1.08	0.84	1.93	2.25	3.31	2.84
1968	1.70	4.30	7.15	3.73	2.26	1.32	1.02	2.85	2.15	1.69	2.78	2.75	2.81
1969	2.64	2.99	5.48	8.40	3.88	1.58	0.87	0.79	0.41	0.66	1.75	0.99	2.54
1970	0.82	0.97	1.36	6.49	2.49	0.96	1.14	0.85	1.21	1.48	2.20	3.06	1.92
1971	1.64	1.95	2.81	7.95	1.99	2.00	1.48	1.62	1.06	0.81	1.06	2.47	2.24
1972	1.65	1.48	2.18	12.00	3.29	2.32	1.71	0.79	0.79	1.92	2.18	2.59	2.74
1973	3.04	2.91	10.72	5.21	3.65	1.92	0.84	0.84	0.50	0.97	2.45	1.79	2.90
1974	2.56	2.56	7.56	6.47	6.44	2.32	1.06	0.76	0.64	0.78	1.72	1.17	2.84
1975	1.49	2.09	4.84	7.36	2.91	1.67	0.71	0.86	1.18	1.06	1.54	1.93	2.30
1976	1.37	3.75	11.06	6.63	4.74	1.99	1.61	1.46	1.75	1.83	1.47	1.24	3.24
1977	0.65	0.66	7.90	4.76	1.62	1.06	0.88	1.27	2.24	3.41	3.46	4.16	2.67
1978	2.66	1.85	3.08	11.27	4.32	1.53	0.72	0.70	1.71	1.43	1.66	1.74	2.72
1979	1.94	1.43	7.92	8.63	4.19	1.81	1.25	1.49	1.66	1.36	2.52	3.64	3.15
1980	2.12	1.10	5.34	5.94	3.08	1.95	1.67	0.95	1.03	1.44	1.28	1.89	2.32
1981	0.94	5.44	2.74	2.99	1.86	1.20	1.66	1.51	2.16	2.98	2.80	1.75	2.34
1982	1.24	1.11	3.24	10.93	2.63	3.56	1.61	1.18	1.58	1.49	3.38	5.60	3.13
1983	3.04	3.54	3.86	4.98	5.35	2.15	0.90	1.21	1.22	1.24	1.51	1.98	2.58
1984	1.11	4.89	4.49	6.08	3.05	1.95	0.91	0.64	1.23	1.00	1.93	2.41	2.48
1985	1.82	3.53	9.13	10.69	2.43	1.63	1.55	1.45	2.40	1.90	6.09	3.60	3.85
1986	2.45	1.99	6.03	3.98	2.82	2.08	3.05	3.21	9.06	6.93	3.42	3.47	4.04
1987	2.56	1.38	5.43	7.00	1.83	1.09	1.17	0.75	0.71	1.09	1.47	2.43	2.24
1988	1.83	2.19	4.35	3.86	1.91	0.62	0.51	0.53	0.71	1.14	2.00	1.49	1.76
1989	1.83	1.34	3.56	3.14	2.35	2.70	0.60	0.48	0.39	0.65	1.65	0.64	1.61
1990	1.64	2.79	6.05	2.88	2.71	1.22	0.87	0.88	0.62	2.31	2.66	4.13	2.40
1991	3.50	2.87	7.08	7.60	2.98	1.24	1.29	1.14	0.52	0.88	0.93	1.94	2.66
1992	1.68	1.49	2.35	5.69	3.35	1.49	1.68	2.53	2.95	3.20	7.10	3.90	3.12
1993	6.32	1.93	3.39	7.47	2.46	2.68	1.28	0.79	0.88	1.20	1.44	1.53	2.62
1994	0.74	1.58	3.64	5.96	3.53	1.26	0.67	0.48	0.41	0.58	1.00	1.02	1.74
1995	4.34	1.15	4.05	3.17	2.63	1.53	0.86	1.43	0.38	1.03	3.37	2.17	2.18
1996	4.03	3.99	3.93	8.29	5.83	4.08	1.59	1.06	2.96	2.73	2.57	4.40	3.79
1997	4.72	6.93	7.51	6.59	4.24	1.60	0.84	0.75	0.71	0.76	1.29	0.97	3.08
1998	2.76	1.80	5.56	3.30	1.64	1.15	0.70	0.44	0.27	0.48	0.61	0.87	1.63
1999	1.54	1.91	2.14	2.29	0.85	0.81	0.56	0.32	0.48	0.84	1.95	1.41	1.26
2000	1.05	2.26	2.49	2.77	3.53	3.85	2.06	2.26	0.93	0.76	1.25	1.23	2.04
2001	1.03	6.20	3.18	6.14	2.09	1.56	0.81	0.43	0.44	1.34	1.47	2.47	2.26
2002	1.64	3.02	3.79	5.09	3.80	2.08	0.85	0.54	0.56	0.75	1.09	0.90	2.01
Maximum	6.32	6.93	11.06	12.00	6.44	4.08	3.05	3.21	9.06	6.93	7.10	5.60	4.04
Average	2.12	2.57	4.85	6.11	3.01	1.78	1.18	1.09	1.28	1.49	2.11	2.28	2.49
Minimum	0.65	0.66	1.36	2.29	0.85	0.62	0.51	0.32	0.27	0.48	0.61	0.51	1.26
Lower 10 Percentile	1.02	1.08	2.47	2.98	1.85	0.95	0.67	0.48	0.41	0.62	1.00	0.96	1.63

2. Eramosa River at Watson Road 7 Day Low Flows (m3/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	3.62	2.19	6.42	5.47	3.54	2.43	1.32	1.21	3.33	3.99	2.79	3.15	1.07	2.19	1.07	2.50	Jan-Apr	May-Sep	Oct-Dec
Average	1.28	1.31	1.89	2.99	1.78	1.07	0.69	0.57	0.71	0.90	1.14	1.40	0.49	1.11	0.50	0.84	1	37	3
Minimum	0.13	0.45	0.39	1.27	0.61	0.38	0.17	0.18	0.11	0.31	0.36	0.36	0.11	0.13	0.11	0.31			
Lower 10 Percentile	0.57	0.77	0.83	1.51	1.20	0.62	0.39	0.30	0.30	0.36	0.57	0.61	0.27	0.54	0.27	0.36			

3. Eramosa River at Watson Road 15 Day Low Flows (m3/s)

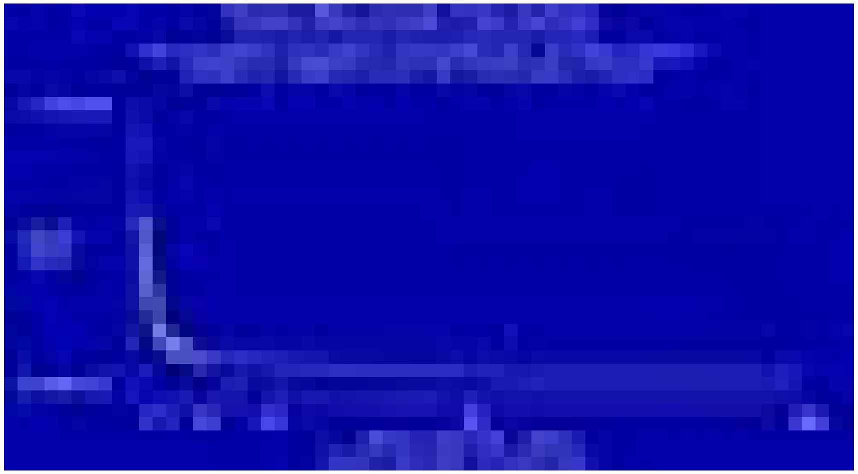
Maximum	3.72	2.70	6.41	7.38	5.31	3.12	1.70	1.42	4.71	4.40	3.58	3.78	1.11	2.94	1.11	2.75	Sum of occurances by Season		
Average	1.40	1.42	2.05	3.71	2.25	1.28	0.83	0.66	0.80	0.95	1.27	1.57	0.55	1.21	0.57	0.89	Jan-Apr	May-Sep	Oct-Dec
Minimum	0.27	0.51	0.47	1.67	0.71	0.44	0.26	0.25	0.18	0.29	0.38	0.42	0.18	0.27	0.18	0.29	2	34	5
Lower 10 Percentile	0.58	0.83	0.91	1.83	1.38	0.74	0.47	0.38	0.35	0.38	0.64	0.84	0.33	0.55	0.33	0.38			

4. Eramosa River at Watson Road 30 Day Low Flows (m3/s)

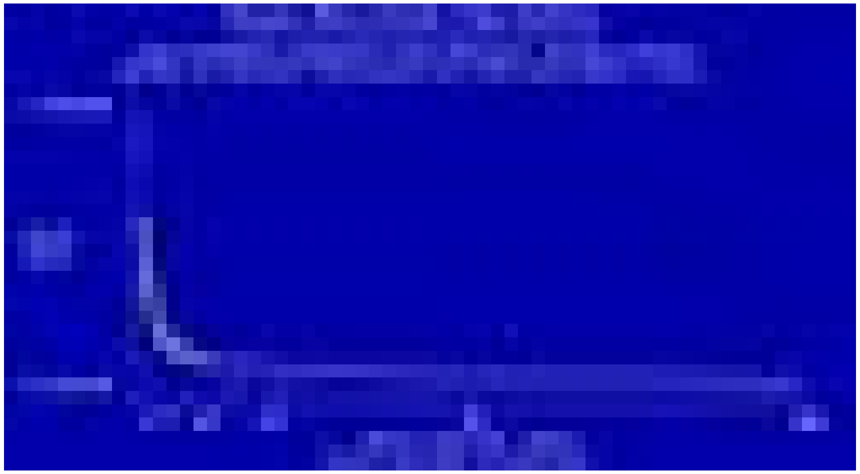
Maximum	4.40	3.88	10.38	10.56	10.57	4.04	2.79	1.98	3.33	10.20	3.26	3.81	1.56	4.48	1.56	3.26	Sum of occurances by Season		
Average	1.62	1.65	2.52	5.18	3.51	1.63	1.03	0.83	0.86	1.16	1.36	1.76	0.65	1.44	0.67	0.98	Jan-Apr	May-Sep	Oct-Dec
Minimum	0.50	0.53	0.63	1.43	0.84	0.62	0.38	0.32	0.25	0.28	0.43	0.48	0.25	0.50	0.25	0.28	5	30	6
Lower 10 Percentile	0.64	0.83	0.94	2.25	1.81	0.96	0.59	0.48	0.38	0.39	0.63	0.89	0.37	0.60	0.38	0.39			

5. Low Flow Frequency Plots

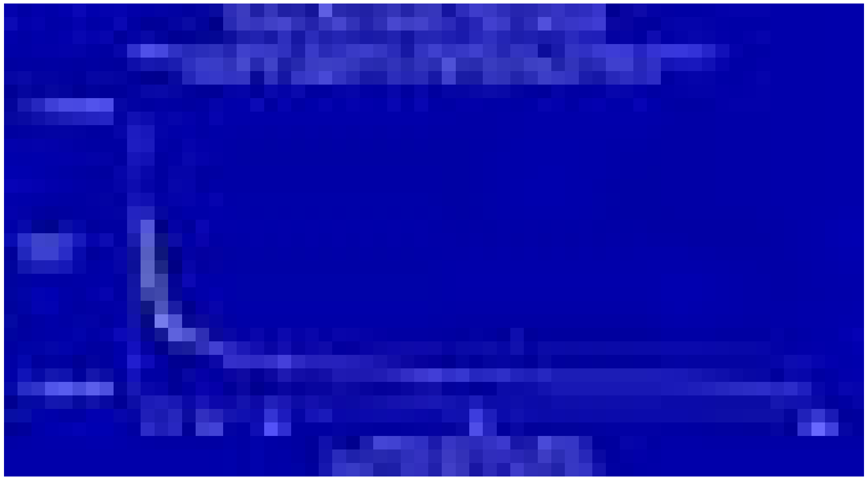
Two Parameter Log Normal				
Method of Moments				
Mean	0.492			
Variance	0.039			
Coefficient of Skew	0.309			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.51	0.46	0.40	0.03
5	0.38	0.33	0.28	0.03
10	0.34	0.28	0.22	0.03
20	0.31	0.24	0.17	0.04
50	0.29	0.21	0.13	0.04
100	0.27	0.19	0.10	0.04



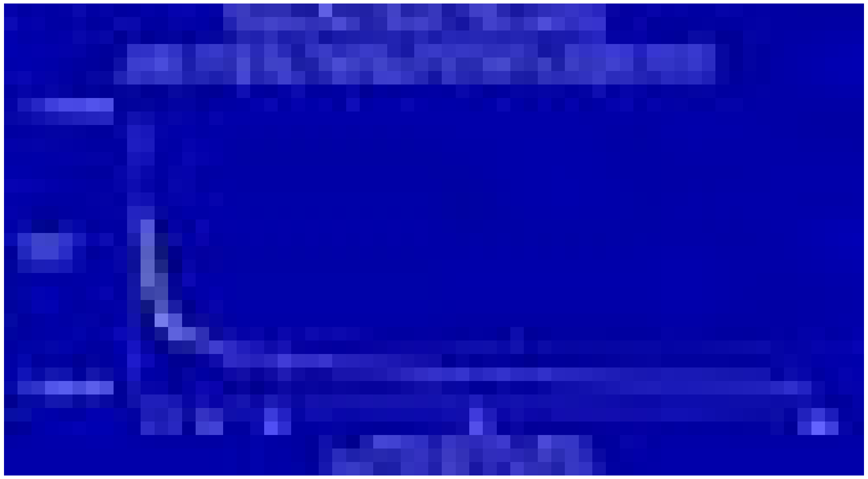
Two Parameter Log Normal				
Maximum Likelihood				
Mean	-0.803			
Variance	0.220			
Coefficient of Skew	-0.905			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.51	0.46	0.40	0.03
5	0.38	0.33	0.29	0.02
10	0.32	0.28	0.23	0.02
20	0.29	0.24	0.20	0.02
50	0.25	0.21	0.16	0.02
100	0.23	0.19	0.14	0.02



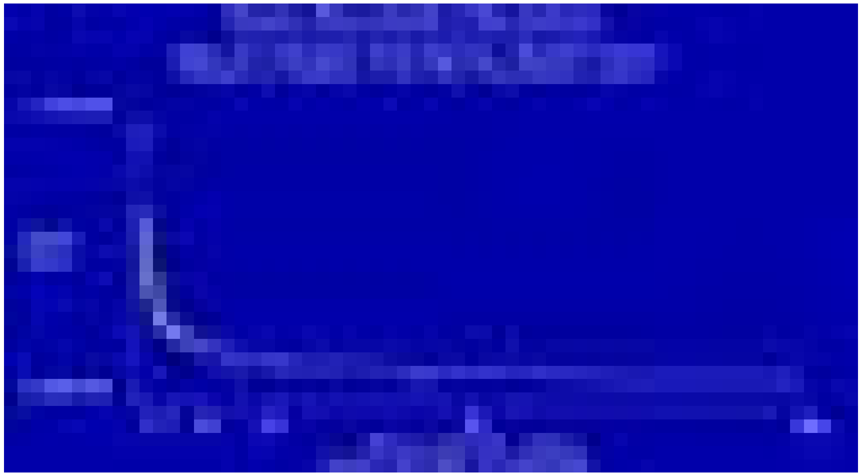
Three Parameter Log Normal				
Method of Moments				
Mean	0.492			
Variance	0.039			
Coefficient of Skew	0.309			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.55	0.48	0.42	0.03
5	0.39	0.32	0.26	0.03
10	0.32	0.25	0.18	0.04
20	0.27	0.19	0.10	0.04
50	0.23	0.12	0.01	0.06
100	0.21	0.08	0.00	0.07



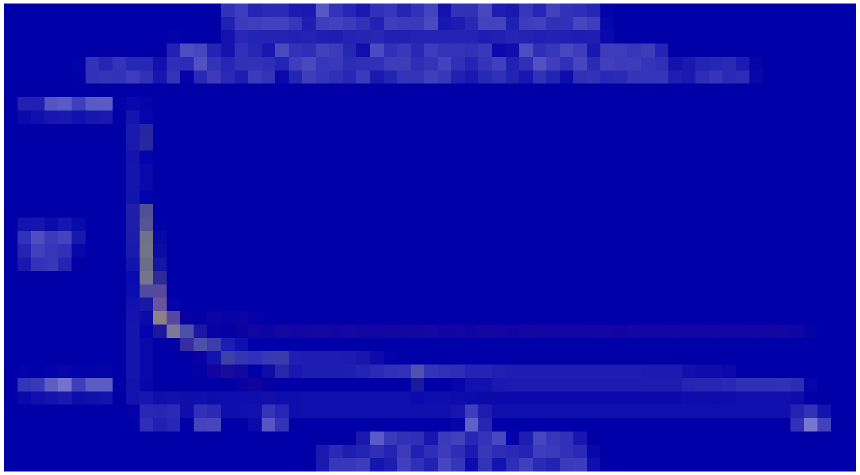
Type III External Distribution				
Method of Moments				
Mean	0.551		Alpha	-1.255
Variance	0.013		Beta	
Coefficient of Skew	0.000		Gamma	
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.55	0.48	0.42	0.03
5	0.39	0.32	0.26	0.03
10	0.32	0.25	0.18	0.04
20	0.27	0.19	0.10	0.04
50	0.23	0.12	0.02	0.05
100	0.21	0.08	0.00	0.06



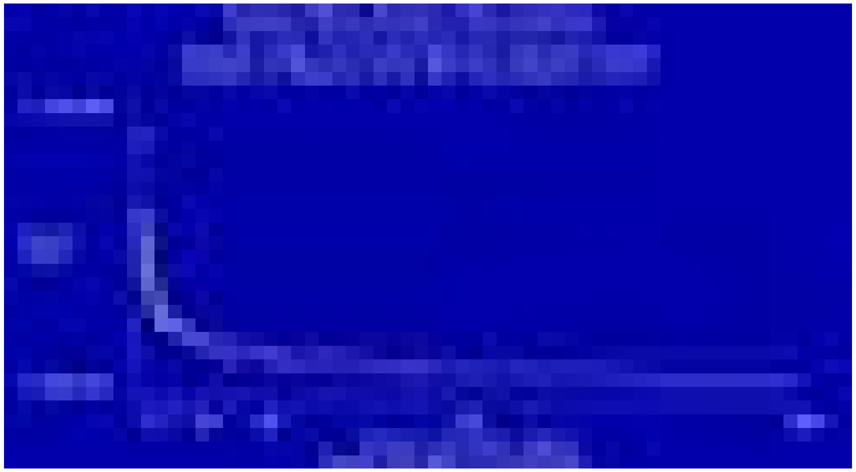
Type III External Distribution				
Method of Smallest Observed Drought				
Mean	0.492		Alpha	2.604
Variance	0.038		Beta	0.551
Coefficient of Skew	0.321		Gamma	0.01993
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.55	0.48	0.41	0.03
5	0.38	0.32	0.26	0.03
10	0.31	0.24	0.18	0.03
20	0.27	0.19	0.11	0.04
50	0.24	0.14	0.04	0.05
100	0.23	0.11	0.00	0.06



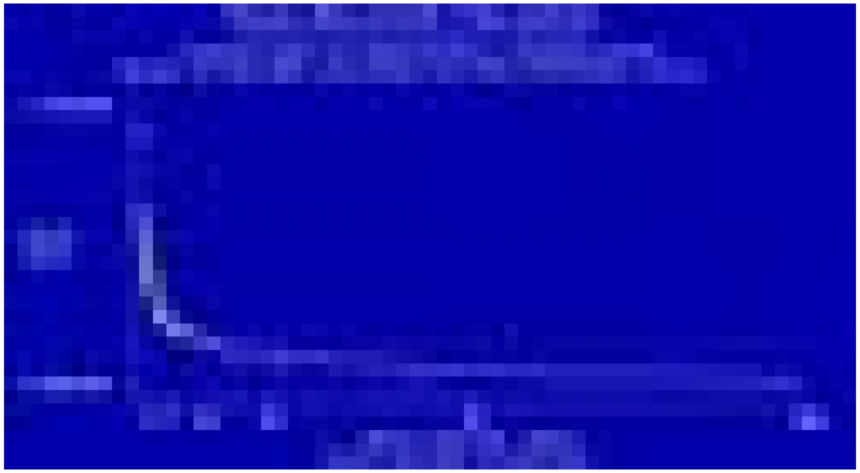
Type III External Distribution Method of Maximum Likelihood				
Mean	0.492		Alpha	3.03
Variance	0.038		Beta	0.556
Coefficient of Skew	0.158		Gamma	-0.04874
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.51	0.49	0.46	0.01
5	0.37	0.32	0.28	0.02
10	0.33	0.24	0.15	0.05
20	0.31	0.18	0.05	0.07
50	0.29	0.12	0.00	0.09
100	0.29	0.08	0.00	0.11



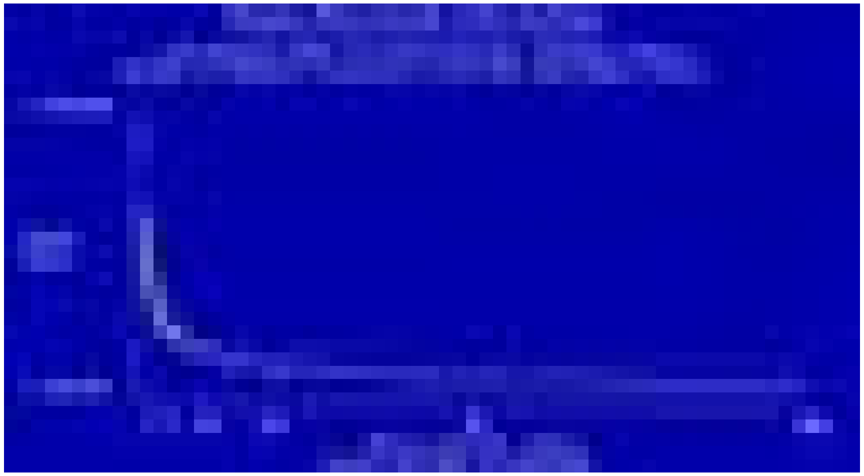
Pearson Type III External Distribution Method of Moments				
Mean	0.492		Alpha	0.03965
Variance	0.039		Beta	24.732
Coefficient of Skew	0.402		Gamma	-0.489
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.51	0.48	0.45	0.01
5	0.34	0.32	0.31	0.01
10	0.28	0.25	0.22	0.02
20	0.25	0.19	0.14	0.03
50	0.22	0.13	0.04	0.05
100	0.21	0.09	0.00	0.06



Pearson Type III External Distribution				
Method of Maximum Likelihood				
Mean	0.492		Alpha	0.03419
Variance	0.038		Beta	32.547
Coefficient of Skew	0.351		Gamma	-0.621
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.54	0.48	0.42	0.03
5	0.39	0.33	0.26	0.03
10	0.32	0.25	0.18	0.04
20	0.27	0.19	0.11	0.04
50	0.23	0.13	0.03	0.05
100	0.21	0.09	0.00	0.06



Pearson Type III External Distribution				
Method of Monments (indirect)				
Mean	-0.803		Alpha	0.276
Variance	0.220		Beta	2.889
Coefficient of Skew	-1.177		Gamma	-1.601
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.57	0.49	0.41	0.04
5	0.39	0.32	0.25	0.04
10	0.31	0.24	0.17	0.04
20	0.26	0.18	0.11	0.04
50	0.22	0.13	0.05	0.04
100	0.19	0.10	0.02	0.04

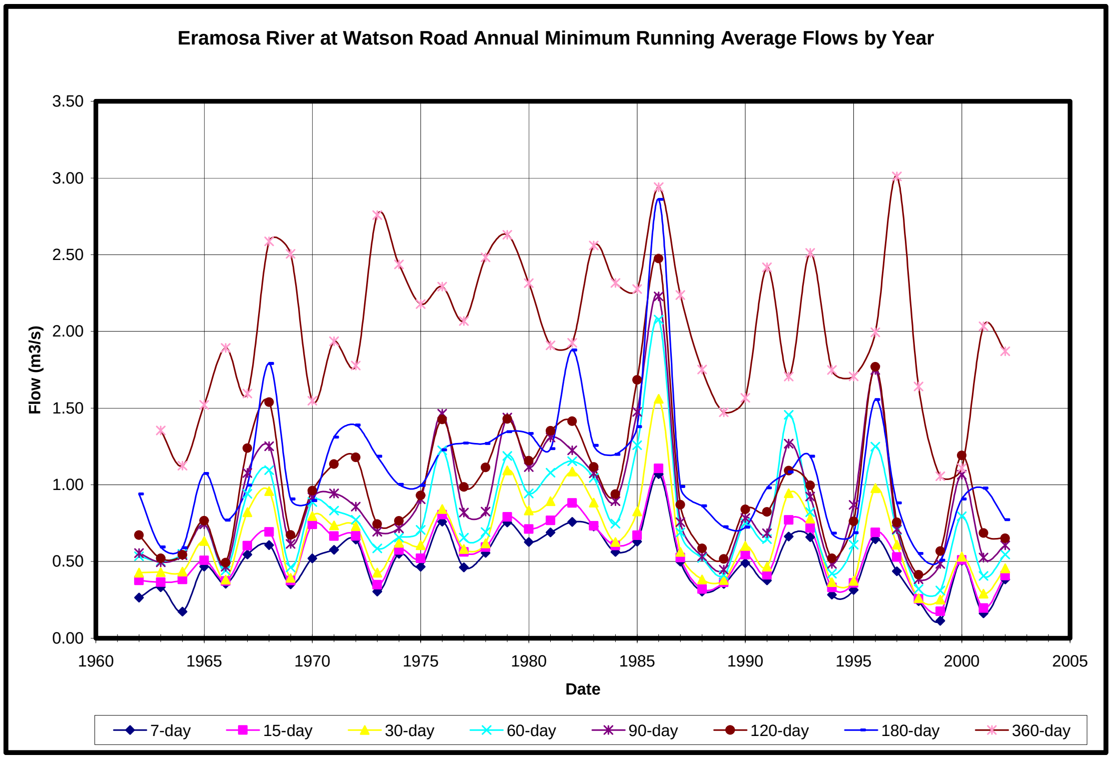


6. 7-DAY LOW FLOW STATISTICS

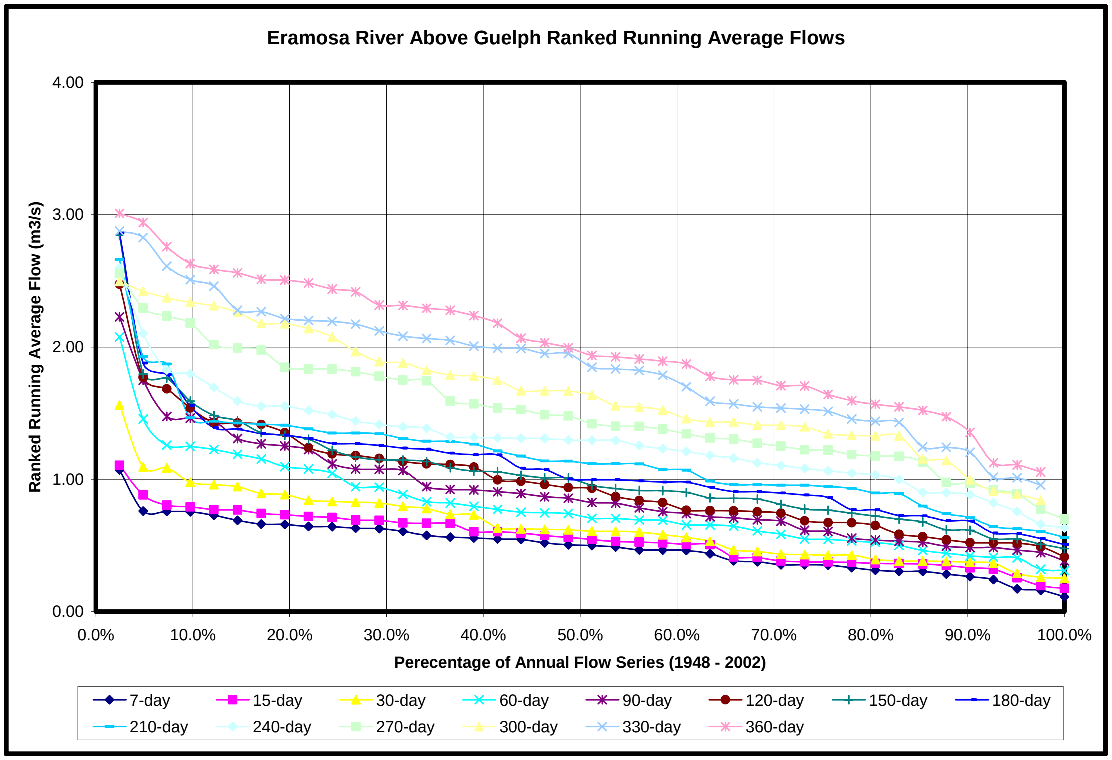
Low Flow Stastics Eramosa River at watson Road 1948 to 2002 Statistical Method	Annual Return Period 7-day Flow (m3/s)					
	2	5	10	20	50	100
Two Parameter Log Normal Method of Moments	0.457	0.330	0.278	0.242	0.207	0.186
Two Parameter Log Normal Maximum Likelihood	0.457	0.330	0.278	0.242	0.207	0.186
Three Parameter Log Normal Method of Moments	0.482	0.324	0.247	0.186	0.120	0.077
Type III External Distribution Method of Moments	0.481	0.324	0.248	0.188	0.123	0.081
Type III External Distribution Method of Smallest Observed Drought	0.482	0.319	0.244	0.190	0.139	0.111
Type III External Distribution Method of Maximum Likelihood	**0.488**	**0.320**	**0.239**	**0.178**	**0.118**	**0.084**
Pearson Type III External Distribution Method of Moments	0.479	0.323	0.249	0.192	0.130	0.092
Pearson Type III External Distribution Method of Maximum Likelihood	0.481	0.325	0.251	0.192	0.129	0.089
Pearson Type III External Distribution Method of Monments (indirect)	0.489	0.318	0.240	0.184	0.131	0.102
Maximum	0.489	0.330	0.278	0.242	0.207	0.186
Average	0.477	0.324	0.253	0.199	0.145	0.112
Minimum	0.457	0.318	0.239	0.178	0.118	0.077

7. Eramosa River at Watson Road Minimum Annual Running Average Flows (m3/s)

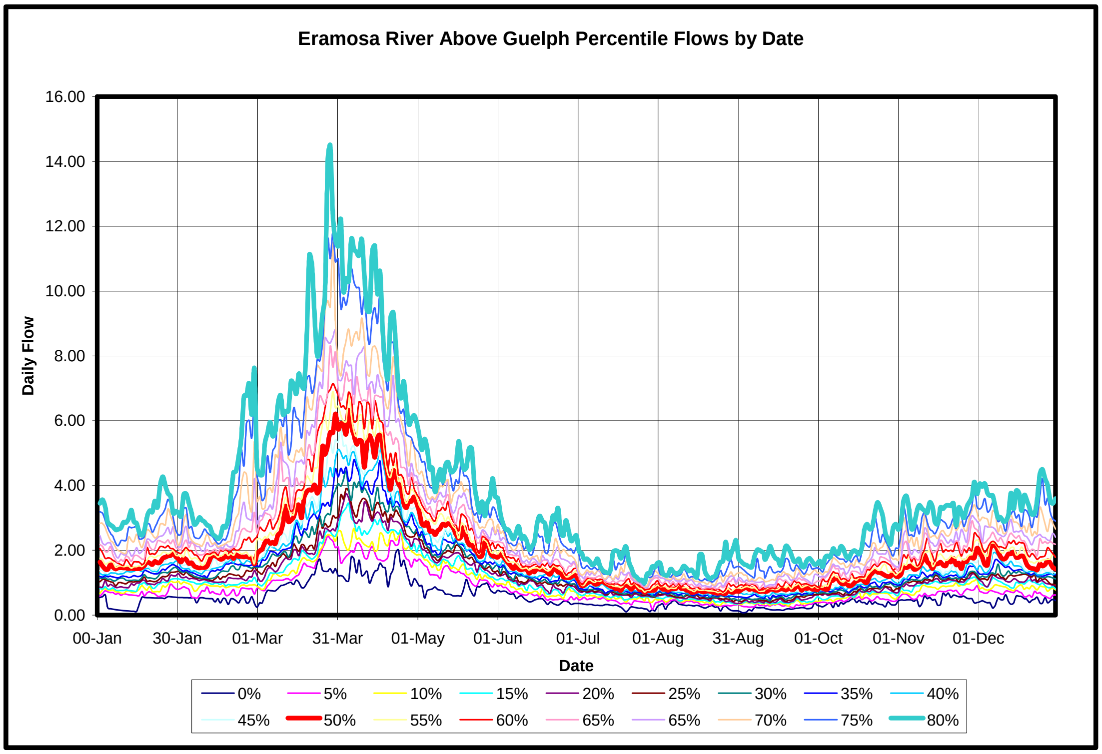
	7-day	15-day	30-day	60-day	90-day	120-day	150-day	180-day	210-day	240-day	270-day	300-day	330-day	360-day
Maximum	1.07	1.11	1.56	2.08	2.23	2.47	2.84	2.86	2.66	2.60	2.56	2.50	2.88	3.01
Average	0.49	0.55	0.65	0.79	0.90	0.98	1.04	1.09	1.16	1.29	1.50	1.67	1.85	2.02
Minimum	0.11	0.18	0.25	0.31	0.38	0.41	0.48	0.51	0.56	0.63	0.70	0.84	0.96	1.06
Lower 10 Percentile	0.27	0.33	0.37	0.42	0.48	0.52	0.61	0.68	0.71	0.88	0.97	1.13	1.24	1.46


Eramosa River at Watson Road Annual Minimum Running Average Flows by Year
Flow (m3/s)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Date
7-day
15-day
30-day
60-day
90-day
120-day
180-day
360-day

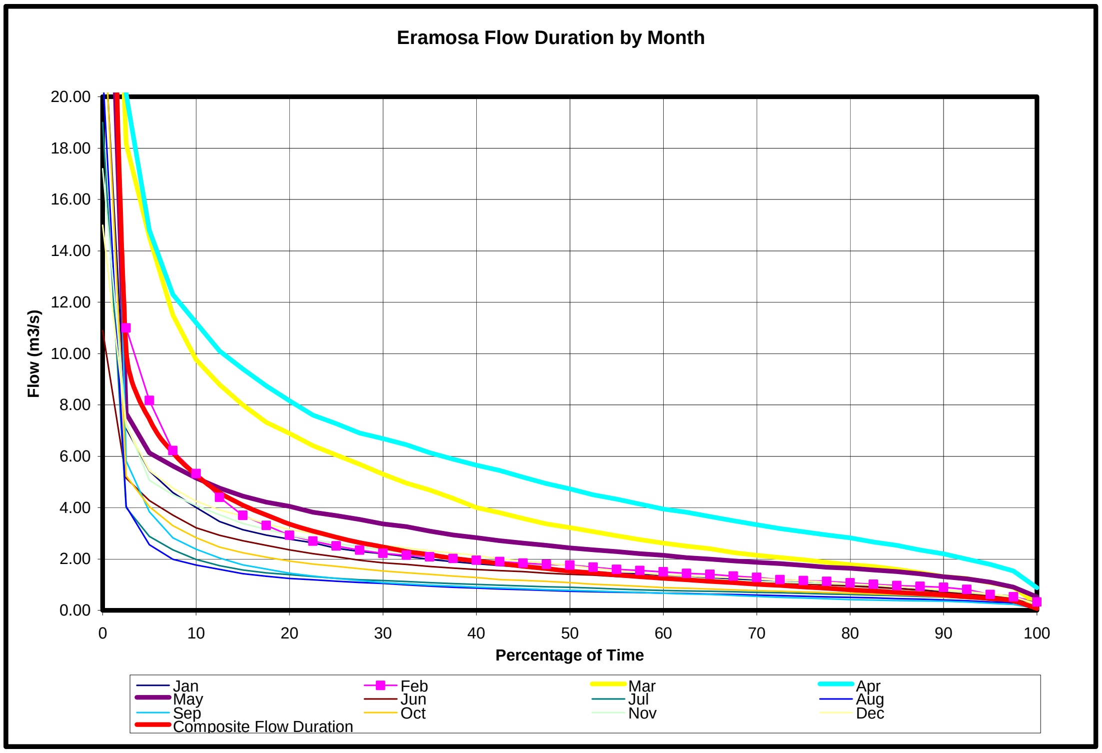
8.


Eramosa River Above Guelph Ranked Running Average Flows
Ranked Running Average Flow (m3/s)
4.00
3.00
2.00
1.00
0.00
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%
Perecentage of Annual Flow Series (1948 - 2002)
7-day
15-day
30-day
60-day
90-day
120-day
150-day
180-day
210-day
240-day
270-day
300-day
330-day
360-day

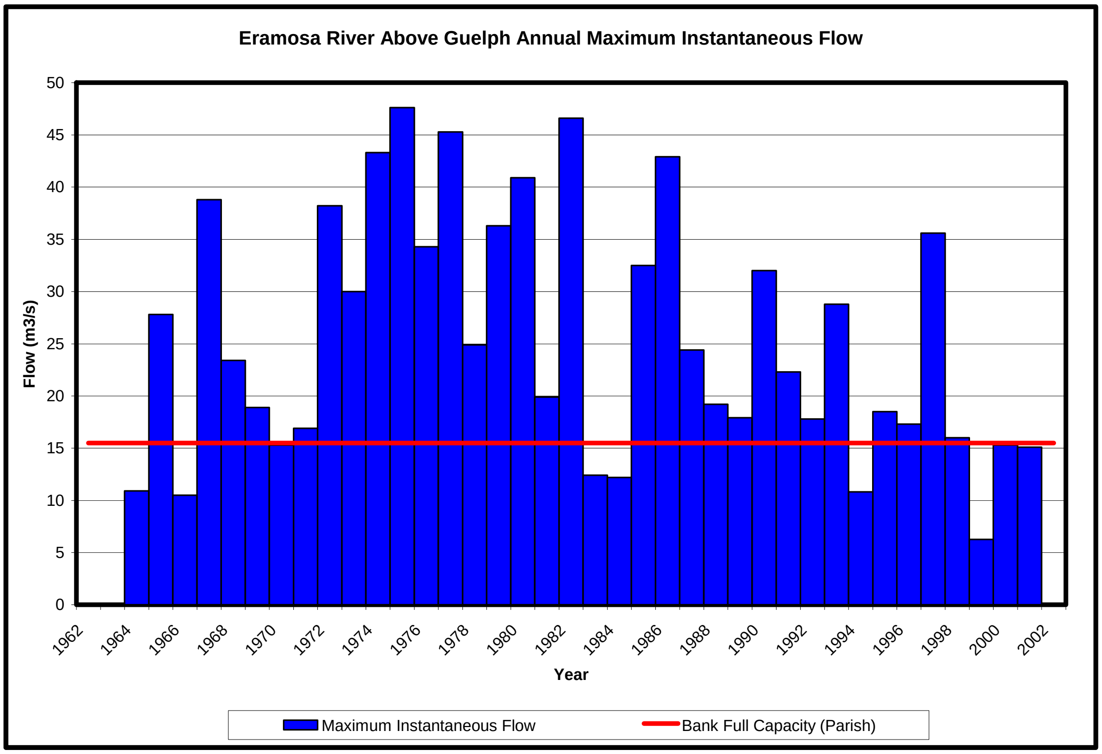
9.


Eramosa River Above Guelph Percentile Flows by Date
Daily Flow
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
00-Jan
30-Jan
01-Mar
31-Mar
01-May
01-Jun
01-Jul
01-Aug
31-Aug
01-Oct
01-Nov
01-Dec
Date
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
65%
70%
75%
80%

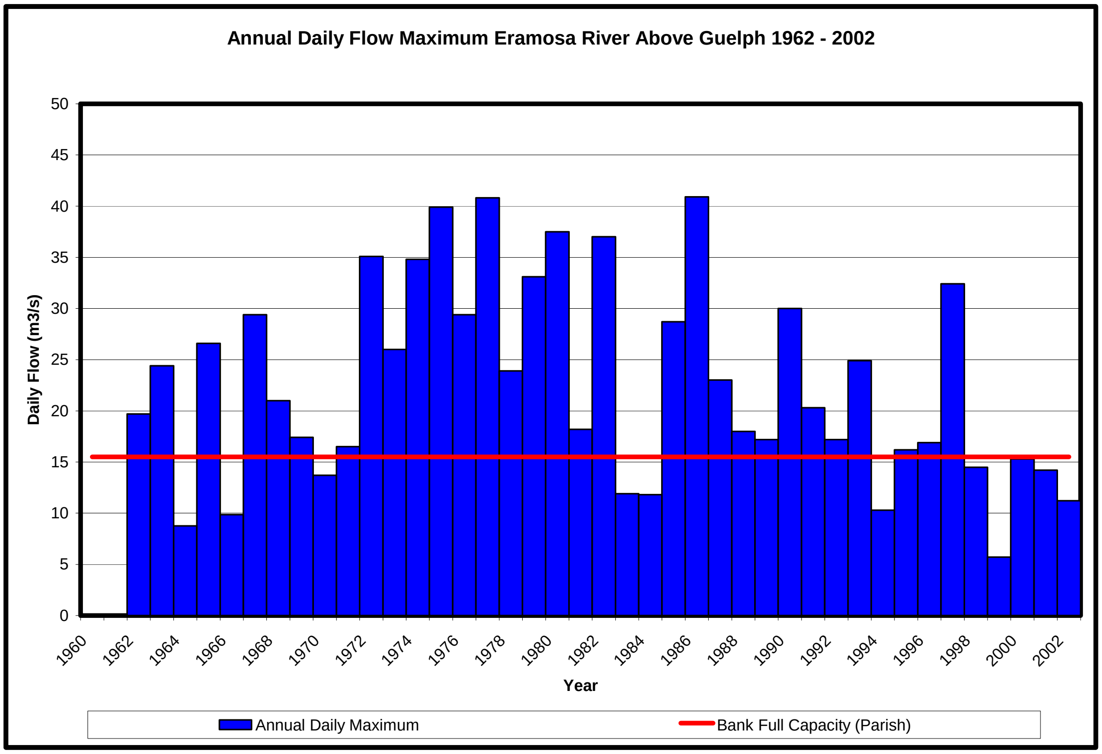
10.


Eramosa Flow Duration by Month
Flow (m3/s)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Percentage of Time
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Composite Flow Duration

11.

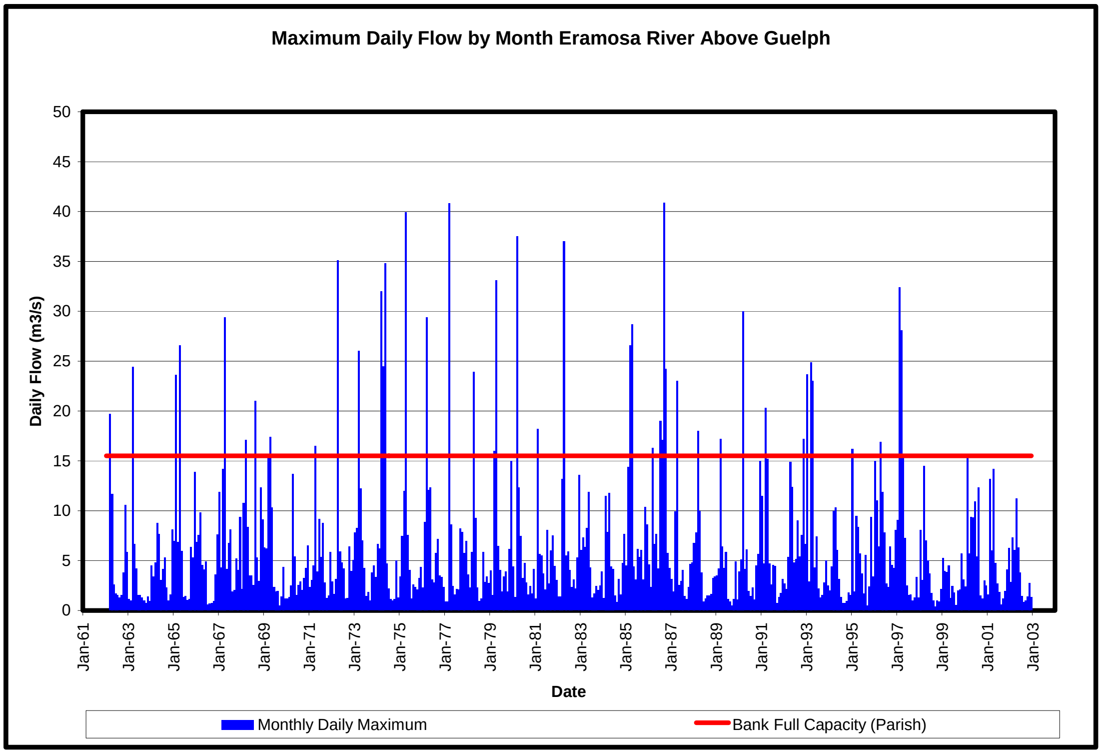

Eramosa River Above Guelph Annual Maximum Instantaneous Flow
Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
50
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year
Maximum Instantaneous Flow
Bank Full Capacity (Parish)

12.


Annual Daily Flow Maximum Eramosa River Above Guelph 1962 - 2002
Daily Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
50
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year
Annual Daily Maximum
Bank Full Capacity (Parish)

13.

14.



15. High Flow Frequency Table
(Eramosa River Above Guelph 1962 to 2002)

Return Period (Years)	Extreme Value (m3/s)	Log Pearson (m3/s)	Three P Log Normal (m3/s)	Walkby (m3/s)
1.003	0.91	3.95	**1.85**	8.29
1.05	8.15	9.3	**7.21**	9.48
1.25	15	15.2	**15.2**	13.7
2	23.8	23.3	**25.9**	23.5
5	34.9	34.6	**36.6**	36.8
10	41.9	42.1	**41.3**	43.3
20	48.3	49.2	**44.5**	47.9
50	56.3	58.6	**47.2**	51.9
100	62	65.7	**48.6**	53.8
200	67.5	72.9	**49.5**	55.2
500	74.4	82.5	**50.2**	56.4

B-3: BLAIR CREEK REACH

Not included due to short gauge record 1998 to 2003

B-4: MILL CREEK REACH

Mill Creek at Side Road 10 Mean Monthly Flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990								0.44	0.44	0.86	0.86	1.49	**0.83**
1991	1.25	1.09	1.83	1.95	0.96	0.58	0.70	0.52	0.39	0.52	0.60	0.88	**0.94**
1992	0.80	0.70	0.91	1.29	0.71	0.40	0.81	0.95	1.05	1.02	1.92	1.32	**0.99**
1993	2.16	1.24	1.44	1.98	0.84	0.77	0.65	0.41	0.53	0.79	0.76	0.80	**1.03**
1994	1.20	1.52	1.23	1.62	1.12	0.49	0.35	0.41	0.32	0.39	0.62	0.75	**0.83**
1995	1.82	0.79	1.34	1.13	0.85	0.55	0.32	0.30	0.29	0.58	1.25	1.00	**0.85**
1996	2.12	2.03	1.36	2.49	1.95	1.49	0.89	0.55	1.34	1.36	1.12	1.68	**1.53**
1997	1.80	2.51	2.28	1.81	1.52	0.81	0.53	0.60	0.68	0.71	1.09	0.85	**1.26**
1998	1.91	1.48	1.61	1.05	0.50	0.47	0.35	0.32	0.28	0.36	0.39	0.48	**0.76**
1999	1.06	0.83	0.90	0.85	0.33	0.29	0.24	0.20	0.35	0.57	0.62	0.62	**0.57**
2000	0.53	0.98	0.67	0.95	1.08	1.11	0.57	0.58	0.45	0.44	0.61	0.78	**0.72**
2001	0.75	1.61	1.04	1.31	0.64	0.45	0.23	0.19	0.23	0.70	0.69	0.94	**0.72**
2002	0.63	0.99	1.10	1.42	1.16	0.51	0.27	0.20	0.21	0.30	0.40	0.39	**0.63**
2003	0.38	0.54	1.27	0.92	0.88	0.43	0.25	0.28	0.35	0.58	1.22	1.13	**0.69**
2004	1.03	1.21	1.98	1.48	1.28	0.61	0.50	0.45	0.43	0.45			**0.96**
Maximum	**2.16**	**2.51**	**2.28**	**2.49**	**1.95**	**1.49**	**0.89**	**0.95**	**1.34**	**1.36**	**1.92**	**1.68**	**1.53**
Average	**1.25**	**1.25**	**1.35**	**1.45**	**0.99**	**0.64**	**0.48**	**0.43**	**0.49**	**0.64**	**0.87**	**0.93**	**0.89**
Minimum	**0.38**	**0.54**	**0.67**	**0.85**	**0.33**	**0.29**	**0.23**	**0.19**	**0.21**	**0.30**	**0.39**	**0.39**	**0.57**
Lower 10 Percentile	**0.56**	**0.73**	**0.90**	**0.93**	**0.54**	**0.41**	**0.24**	**0.20**	**0.25**	**0.37**	**0.46**	**0.52**	**0.65**

2. Mill Creek Side Road 10 7-Day Low Flows (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec
Maximum	1.47	1.40	1.59	1.43	1.25	0.85	0.61	0.50	0.83	1.01	0.87	1.03	0.43	1.20	0.43	0.87
Average	0.77	0.85	0.80	0.88	0.62	0.42	0.34	0.31	0.33	0.43	0.56	0.66	0.28	0.67	0.28	0.42
Minimum	0.34	0.42	0.53	0.47	0.29	0.22	0.19	0.14	0.14	0.26	0.33	0.35	0.14	0.34	0.14	0.26
Lower 10 Percentile	0.46	0.51	0.54	0.53	0.36	0.27	0.20	0.17	0.15	0.28	0.35	0.40	0.14	0.46	0.14	0.28

Sum of occurances by Season		
Jan-Apr	**May-Sep**	**Oct-Dec**
0	14	0

3. Mill Creek Side Road 10 15-Day Low Flows (m3/s)

Maximum	1.67	1.72	1.71	1.84	1.85	1.16	0.71	0.65	0.87	1.05	1.09	1.12	0.47	1.40	0.47	0.90
Average	0.81	0.95	**0.92**	1.07	0.78	0.50	0.37	0.34	0.35	0.44	0.59	0.71	0.30	0.74	0.30	0.44
Minimum	0.35	0.38	0.58	0.54	0.31	0.24	0.19	0.15	0.15	0.25	0.34	0.36	0.15	0.35	0.15	0.25
Lower 10 Percentile	0.47	0.53	0.60	0.64	0.38	0.31	0.22	0.18	0.17	0.29	0.37	0.43	0.16	0.47	0.16	0.29

Sum of occurances by Season		
Jan-Apr	**May-Sep**	**Oct-Dec**
0	14	0

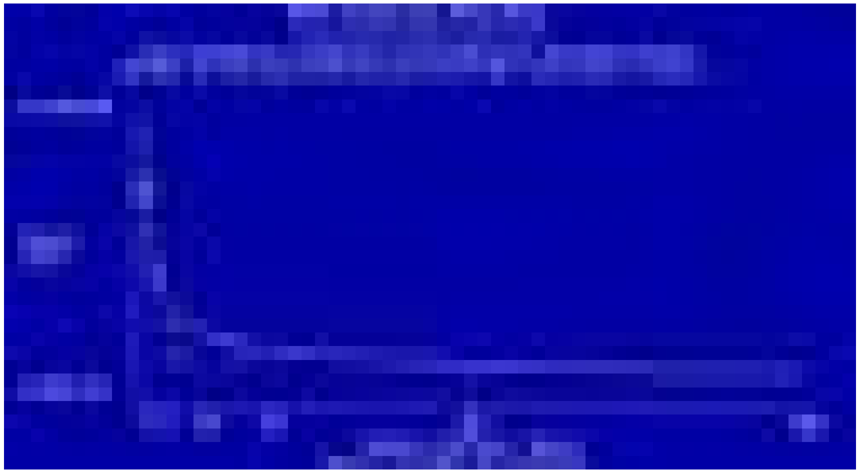
4. Mill Creek Side Road 10 30-Day Low Flows (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	1.67	2.01	2.11	1.81	1.96	1.45	0.86	0.76	0.93	1.24	1.12	1.27	0.50	1.62	0.50	1.10	Jan-Apr	May-Sep	Oct-Dec
Average	0.85	1.01	1.04	1.16	0.95	0.62	0.42	0.39	0.38	0.46	0.62	0.77	0.32	0.80	0.32	0.45	0	14	0
Minimum	0.37	0.38	0.54	0.55	0.33	0.29	0.23	0.17	0.17	0.21	0.31	0.38	0.17	0.37	0.17	0.21			
Lower 10 Percentile	0.49	0.57	0.67	0.72	0.50	0.39	0.24	0.20	0.19	0.25	0.37	0.44	0.18	0.49	0.18	0.25			

5. Low Flow Frequency Plots

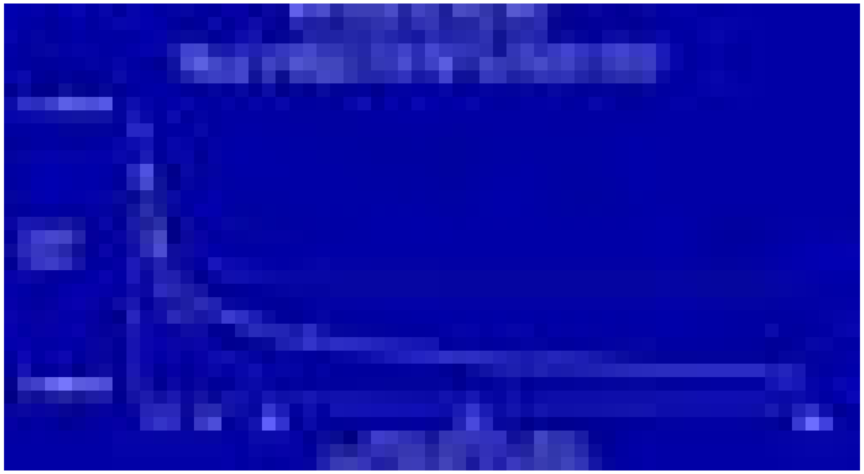
Two Parameter Log Normal Method of Moments				
Mean	0.283			
Variance	0.009			
Coefficient of Skew	-0.262			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.32	0.27	0.22	0.02
5	0.25	0.20	0.16	0.02
10	0.23	0.17	0.12	0.03
20	0.21	0.15	0.09	0.03
50	0.20	0.13	0.07	0.03
100	0.20	0.12	0.05	0.04

Two Parameter Log Normal				
Maximum Likelihood				
Mean	-1.330			
Variance	0.158			
Coefficient of Skew	-0.547			
Return Period	**Upper**	**Mean**	**Lower**	**Std**
Flows (m3/s)	**95%**		**95%**	**Error**
2	0.31	0.27	0.22	0.02
5	0.24	0.20	0.16	0.02
10	0.22	0.17	0.13	0.02
20	0.20	0.15	0.11	0.02
50	0.18	0.13	0.09	0.02
100	0.16	0.12	0.08	0.02

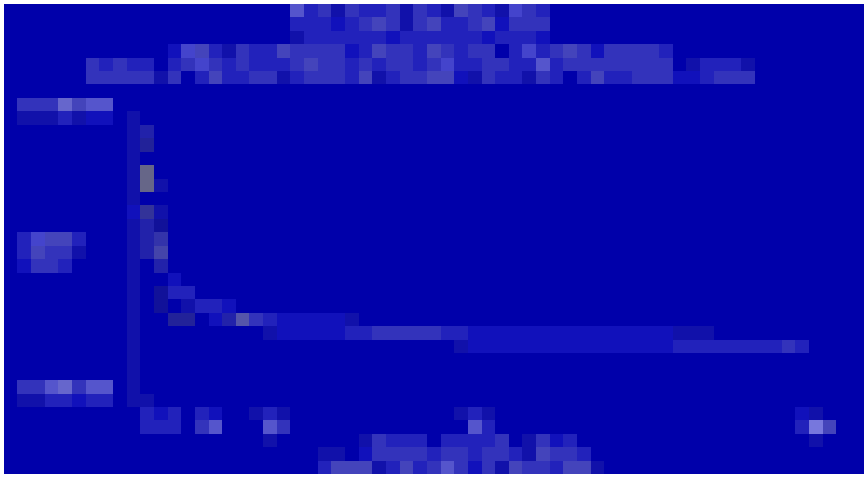


Three Parameter Log Normal				
Method of Moments				
Mean				
Variance				
Coefficient of Skew				
Return Period	**Upper**	**Mean**	**Lower**	**Std**
Flows (m3/s)	**95%**		**95%**	**Error**
2				
5				
10				
20				
50				
100				

Type III External Distribution Method of Moments				
Mean	0.283		Alpha	5.24
Variance	0.009		Beta	0.32
Coefficient of Skew	-0.293		Gamma	-0.15
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.34	0.29	0.23	0.03
5	0.27	0.20	0.14	0.03
10	0.23	0.16	0.08	0.04
20	0.21	0.12	0.03	0.05
50	0.19	0.07	0.00	0.06
100	0.19	0.05	0.00	0.08

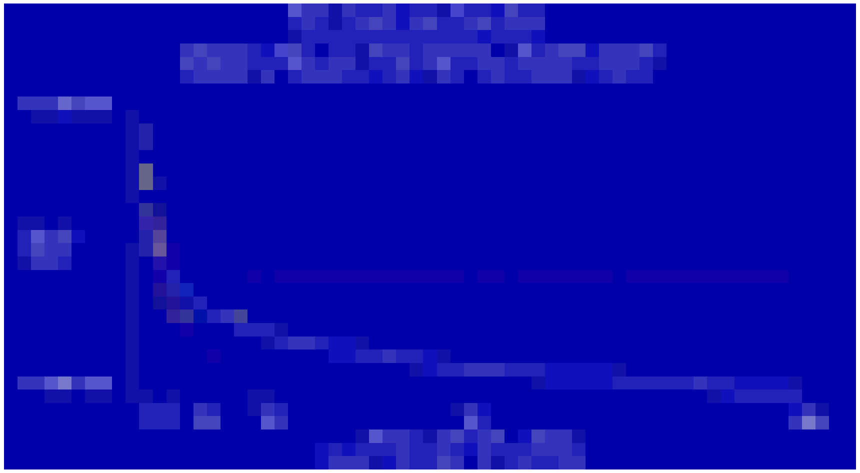


Type III External Distribution Method of Smallest Observed Drought				
Mean	0.283		Alpha	2.44
Variance	0.009		Beta	0.31
Coefficient of Skew	0.386		Gamma	0.07
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.00	0.28	0.00	0.00
5	0.00	0.20	0.00	0.00
10	0.00	0.16	0.00	0.00
20	0.00	0.14	0.00	0.00
50	0.00	0.12	0.00	0.00
100	0.00	0.10	0.00	0.00



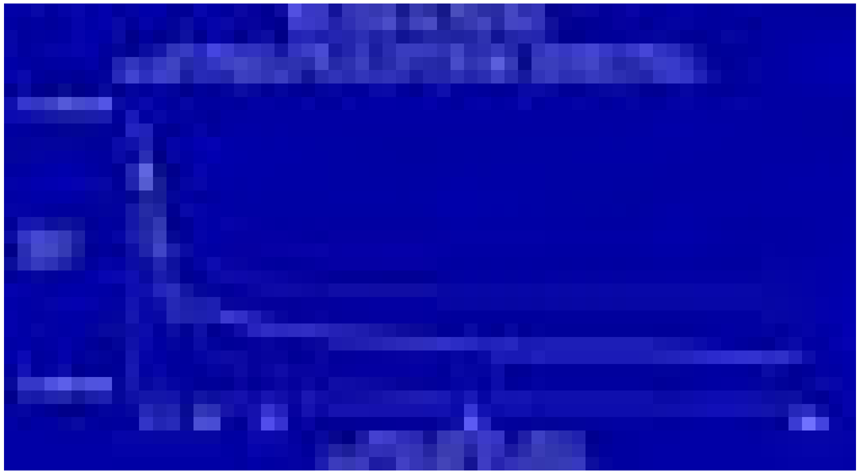
Type III External Distribution Method of Maximum Likelihood				
Mean			Alpha	
Variance			Beta	
Coefficient of Skew			Gamma	
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2				
5				
10				
20				
50				
100				

Pearson Type III External Distribution Method of Moments				
Mean	0.283		Alpha	0.03
Variance	0.010		Beta	14.29
Coefficient of Skew	-0.529		Gamma	-0.09
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.32	0.29	0.27	0.01
5	0.25	0.20	0.16	0.02
10	0.22	0.15	0.08	0.04
20	0.21	0.11	0.01	0.05
50	0.21	0.05	0.00	0.08
100	0.21	0.02	0.00	0.10



Pearson Type III External Distribution				
Method of Maximum Likelihood				
Mean	0.283		Alpha	0.08
Variance	0.014		Beta	2.03
Coefficient of Skew	1.404		Gamma	0.11
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.31	0.26	0.20	0.03
5	0.22	0.18	0.14	0.02
10	0.19	0.16	0.12	0.02
20	0.17	0.14	0.11	0.02
50	0.15	0.13	0.11	0.01
100	0.14	0.12	0.10	0.01

Pearson Type III External Distribution				
Method of Monments (indirect)				
Mean	-1.330		Alpha	0.219
Variance	0.158		Beta	3.282
Coefficient of Skew	-1.104		Gamma	-2.049
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.35	0.28	0.21	0.04
5	0.26	0.20	0.14	0.03
10	0.22	0.16	0.09	0.03
20	0.20	0.13	0.05	0.04
50	0.18	0.09	0.01	0.04
100	0.17	0.08	0.00	0.05

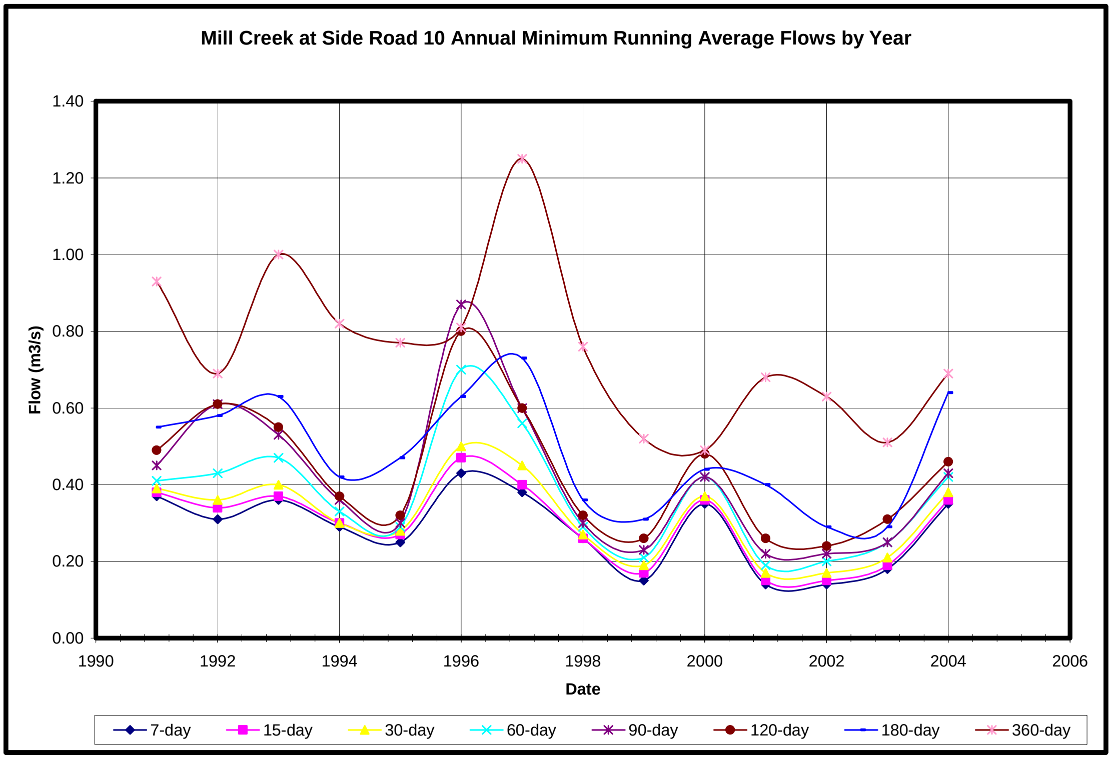


6. 7-DAY LOW FLOW STATISTICS

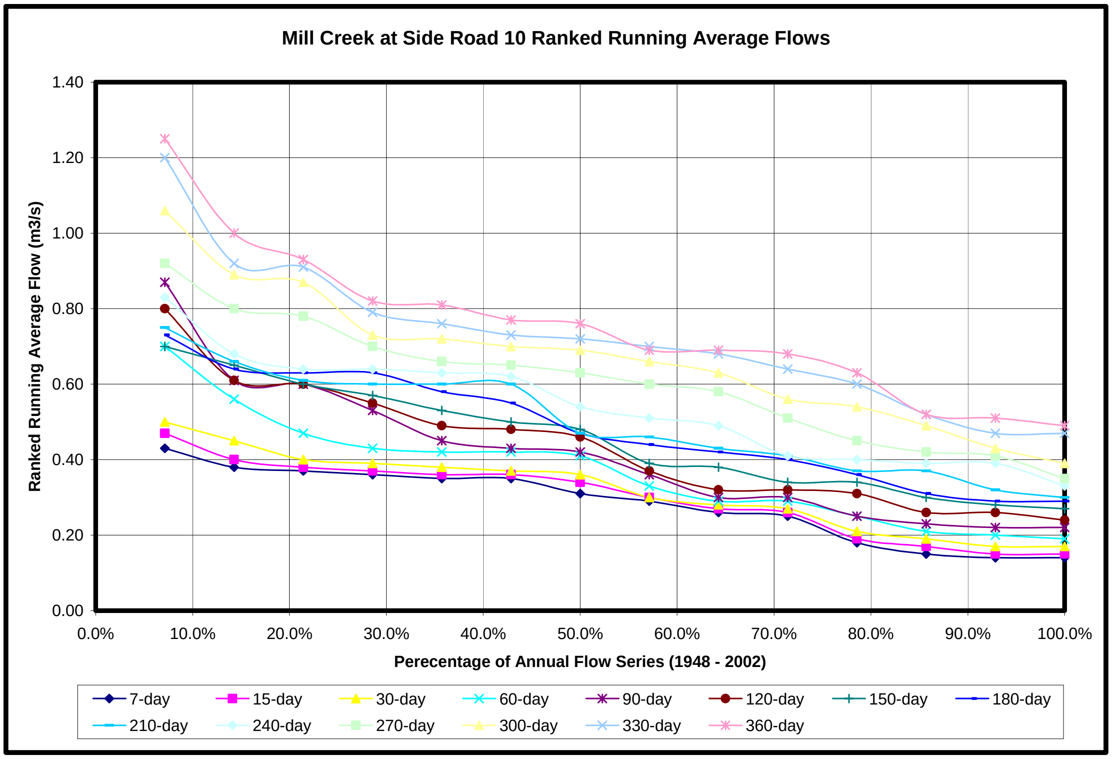
Low Flow Stastics Mill Creek Side Road 10 1990 to 2004	**Annual Return Period 7-day Flow (m3/s)**					
Statistical Method	**2**	**5**	**10**	**20**	**50**	**100**
Two Parameter Log Normal Method of Moments	0.267	0.201	0.174	0.154	0.134	0.122
Two Parameter Log Normal Maximum Likelihood	0.267	0.201	0.174	0.154	0.134	0.122
Three Parameter Log Normal Method of Moments						
Type III External Distribution Method of Moments	0.288	0.204	0.157	0.118	0.074	0.047
Type III External Distribution Method of Smallest Observed Drought	0.276	0.199	0.164	0.139	0.116	0.104
Type III External Distribution Method of Maximum Likelihood						
Pearson Type III External Distribution Method of Moments	0.291	0.204	0.153	0.108	0.055	0.017
Pearson Type III External Distribution Method of Maximum Likelihood	0.256	0.184	0.158	0.142	0.130	0.123
Pearson Type III External Distribution Method of Monments (indirect)	0.284	0.197	0.156	0.125	0.095	0.077
Pearson Type III External Distribution Method of Maximum Likelihood	0.228	0.167	0.151	0.143	0.138	0.136
Pearson Type III External Distribution Method of Monments (indirect)	0.284	0.197	0.156	0.125	0.095	0.077
Maximum	0.291	0.204	0.174	0.154	0.138	0.136
Average	0.271	0.195	0.160	0.134	0.108	0.092
Minimum	0.228	0.167	0.151	0.108	0.055	0.017

7. Mill Creek Side Road 10 Minimum Annual Running Average Flows (m3/s)

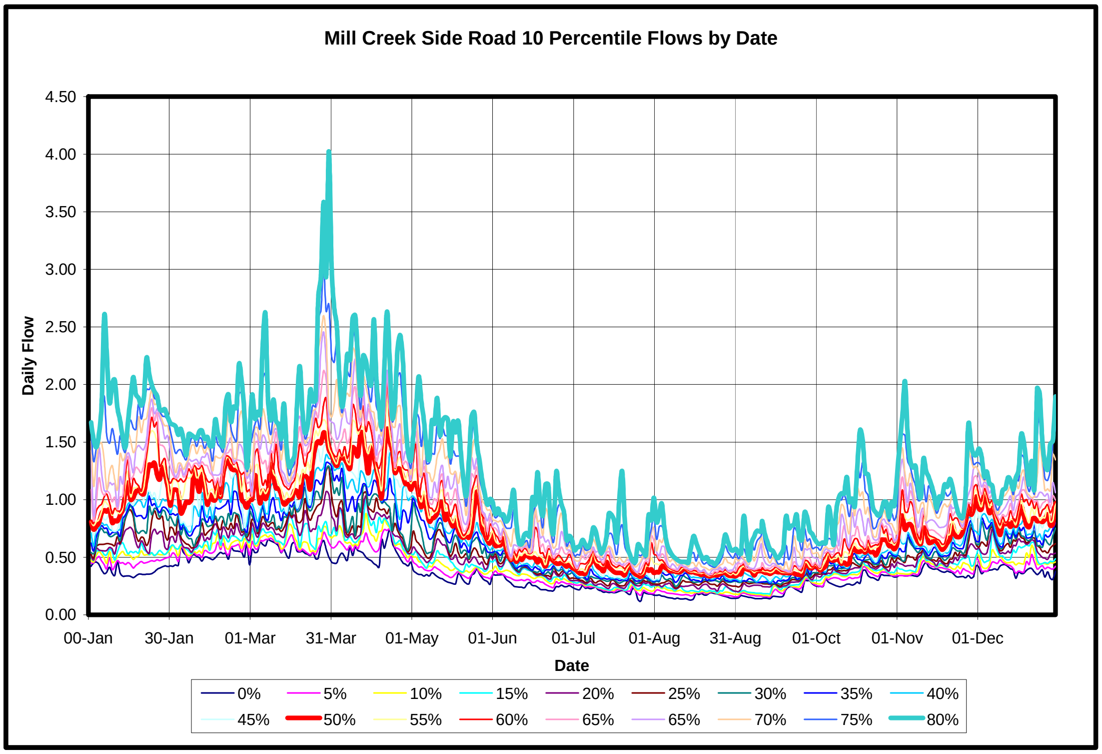
Year	7-day	15-day	30-day	60-day	90-day	120-day	150-day	180-day	210-day	240-day	270-day	300-day	330-day	360-day
Maximum	0.43	0.47	0.50	0.70	0.87	0.80	0.70	0.73	0.75	0.83	0.92	1.06	1.20	1.25
Average	0.28	0.30	0.32	0.37	0.41	0.43	0.45	0.48	0.50	0.54	0.60	0.67	0.72	0.75
Minimum	0.14	0.15	0.17	0.19	0.22	0.24	0.27	0.29	0.30	0.33	0.35	0.39	0.47	0.49
Lower 10 Percentile	0.14	0.16	0.18	0.20	0.22	0.26	0.29	0.30	0.34	0.39	0.41	0.45	0.49	0.51


Mill Creek at Side Road 10 Annual Minimum Running Average Flows by Year
Flow (m3/s)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1990
1992
1994
1996
1998
2000
2002
2004
2006
Date
7-day
15-day
30-day
60-day
90-day
120-day
180-day
360-day

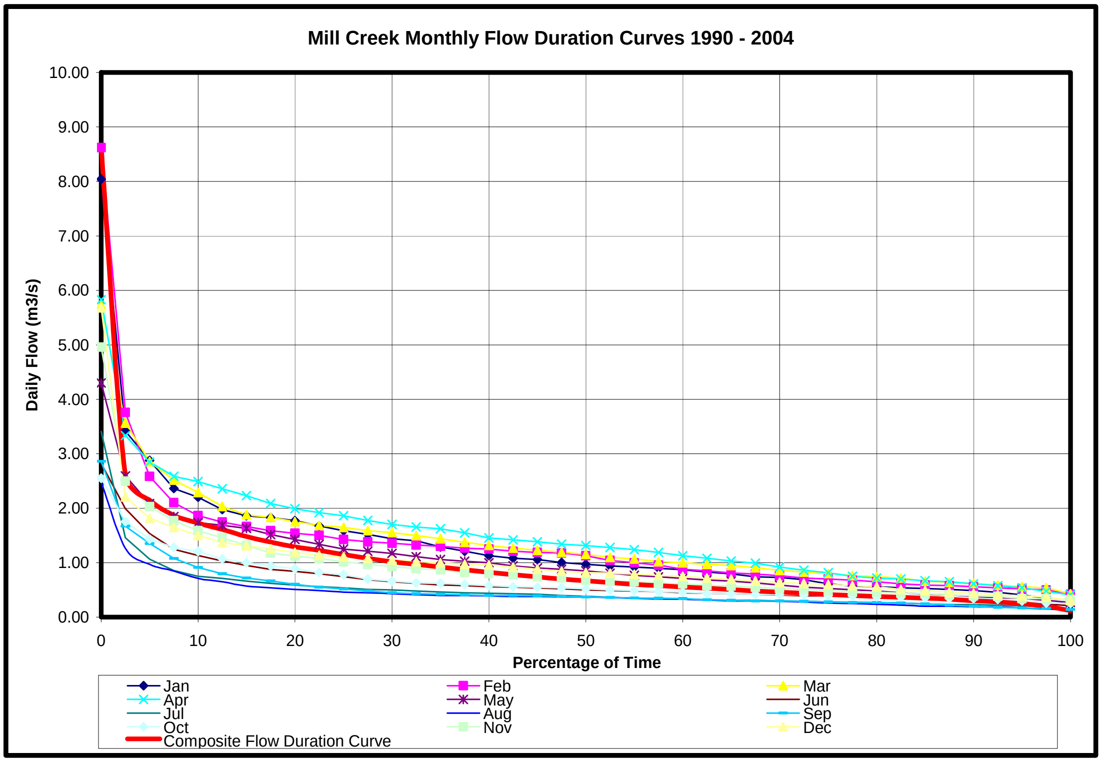
8.


Mill Creek at Side Road 10 Ranked Running Average Flows
Ranked Running Average Flow (m3/s)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%
Perecentage of Annual Flow Series (1948 - 2002)
7-day
15-day
30-day
60-day
90-day
120-day
150-day
180-day
210-day
240-day
270-day
300-day
330-day
360-day

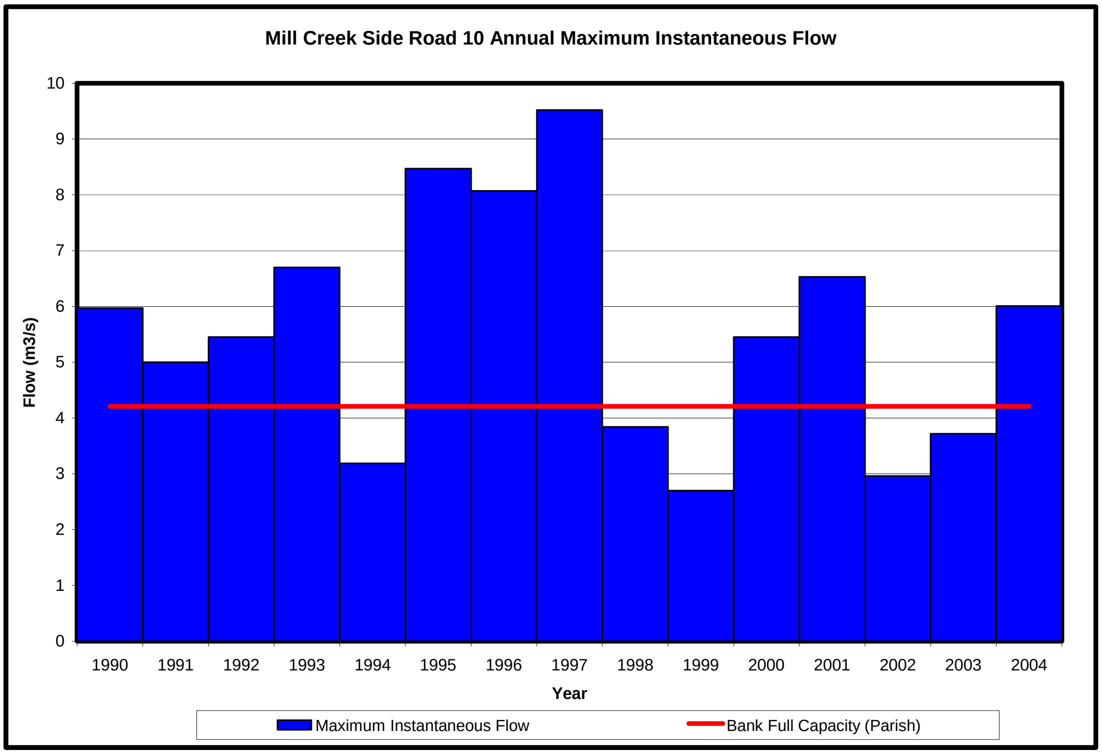
9.


Mill Creek Side Road 10 Percentile Flows by Date
Daily Flow
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
00-Jan
30-Jan
01-Mar
31-Mar
01-May
01-Jun
01-Jul
01-Aug
31-Aug
01-Oct
01-Nov
01-Dec
Date
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
65%
70%
75%
80%

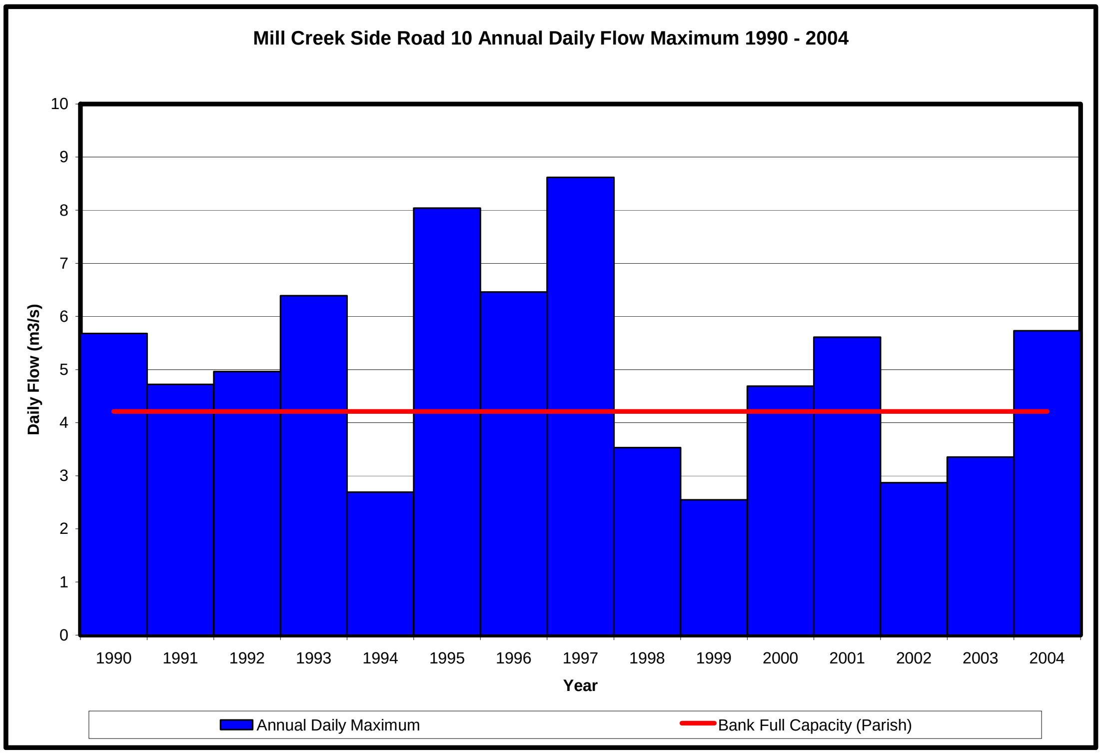
10.


Mill Creek Monthly Flow Duration Curves 1990 - 2004
Daily Flow (m3/s)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Percentage of Time
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Composite Flow Duration Curve

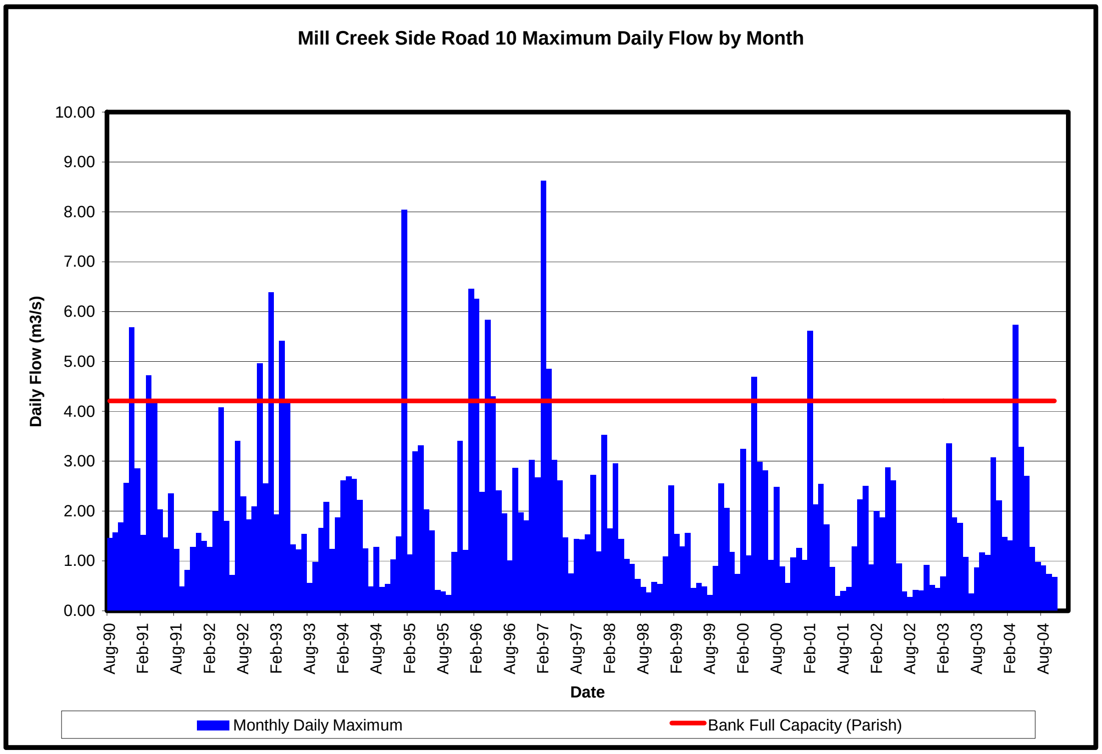
11.


Mill Creek Side Road 10 Annual Maximum Instantaneous Flow
Flow (m3/s)
0
1
2
3
4
5
6
7
8
9
10
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year
Maximum Instantaneous Flow
Bank Full Capacity (Parish)

12.


Mill Creek Side Road 10 Annual Daily Flow Maximum 1990 - 2004
Daily Flow (m3/s)
0
1
2
3
4
5
6
7
8
9
10
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year
Annual Daily Maximum
Bank Full Capacity (Parish)

13.



14.

15. High Flow Frequency Table
(Mill Creek at Side Road 10 1990 to 2003)

Return Period Period (yr)	Extreme Value (m3/s)	Log Pearson (m3/s)	Three P Log Normal (m3/s)	Walkby (m3/s)
1.003	0.75	1.53	**1.58**	2.53
1.05	2.36	2.68	**2.63**	2.72
1.25	3.78	3.82	**3.76**	3.41
2	5.43	5.30	**5.29**	4.94
5	7.30	7.16	**7.26**	7.06
10	8.35	8.32	**8.49**	8.25
20	9.23	9.40	**9.62**	9.23
50	10.2	10.7	**11.0**	10.3
100	10.9	11.7	**12.0**	11.1
200	11.4	12.7	**13.0**	11.7
500	12.1	14.0	**14.2**	12.5

B-5: WHITEMANS CREEK REACH

Whitemans Creek Near Mt Vernon Mean Monthly Flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1962	0.96	0.86	9.95	4.68	1.65	1.34	0.68	1.14	0.77	1.42	3.21	3.24	2.49
1963	1.10	0.82	10.62	4.61	2.85	1.31	0.70	0.57	0.51	0.47	0.63	0.62	2.07
1964	1.03	1.13	5.75	5.82	2.74	0.96	0.67	2.05	1.17	0.81	0.92	3.15	2.18
1965	3.79	10.32	9.54	15.69	3.89	1.22	1.06	0.93	0.62	1.10	2.08	5.13	4.61
1966	2.85	3.89	10.29	5.57	3.23	1.98	0.56	0.72	0.71	0.75	2.12	9.03	3.47
1967	5.15	3.43	8.91	12.80	3.86	3.83	3.05	2.23	1.32	3.57	5.29	8.51	5.16
1968	2.56	11.85	10.67	4.85	2.47	1.77	1.14	0.64	1.03	1.16	2.07	3.88	3.67
1969	5.03	6.42	9.58	11.33	6.02	2.17	0.90	0.74	0.50	0.79	1.97	1.60	3.92
1970	1.18	2.19	6.70	8.91	3.19	1.17	1.37	0.76	0.83	1.08	2.30	4.53	2.85
1971	2.22	2.99	10.49	11.07	2.07	1.19	0.71	0.48	0.49	0.56	0.66	1.51	2.87
1972	2.50	1.42	12.59	15.11	4.20	2.43	2.86	3.33	1.12	2.30	5.13	5.44	4.87
1973	6.95	5.16	20.96	8.31	4.65	2.24	1.26	0.82	0.51	0.86	4.71	4.94	5.11
1974	8.53	6.44	12.00	9.21	8.53	2.84	1.62	0.85	0.81	0.86	2.02	1.99	4.64
1975	3.20	6.47	11.80	9.57	2.68	2.68	1.23	1.70	2.68	1.72	2.59	4.47	4.23
1976	2.79	14.00	20.75	8.64	7.40	2.05	2.77	3.52	1.77	2.16	2.41	2.02	5.86
1977	1.22	1.33	16.62	8.52	2.26	1.49	1.34	1.42	5.21	6.54	4.02	9.76	4.98
1978	3.26	2.48	10.10	19.74	4.43	1.65	0.82	0.80	1.95	1.99	2.64	3.80	4.47
1979	4.53	2.90	16.32	16.97	4.76	1.98	1.02	2.33	1.59	2.24	5.60	9.48	5.81
1980	4.95	2.01	10.52	12.12	5.01	2.30	1.78	1.60	1.21	1.84	1.90	2.97	4.02
1981	1.29	13.04	5.26	5.24	3.32	1.95	1.16	1.57	5.71	5.25	3.80	2.65	4.19
1982	2.52	1.72	14.23	18.90	4.15	6.22	1.95	1.89	2.77	2.67	7.04	13.44	6.46
1983	5.07	6.75	6.29	8.10	8.55	3.20	1.99	7.83	2.16	2.70	3.94	8.23	5.40
1984	2.89	18.46	10.78	9.48	4.14	5.18	2.05	0.95	1.85	1.42	2.89	4.83	5.41
1985	4.64	9.05	19.91	13.01	2.38	1.78	1.89	1.65	3.05	4.34	14.82	6.80	6.94
1986	5.21	3.06	15.08	6.30	4.59	2.70	1.70	1.61	2.30	7.30	3.85	7.13	5.07
1987	4.31	2.35	10.03	11.17	2.19	1.53	1.95	0.87	0.86	1.22	2.52	7.28	3.86
1988	2.35	2.43	7.44	4.95	2.55	0.92	0.79	1.75	0.80	1.91	4.74	2.98	2.80
1989	3.85	2.71	5.50	5.48	2.20	3.11	1.04	0.55	0.56	0.81	2.03	1.26	2.42
1990	5.23	8.80	10.49	4.88	4.76	2.18	3.11	1.49	1.27	3.92	5.47	9.56	5.10
1991	6.50	6.35	14.32	9.00	3.15	1.48	0.99	1.22	0.67	0.96	1.42	3.21	4.11
1992	2.80	5.03	7.54	7.70	3.90	1.50	4.54	5.05	8.80	5.92	15.88	7.20	6.32
1993	13.38	3.10	8.53	11.01	3.63	2.71	1.32	0.83	1.10	1.50	2.05	3.22	4.37
1994	1.54	3.78	10.15	9.43	5.43	2.72	2.45	1.20	0.73	0.84	1.26	1.85	3.45
1995	8.91	1.90	6.42	5.06	4.16	2.26	1.41	1.42	0.60	1.33	8.48	4.09	3.84
1996	6.69	8.11	6.48	13.43	12.46	7.72	2.35	1.28	6.72	6.38	5.25	9.01	7.16
1997	8.02	15.59	14.18	6.19	6.22	3.30	4.51	1.83	1.53	1.57	3.21	3.61	5.81
1998	9.31	7.35	11.60	5.98	2.24	1.25	0.99	0.86	0.93	1.25	1.49	1.35	3.72
1999	2.35	5.40	5.04	4.15	1.60	1.35	0.43	0.30	0.86	0.95	1.77	3.14	2.28
2000	1.91	4.17	4.45	4.73	4.28	8.50	6.43	3.63	2.47	1.72	2.17	2.93	3.95
2001	2.31	14.12	9.87	6.15	4.09	2.62	0.57	0.36	0.55	2.32	2.41	6.48	4.32
2002	3.23	7.30	7.20	9.85	4.95	2.36	3.08	2.26	0.80	0.99	2.35	1.76	3.84
Maximum	13.38	18.46	20.96	19.74	12.46	8.50	6.43	7.83	8.80	7.30	15.88	13.44	7.16
Average	4.10	5.77	10.61	9.11	4.17	2.52	1.76	1.63	1.75	2.18	3.68	4.83	4.34
Minimum	0.96	0.82	4.45	4.15	1.60	0.92	0.43	0.30	0.49	0.47	0.63	0.62	2.07
Lower 10 Percentile	1.22	1.42	5.75	4.85	2.20	1.22	0.68	0.57	0.55	0.81	1.42	1.60	2.49

2. Whitemans Creek Near Mt Vernon 7 Day Low Flows (m3/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	12.29	20.74	15.89	11.32	11.99	10.31	10.12	11.44	10.14	11.54	11.54	14.05	1.41	10.18	1.41	10.09	**Jan-Apr**	**May-Sep**	**Oct-Dec**
Average	3.63	4.71	7.28	9.31	3.42	1.97	1.03	1.05	1.06	2.14	2.28	4.40	0.64	2.09	0.64	1.35	2	38	2
Minimum	0.58	0.72	0.74	3.09	0.99	0.56	0.13	0.20	0.32	0.43	0.50	0.57	0.13	0.58	0.13	0.43			
Lower 10 Percentile	0.95	1.14	1.45	3.57	1.43	0.91	0.28	0.34	0.45	0.56	0.84	1.06	0.24	0.92	0.24	0.56			

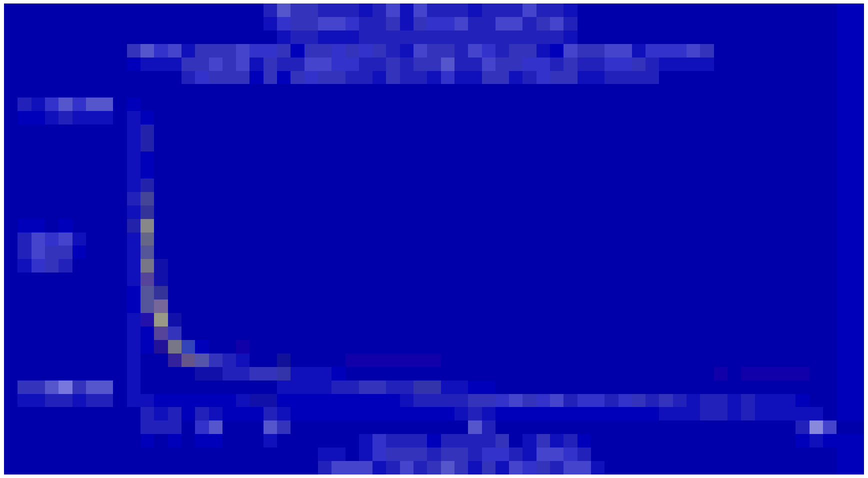
3. Whitemans Creek Near Mt Vernon 15 Day Low Flows (m3/s)

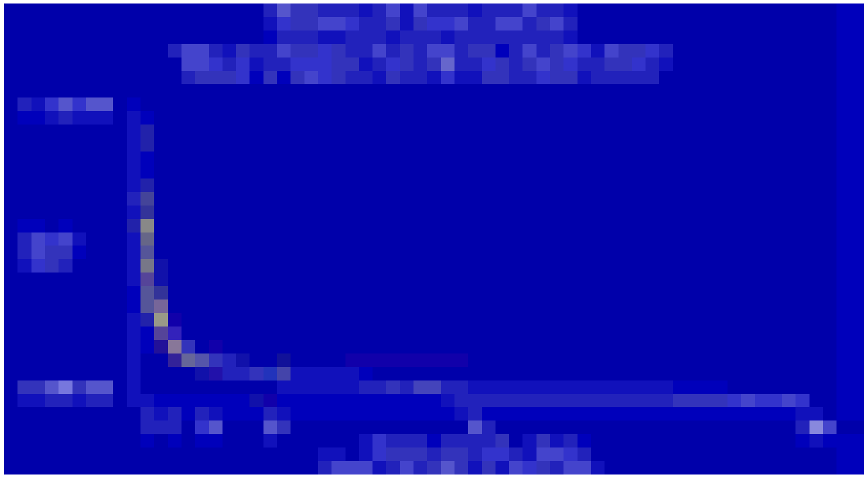
Maximum	6.07	6.19	18.27	12.39	10.47	4.81	3.30	3.01	7.34	4.10	6.55	7.71	1.44	4.52	1.44	3.96	**Sum of occurances by Season**		
Average	2.27	2.30	4.07	5.57	3.04	1.72	1.06	0.95	1.05	1.29	1.95	2.73	0.72	1.83	0.73	1.22	Jan-Apr	May-Sep	Oct-Dec
Minimum	0.59	0.75	0.76	2.46	1.08	0.65	0.22	0.23	0.31	0.45	0.48	0.59	0.22	0.59	0.22	0.45	2	36	4
Lower 10 Percentile	0.99	1.16	1.44	3.03	1.61	0.98	0.38	0.47	0.47	0.54	0.83	1.19	0.33	0.94	0.33	0.54			

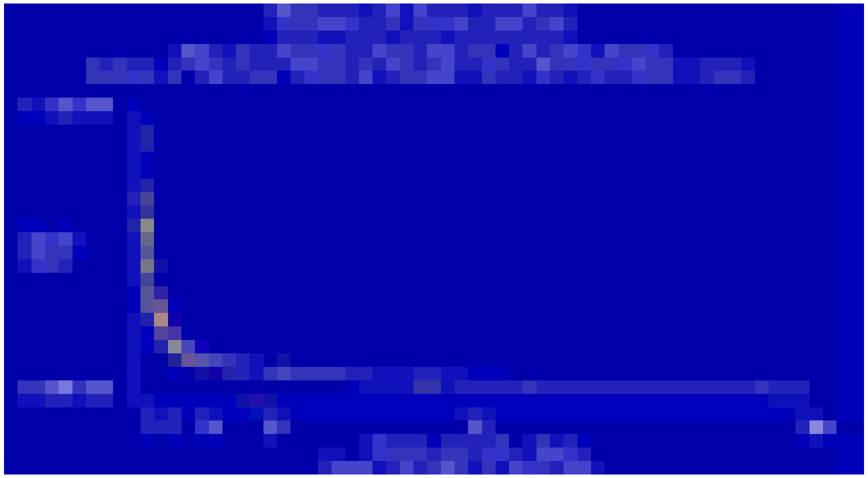
4. Whitemans Creek Near Mt Vernon 30 Day Low Flows (m3/s)

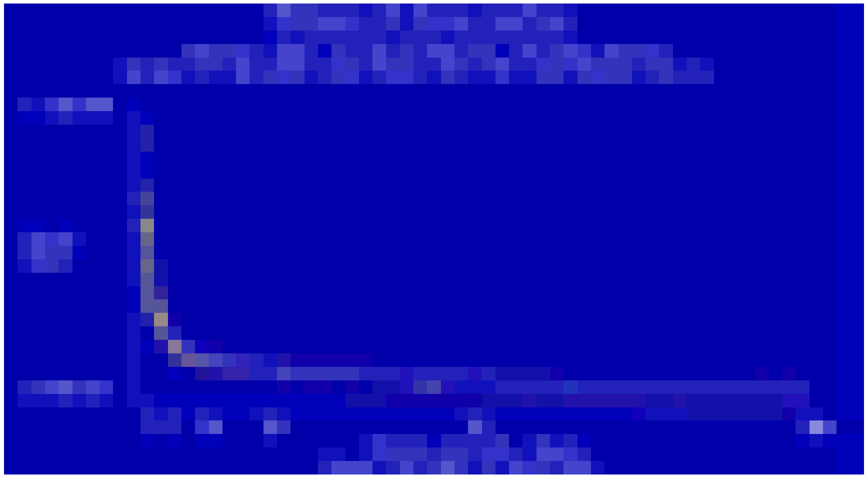
Maximum	10.86	11.70	14.09	17.08	12.33	10.04	10.09	3.57	10.14	10.02	10.88	10.61	1.74	10.20	1.74	5.20	**Sum of occurances by Season**		
Average	3.36	4.02	6.90	9.23	5.84	2.26	1.51	1.18	1.21	1.57	2.16	3.21	0.84	2.39	0.86	1.36	**Jan-Apr**	**May-Sep**	**Oct-Dec**
Minimum	0.60	0.82	0.80	2.56	1.57	0.92	0.39	0.23	0.30	0.46	0.47	0.62	0.23	0.60	0.23	0.46	4	34	6
Lower 10 Percentile	1.16	1.17	1.41	4.21	2.23	1.17	0.57	0.55	0.50	0.54	0.81	1.21	0.46	1.12	0.46	0.54			

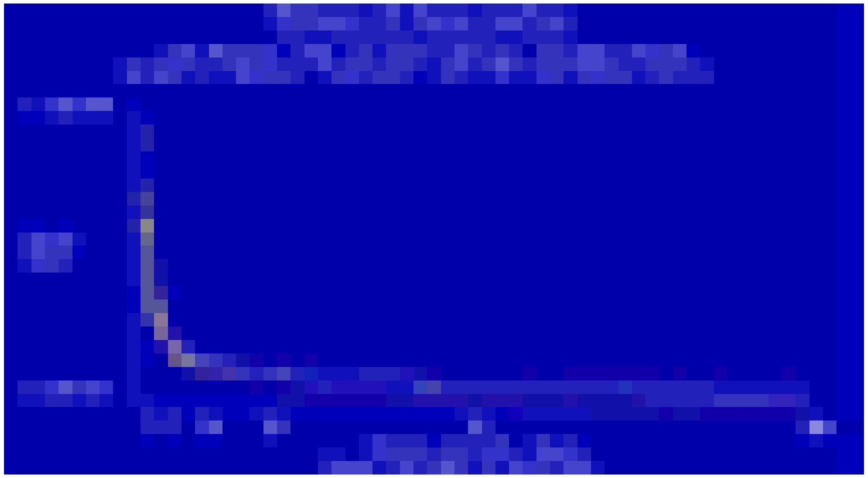
5. Low Flow Frequency Plots









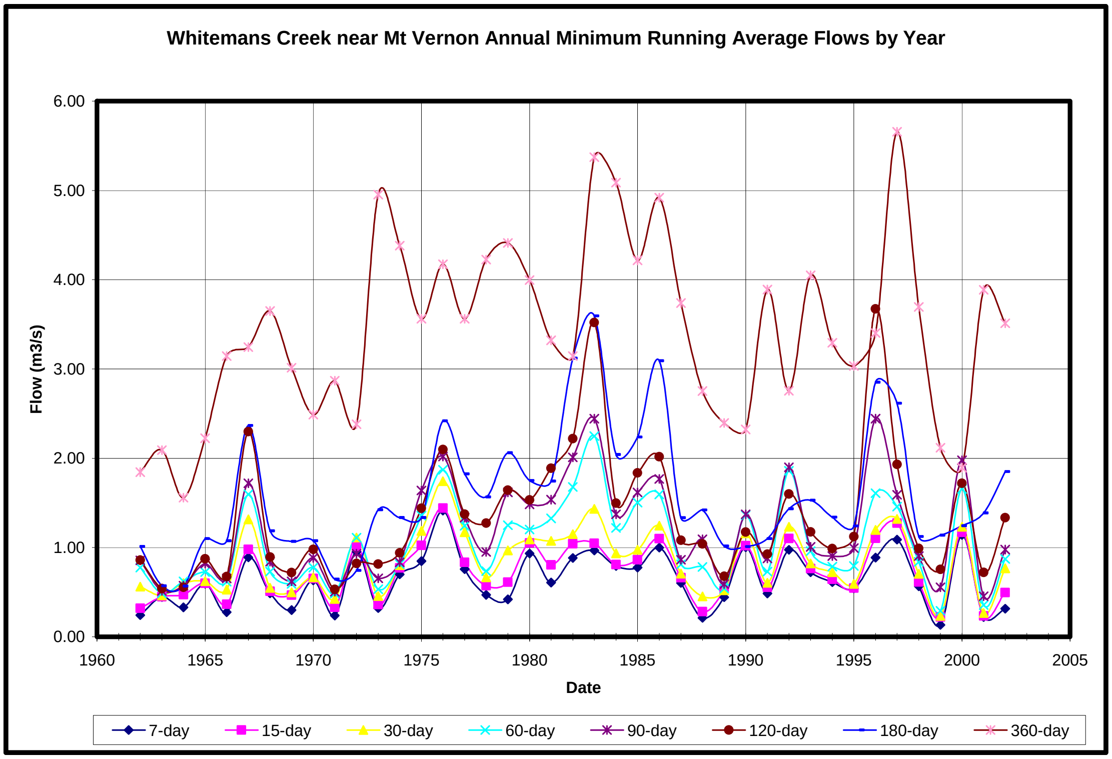


6. 7-DAY LOW FLOW STATISTICS

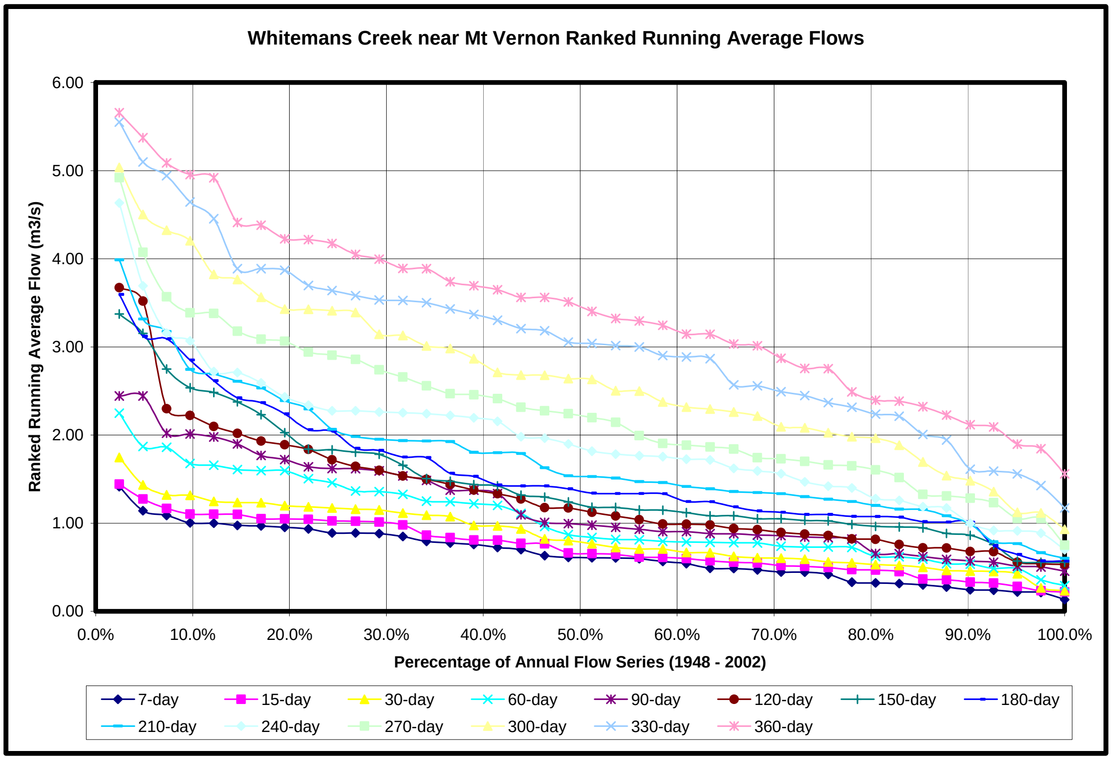
Low Flow Stastics Whitemans Creek Near Mt Vernon 1961 to 2002	**Annual Return Period 7-day Flow (m3/s)**					
Statistical Method	**2**	**5**	**10**	**20**	**50**	**100**
Two Parameter Log Normal Method of Moments	0.575	0.394	0.323	0.274	0.228	0.202
Two Parameter Log Normal Maximum Likelihood	0.575	0.394	0.323	0.274	0.228	0.202
Three Parameter Log Normal Method of Moments	0.621	0.379	0.261	0.167	0.066	0.003
Type III External Distribution Method of Moments	0.621	0.377	0.256	0.173	0.095	0.052
Type III External Distribution Method of Smallest Observed Drought	**0.609**	**0.370**	**0.268**	**0.198**	**0.135**	**0.103**
Type III External Distribution Method of Maximum Likelihood						
Pearson Type III External Distribution Method of Moments	0.617	0.378	0.265	0.176	0.082	0.027
Pearson Type III External Distribution Method of Maximum Likelihood	0.592	0.371	0.278	0.211	0.147	0.110
Pearson Type III External Distribution Method of Monments (indirect)	0.599	0.364	0.268	0.203	0.145	0.144
Maximum	0.621	0.394	0.323	0.274	0.228	0.202
Average	0.601	0.378	0.280	0.210	0.141	0.105
Minimum	0.575	0.364	0.256	0.167	0.066	0.003

7. Whitemans Creek Near Mt Vernon Minimum Annual Running Average Flows (m3/s)

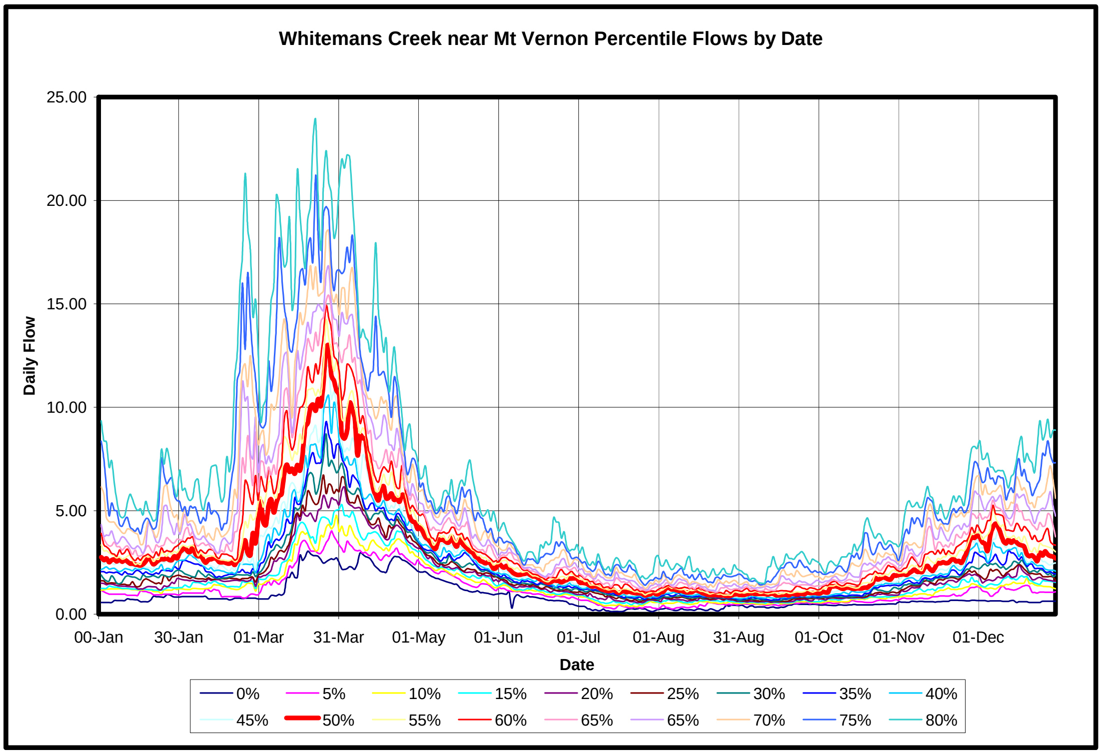
	7-day	15-day	30-day	60-day	90-day	120-day	150-day	180-day	210-day	240-day	270-day	300-day	330-day	360-day
Maximum	1.41	1.44	1.74	2.25	2.44	3.67	3.37	3.59	3.99	4.63	4.92	5.04	5.55	5.66
Average	0.64	0.72	0.85	1.04	1.19	1.34	1.46	1.58	1.73	1.95	2.27	2.66	3.06	3.42
Minimum	0.13	0.22	0.23	0.29	0.45	0.53	0.56	0.57	0.60	0.70	0.75	0.93	1.17	1.56
Lower 10 Percentile	0.24	0.33	0.46	0.53	0.57	0.68	0.86	1.01	0.99	1.00	1.28	1.48	1.61	2.12


Whitemans Creek near Mt Vernon Annual Minimum Running Average Flows by Year
Flow (m3/s)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Date
7-day
15-day
30-day
60-day
90-day
120-day
180-day
360-day

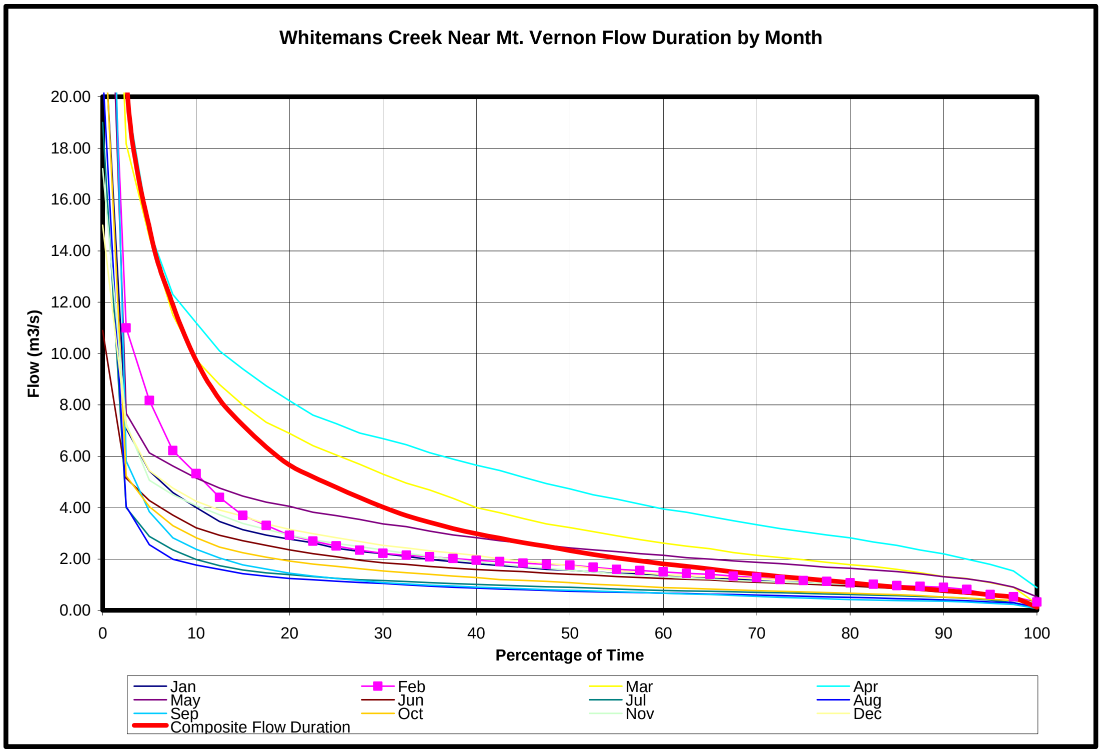
8.


Whitemans Creek near Mt Vernon Ranked Running Average Flows
Ranked Running Average Flow (m3/s)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%
Perecentage of Annual Flow Series (1948 - 2002)
7-day
15-day
30-day
60-day
90-day
120-day
150-day
180-day
210-day
240-day
270-day
300-day
330-day
360-day

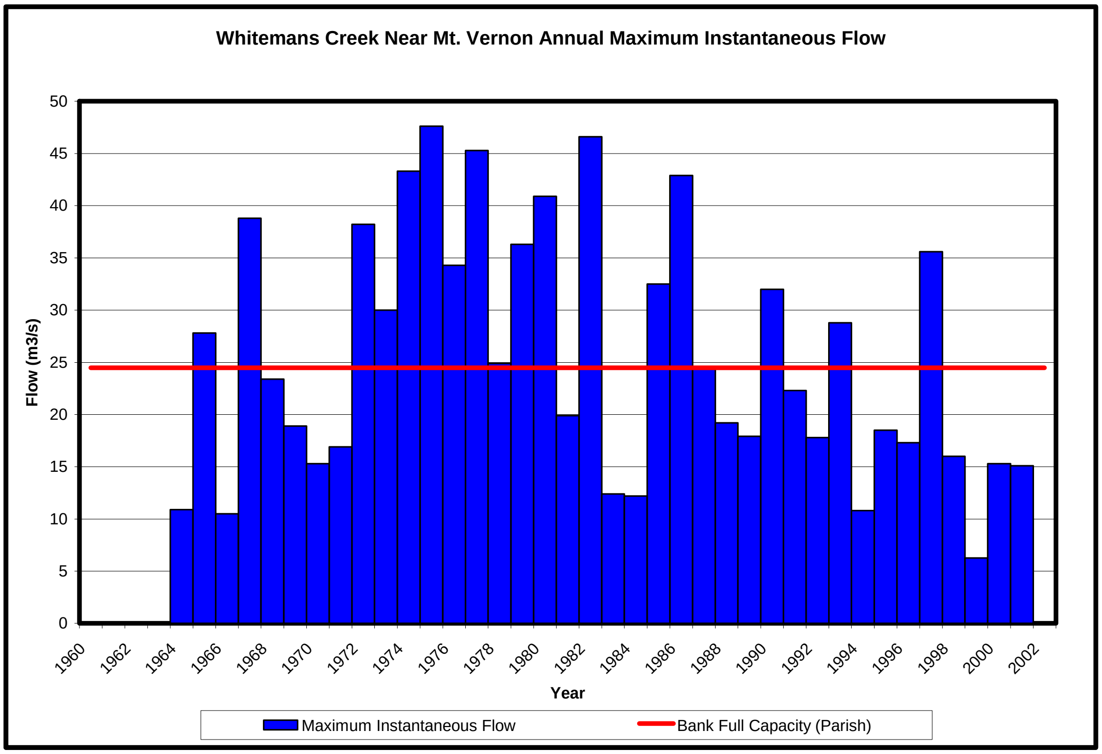
9.


Whitemans Creek near Mt Vernon Percentile Flows by Date
Daily Flow
25.00
20.00
15.00
10.00
5.00
0.00
00-Jan
30-Jan
01-Mar
31-Mar
01-May
01-Jun
01-Jul
01-Aug
31-Aug
01-Oct
01-Nov
01-Dec
Date
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
65%
70%
75%
80%

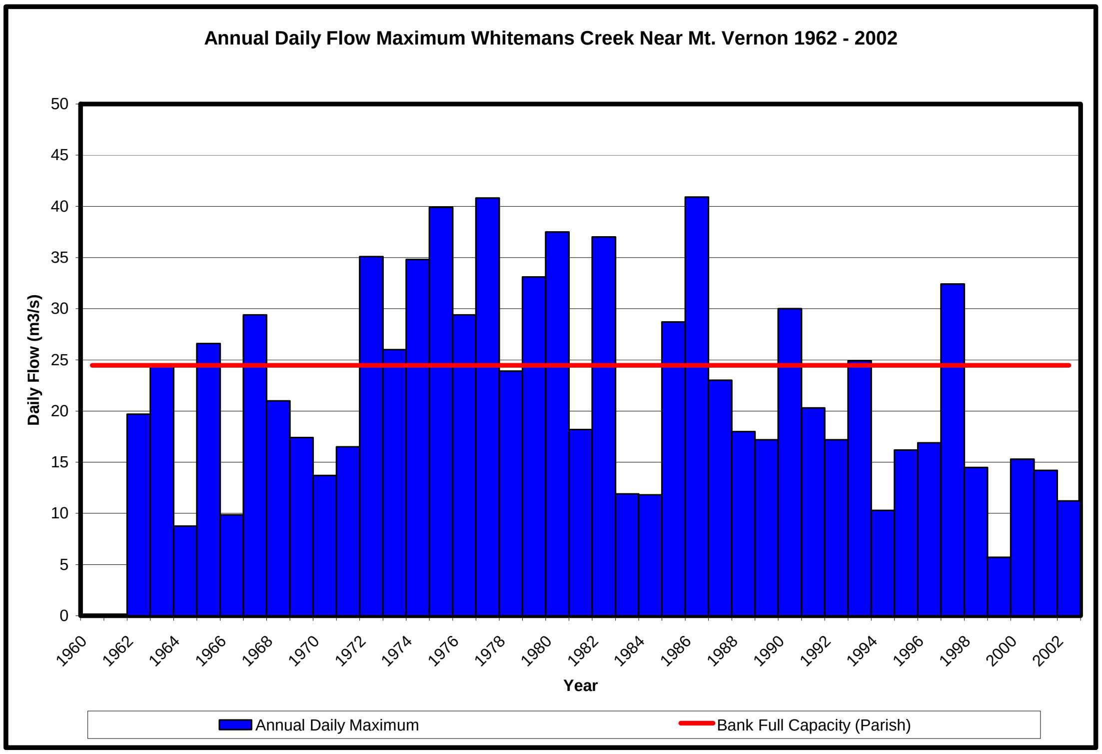
10.


Whitemans Creek Near Mt. Vernon Flow Duration by Month
Flow (m3/s)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Percentage of Time
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Composite Flow Duration

11.

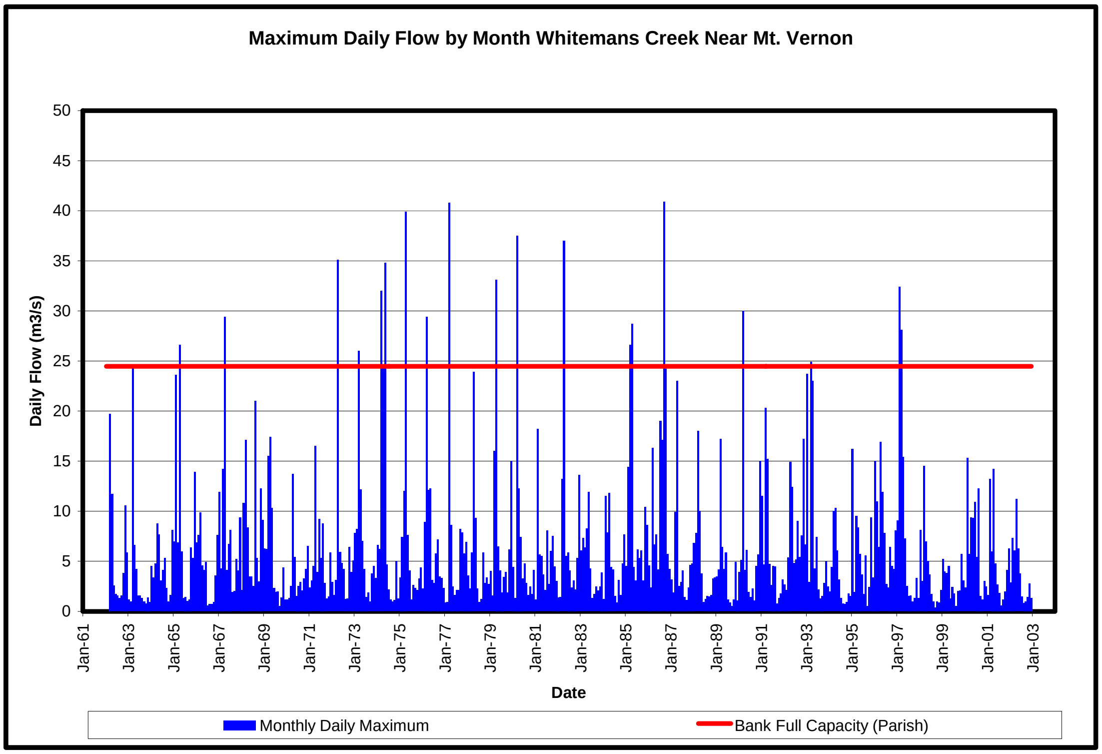

Whitemans Creek Near Mt. Vernon Annual Maximum Instantaneous Flow
Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
50
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year
Maximum Instantaneous Flow
Bank Full Capacity (Parish)

12.


Annual Daily Flow Maximum Whitemans Creek Near Mt. Vernon 1962 - 2002
Daily Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
50
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year
Annual Daily Maximum
Bank Full Capacity (Parish)

13.

14.



Maximum Daily Flow by Month Whitemans Creek Near Mt. Vernon

15. High Frequency Flows
(Whitemans Creek near Mt Vernon 1962 to 2003)

Return Period Period (yr)	Extreme Value (m3/s)	Log Pearson (m3/s)	Three P Log Normal (m3/s)	Walkby (m3/s)
1.003	0.91	3.95	**1.85**	8.29
1.05	8.15	9.3	**7.21**	9.48
1.25	15	15.2	**15.2**	13.7
2	23.8	23.3	**25.9**	23.5
5	34.9	34.6	**36.6**	36.8
10	41.9	42.1	**41.3**	43.3
20	48.3	49.2	**44.5**	47.9
50	56.3	58.6	**47.2**	51.9
100	62	65.7	**48.6**	53.8
200	67.5	72.9	**49.5**	55.2
500	74.4	82.5	**50.2**	56.4

B-6: GRAND RIVER AT BLAIR, DOON AND GALT REACHES

Grand River at Doon Mean Monthly Flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1974	34.11	28.12	77.67	70.04	82.46	17.48	11.70	10.76	10.87	11.39	13.03	9.03	**31.39**
1975	15.20	23.38	48.87	95.03	19.39	16.89	11.61	18.55	16.76	13.79	17.16	30.54	**27.26**
1976	15.96	45.35	145.07	46.14	32.45	10.91	20.26	12.73	16.19	20.87	19.31	15.57	**33.40**
1977	8.26	6.37	92.42	36.51	9.47	7.44	8.85	10.07	25.35	56.19	36.13	45.86	**28.58**
1978	16.89	13.06	27.19	123.75	26.33	10.47	10.06	9.48	11.66	10.70	12.91	14.48	**23.92**
1979	23.14	13.29	107.72	100.18	24.45	12.99	10.75	10.11	9.13	9.24	23.81	49.46	**32.86**
1980	33.28	10.74	39.78	65.00	15.92	13.14	14.08	17.62	16.60	20.97	20.30	25.65	**24.42**
1981	13.60	64.20	24.63	25.36	15.76	12.64	13.46	15.51	34.40	45.24	33.99	35.31	**27.84**
1982	12.47	7.93	44.85	112.96	15.31	18.93	13.18	20.50	22.50	17.48	51.97	98.92	**36.42**
1983	31.77	24.84	31.74	52.56	59.89	17.84	13.17	16.23	15.02	17.61	21.34	32.18	**27.85**
1984	12.92	74.09	55.72	49.75	16.87	18.33	14.99	16.40	17.68	12.17	25.00	54.75	**30.72**
1985	25.56	41.94	117.43	117.64	16.32	16.17	13.80	21.24	26.30	22.60	62.58	47.73	**44.11**
1986	20.80	14.33	75.89	29.90	26.16	16.63	19.28	26.29	126.53	82.71	32.37	33.07	**42.00**
1987	23.11	13.72	61.81	59.20	14.35	12.84	17.79	17.16	13.26	15.31	20.87	53.94	**26.95**
1988	22.00	32.03	49.53	43.61	14.40	11.08	12.74	13.19	13.66	13.88	40.26	22.33	**24.06**
1989	26.39	15.92	41.24	50.33	17.61	30.31	12.07	12.66	12.13	14.91	35.06	18.20	**23.90**
1990	31.91	43.97	67.88	33.39	23.05	13.52	14.35	15.72	12.74	49.07	64.66	67.97	**36.52**
1991	33.25	27.51	99.42	89.24	19.12	13.09	15.23	13.40	11.43	14.81	13.76	22.79	**31.09**
1992	22.53	17.22	50.46	75.24	29.28	11.86	20.18	49.65	50.34	32.16	113.43	43.27	**42.97**
1993	74.26	15.23	28.64	79.24	15.18	30.20	16.65	13.00	15.93	16.24	18.41	23.87	**28.90**
1994	9.95	16.09	29.34	69.00	36.86	13.61	14.09	14.11	12.34	13.46	13.27	17.76	**21.66**
1995	51.16	10.47	45.38	37.42	19.53	22.96	14.39	15.76	13.22	14.29	57.18	22.88	**27.05**
1996	47.97	32.91	50.01	101.47	53.51	39.52	22.28	15.73	19.08	25.51	32.54	62.10	**41.88**
1997	40.16	73.80	88.79	63.77	38.16	13.13	12.75	12.07	13.21	12.23	26.72	18.67	**34.46**
1998	50.67	23.85	73.30	27.52	11.81	11.04	10.41	10.11	9.13	6.21	6.00	5.75	**20.48**
1999	8.99	21.51	20.37	15.83	8.19	10.14	10.33	8.83	10.42	10.25	16.00	32.24	**14.43**
2000	16.62	24.48	21.44	31.61	65.24	74.19	31.50	24.87	18.16	13.33	17.41	25.46	**30.36**
2001	14.34	74.79	53.53	82.49	21.78	16.49	11.29	12.95	12.44	30.86	33.21	50.26	**34.53**
2002	20.35	33.11	56.99	58.99	40.61	23.11	14.60	14.12	11.21	9.01	8.02	8.32	**24.87**
2003	5.69	6.85	44.49	34.71	29.94	14.49	12.17	17.21	11.09	21.95	71.44	58.22	**27.35**
Maximum	**74.26**	**74.79**	**145.07**	**123.75**	**82.46**	**74.19**	**31.50**	**49.65**	**126.53**	**82.71**	**113.43**	**98.92**	**44.11**
Average	**25.44**	**28.37**	**59.05**	**62.60**	**27.31**	**18.38**	**14.60**	**16.20**	**20.29**	**21.81**	**31.94**	**34.89**	**30.07**
Minimum	**5.69**	**6.37**	**20.37**	**15.83**	**8.19**	**7.44**	**8.85**	**8.83**	**9.13**	**6.21**	**6.00**	**5.75**	**14.43**
Lower 10	**9.86**	**10.21**	**26.94**	**29.66**	**14.10**	**10.87**	**10.40**	**10.11**	**10.83**	**10.15**	**13.02**	**13.93**	**23.68**

2. Grand River at Doon 7-day Minimum Flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	24.64	26.10	68.71	46.91	22.34	17.34	18.00	16.14	41.86	44.71	36.66	61.21	12.58	16.83	12.84	22.07	Jan-Apr	May-Sep	Oct-Dec
Average	12.15	12.92	20.08	22.63	13.56	11.64	11.38	11.52	12.99	13.59	15.76	20.31	8.54	10.60	10.13	11.99	15	8	7
Minimum	3.90	4.75	5.38	12.68	7.43	6.73	6.29	6.94	7.62	4.93	4.60	3.92	3.90	3.90	6.29	3.92			
Lower 10 Percentile	6.65	8.20	7.62	13.89	10.60	8.83	9.15	8.40	8.80	8.20	9.00	9.29	5.31	6.65	8.05	8.00			

3. Grand River at Doon 15-day Minimum Flow (m3/s)

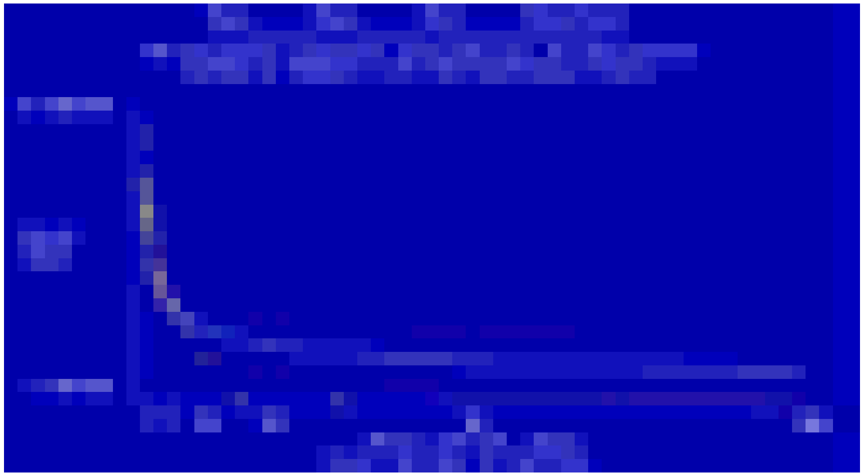
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	28.82	33.21	76.32	92.03	37.52	18.62	25.36	16.51	39.16	50.39	37.12	71.37	13.07	19.92	14.44	24.30	Jan-Apr	May-Sep	Oct-Dec
Average	14.00	14.24	22.85	34.44	17.08	12.55	12.28	12.19	13.77	15.05	16.63	23.22	9.07	11.57	10.88	13.46	16	9	5
Minimum	3.91	4.80	5.47	13.37	7.85	6.96	6.66	6.75	8.19	5.04	4.76	4.54	3.91	3.91	6.66	4.54			
Lower 10 Percentile	7.54	8.74	8.26	16.87	11.77	9.76	9.67	9.19	8.79	9.05	9.10	10.66	5.57	7.18	8.57	8.50			

4. Grand River at Doon 30-day Minimum Flow (m3/s)

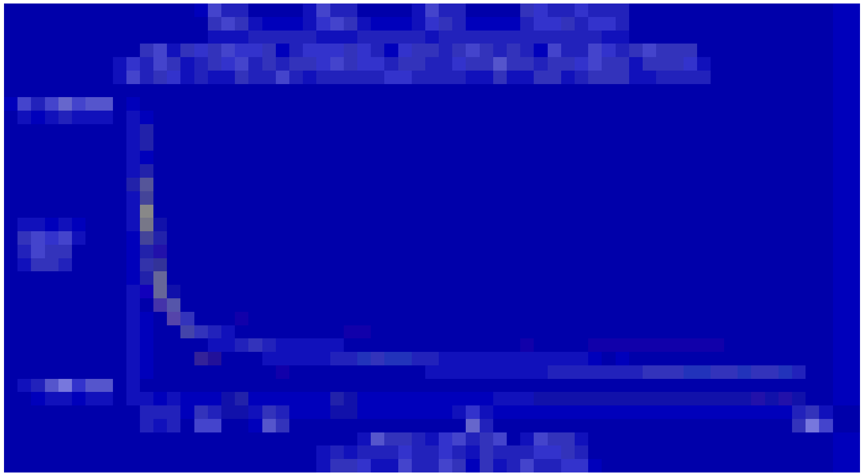
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	42.41	32.86	68.73	117.58	51.58	40.97	29.54	24.37	47.78	79.23	50.64	60.64	13.20	29.49	16.22	31.60	Jan-Apr	May-Sep	Oct-Dec
Average	18.61	16.42	24.25	45.66	22.99	15.37	13.24	13.29	14.54	16.59	18.48	25.52	9.78	13.68	11.63	14.59	14	11	5
Minimum	4.09	5.48	5.80	15.83	8.14	7.38	7.22	7.45	8.76	6.10	5.09	5.72	4.09	4.09	7.22	5.09			
Lower 10 Percentile	8.58	9.29	8.83	22.98	13.73	10.46	10.32	10.02	9.28	9.88	9.60	12.50	5.90	7.43	9.04	9.09			

5. Low Flow Frequency Plots

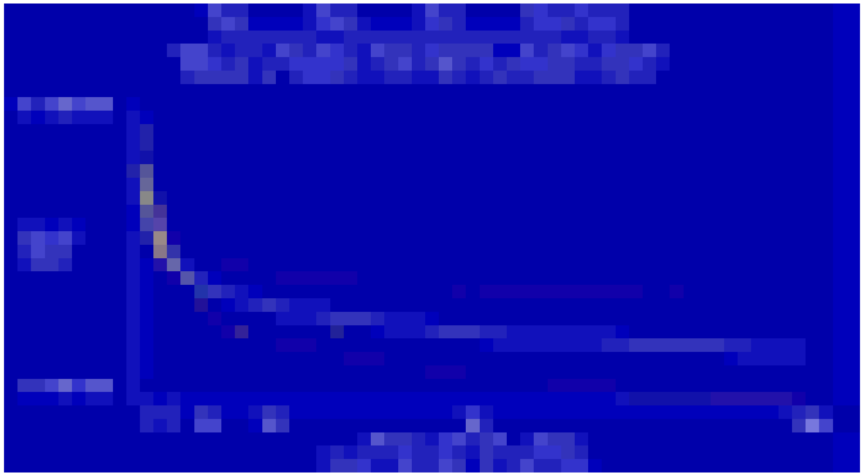
Two Parameter Log Normal Method of Moments				
Mean	8.676			
Variance	4.271			
Coefficient of Skew	-0.645			
Return Period Flows (m3/s)	Upper 95%	Mean	Lower 95%	Std Error
2	10.77	10.05	9.33	0.37
5	7.65	6.93	6.21	0.37
10	6.15	5.34	4.53	0.41
20	5.37	4.46	3.55	0.46
50	4.74	3.72	2.69	0.52
100	4.45	3.35	2.25	0.56



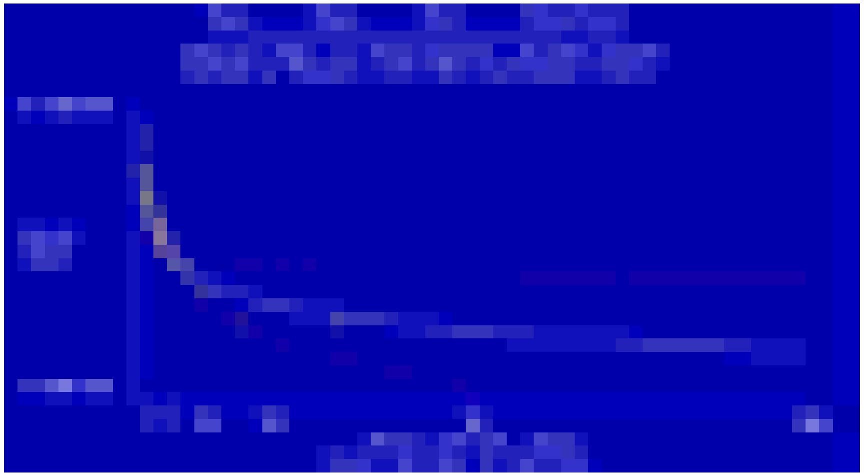
Two Parameter Log Normal Maximum Likelihood				
Mean	2.127			
Variance	7.949			
Coefficient of Skew	-1.298			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	10.77	10.05	9.33	0.37
5	7.65	6.93	6.21	0.35
10	6.15	5.34	4.53	0.37
20	5.37	4.46	3.55	0.38
50	4.74	3.72	2.69	0.40
100	4.45	3.35	2.25	0.41



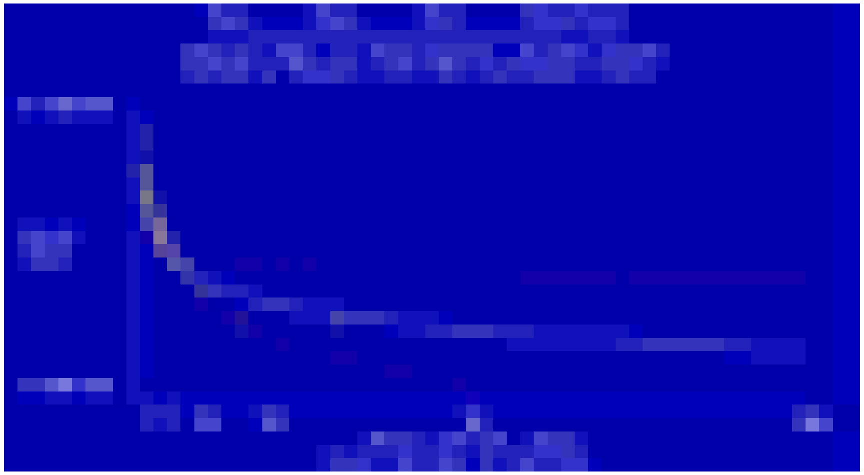
Type III External Distribution Method of Moments				
Mean	5.676		Alpha	11.10
Variance	4.124		Beta	9.55
Coefficient of Skew	-0.680		Gamma	-9.96
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	9.64	8.92	8.18	0.37
5	8.08	7.08	6.08	0.51
10	7.25	5.97	4.68	0.66
20	6.58	4.97	3.36	0.82
50	5.84	3.77	1.69	1.06
100	5.38	2.93	0.48	1.25



Pearson Type III External Distribution Method of Moments				
Mean	8.676		Alpha	0.96
Variance	4.271		Beta	4.65
Coefficient of Skew	-0.928		Gamma	4.22
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	9.41	8.99	8.56	0.22
5	7.89	7.10	6.31	0.40
10	7.16	5.92	4.67	0.64
20	6.67	4.83	2.97	0.95
50	6.32	3.49	0.65	1.45
100	6.16	2.51	0.00	1.86



Pearson Type III External Distribution Method of Monments (indirect)				
Mean	2.127		Alpha	0.263
Variance	0.079		Beta	1.147
Coefficient of Skew	-1.867		Gamma	1.825
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	10.35	9.08	7.81	0.65
5	8.40	7.04	5.67	0.70
10	7.26	5.83	4.40	0.73
20	6.59	4.83	3.05	0.90
50	6.06	3.75	1.43	1.18
100	5.74	3.09	0.44	1.35

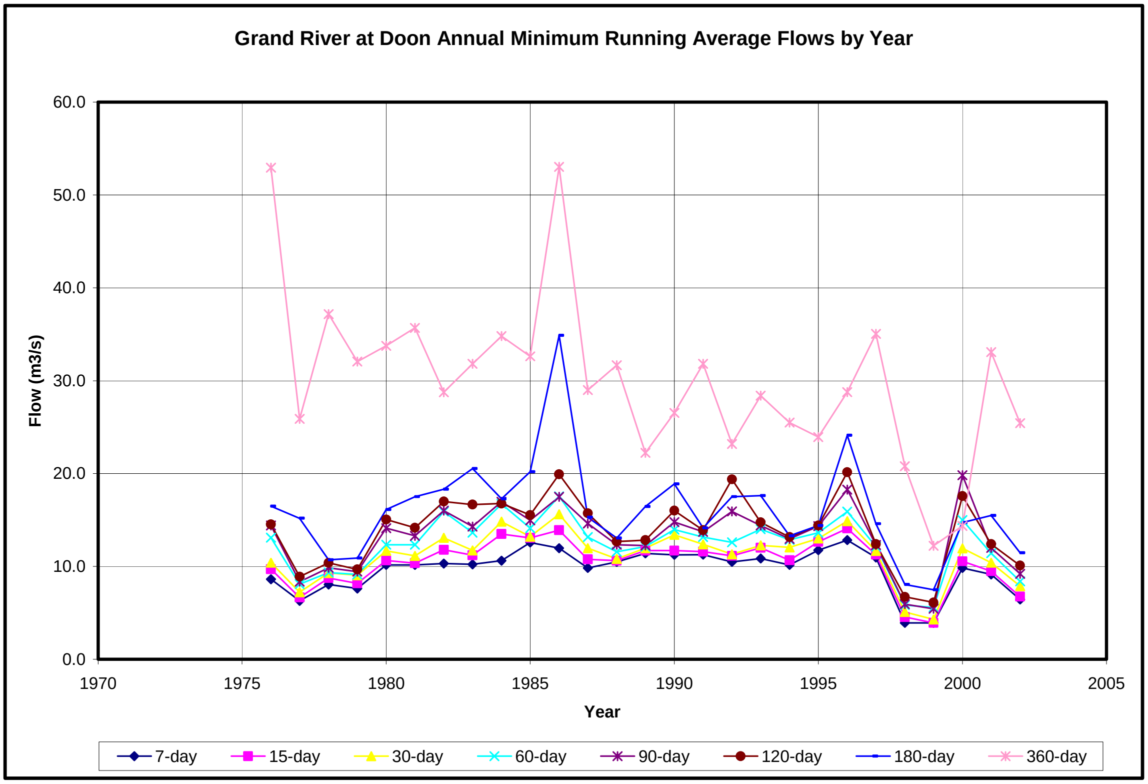


6. 7-DAY LOW FLOW STATISTICS

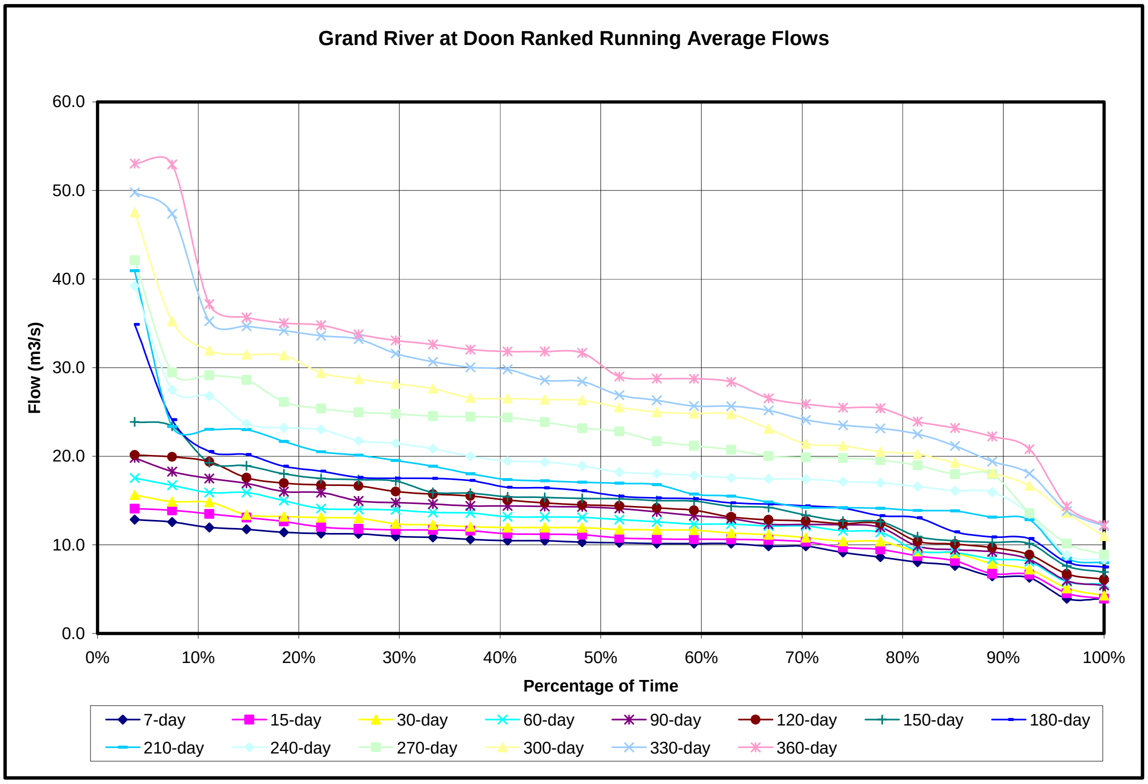
Low Flow Statistics Grand River at Doon Gauge Station	**Annual Return Period 7-day Flow (m3/s)**					
Statistical Method	**2**	**5**	**10**	**20**	**50**	**100**
Two Parameter Log Normal Method of Moments	10.050	6.930	5.340	4.461	3.715	3.350
Two Parameter Log Normal Maximum Likelihood	**10.050**	**6.930**	**5.340**	**4.461**	**3.715**	**3.350**
Three Parameter Log Normal Method of Moments						
Type III External Distribution Method of Moments	8.920	7.081	5.967	4.968	3.766	2.930
Type III External Distribution Method of Smallest Observed Drought						
Type III External Distribution Method of Maximum Likelihood						
Pearson Type III External Distribution Method of Moments	8.988	7.100	5.918	4.832	3.486	2.512
Pearson Type III External Distribution Method of Maximum Likelihood						
Pearson Type III External Distribution Method of Monments (indirect)	9.081	7.036	5.825	4.825	3.746	3.088
Maximum	10.050	7.100	5.967	4.968	3.766	3.350
Average	9.418	7.015	5.678	4.709	3.686	3.046
Minimum	8.920	6.930	5.340	4.461	3.486	2.512

7. Grand River at Doon Minimum Annual Running Average Flows (m3/s)

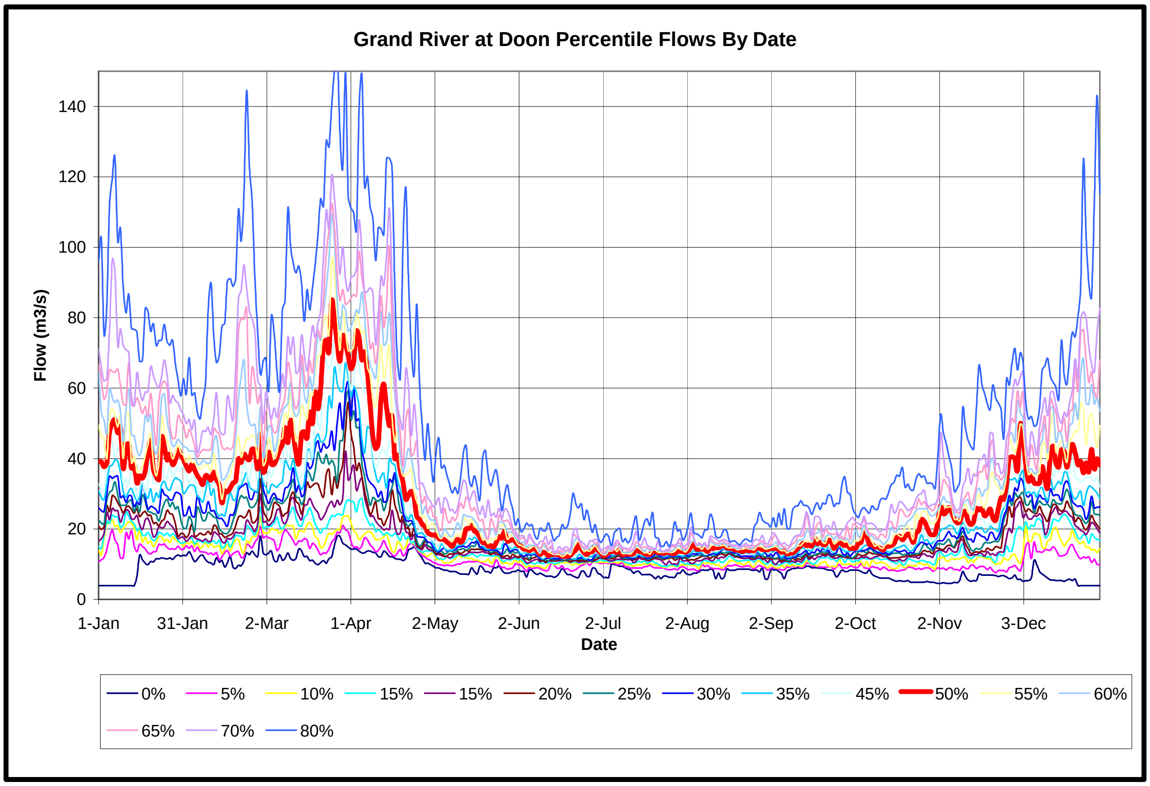
	7-day	15-day	30-day	60-day	90-day	120-day	150-day	180-day	210-day	240-day	270-day	300-day	330-day	360-day
Maximum	12.8	14.1	15.6	17.5	19.8	20.1	23.9	34.9	40.9	39.2	42.1	47.5	49.8	53.0
Average	9.7	10.4	11.2	12.4	13.2	14.0	14.9	16.1	17.5	19.4	22.4	25.3	28.0	30.0
Minimum	3.9	3.9	4.3	5.6	5.4	6.1	6.9	7.5	8.0	8.3	8.9	11.0	12.1	12.2
Lower 10 Precentile	6.4	6.7	7.6	8.3	8.9	9.4	10.2	10.8	13.0	15.0	16.2	17.5	18.9	21.7


Grand River at Doon Annual Minimum Running Average Flows by Year
Flow (m3/s)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1970
1975
1980
1985
1990
1995
2000
2005
Year
7-day
15-day
30-day
60-day
90-day
120-day
180-day
360-day

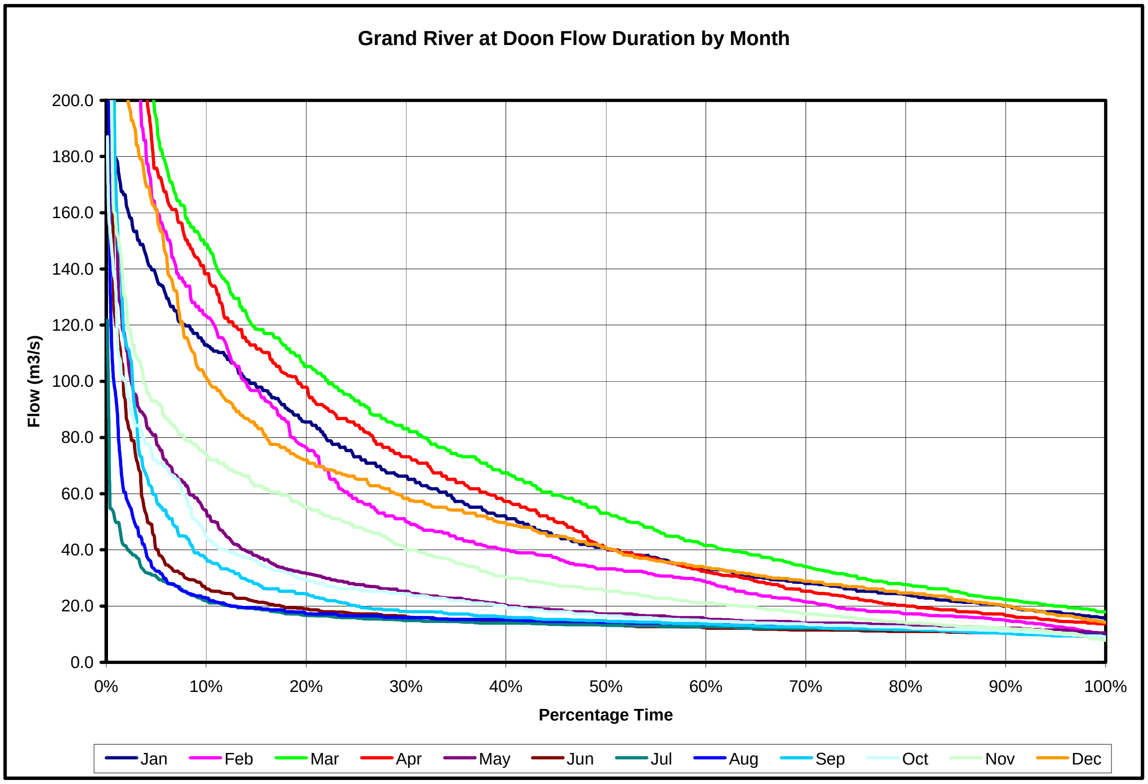
8.


Grand River at Doon Ranked Running Average Flows
Flow (m3/s)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentage of Time
7-day
15-day
30-day
60-day
90-day
120-day
150-day
180-day
210-day
240-day
270-day
300-day
330-day
360-day

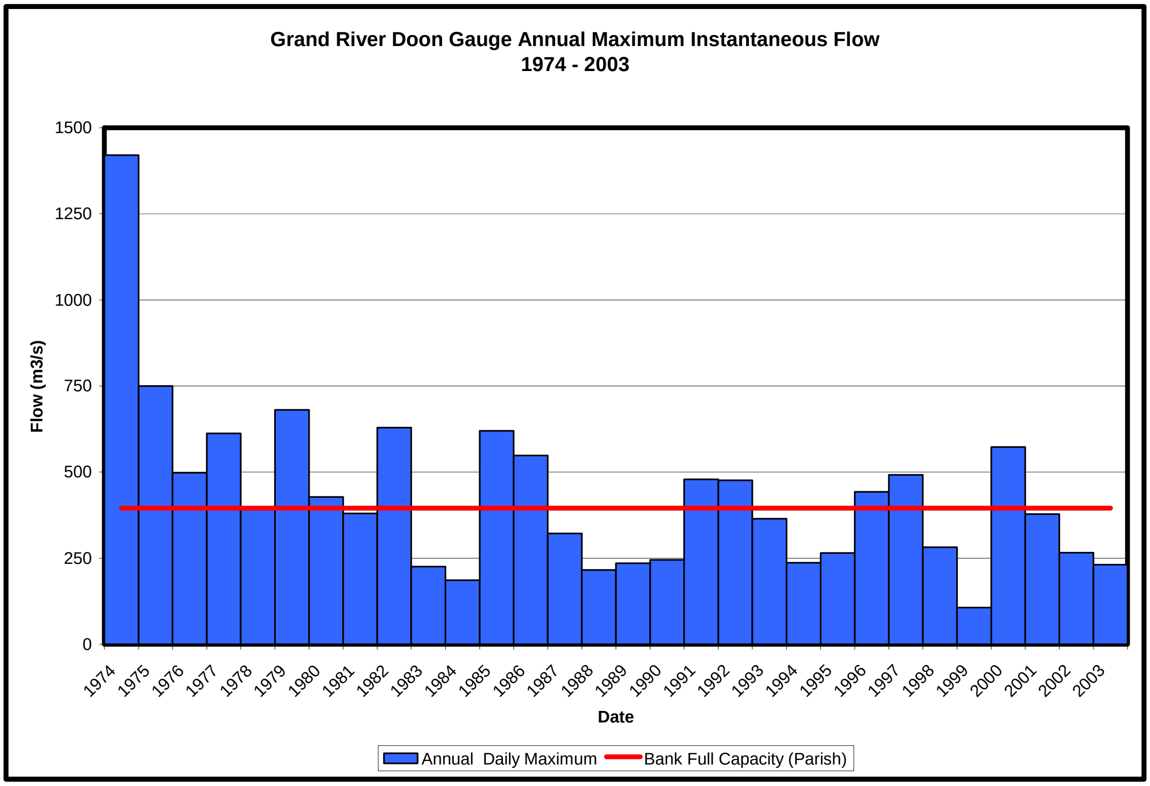
9.


Grand River at Doon Percentile Flows By Date
Flow (m3/s)
0
20
40
60
80
100
120
140
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
2-Sep
2-Oct
2-Nov
3-Dec
Date
0%
5%
10%
15%
15%
20%
25%
30%
35%
45%
50%
55%
60%
65%
70%
80%

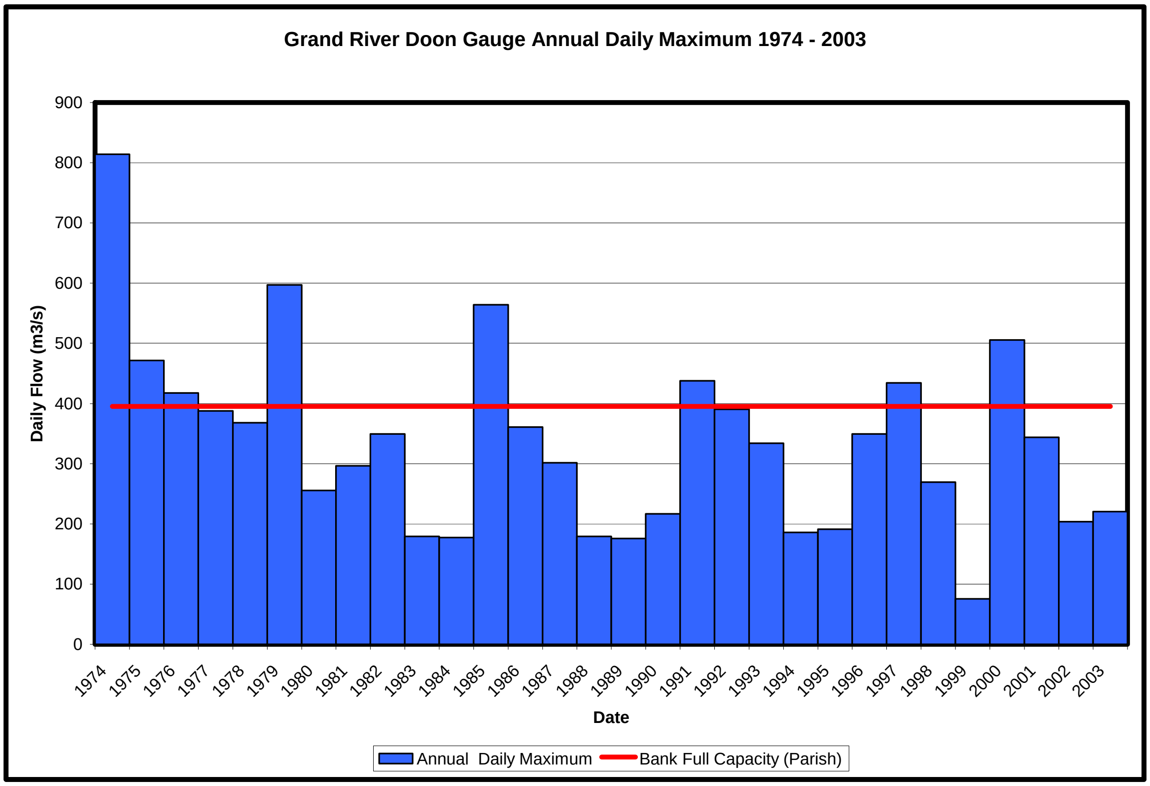
10.


Grand River at Doon Flow Duration by Month
Flow (m3/s)
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentage Time
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

11.

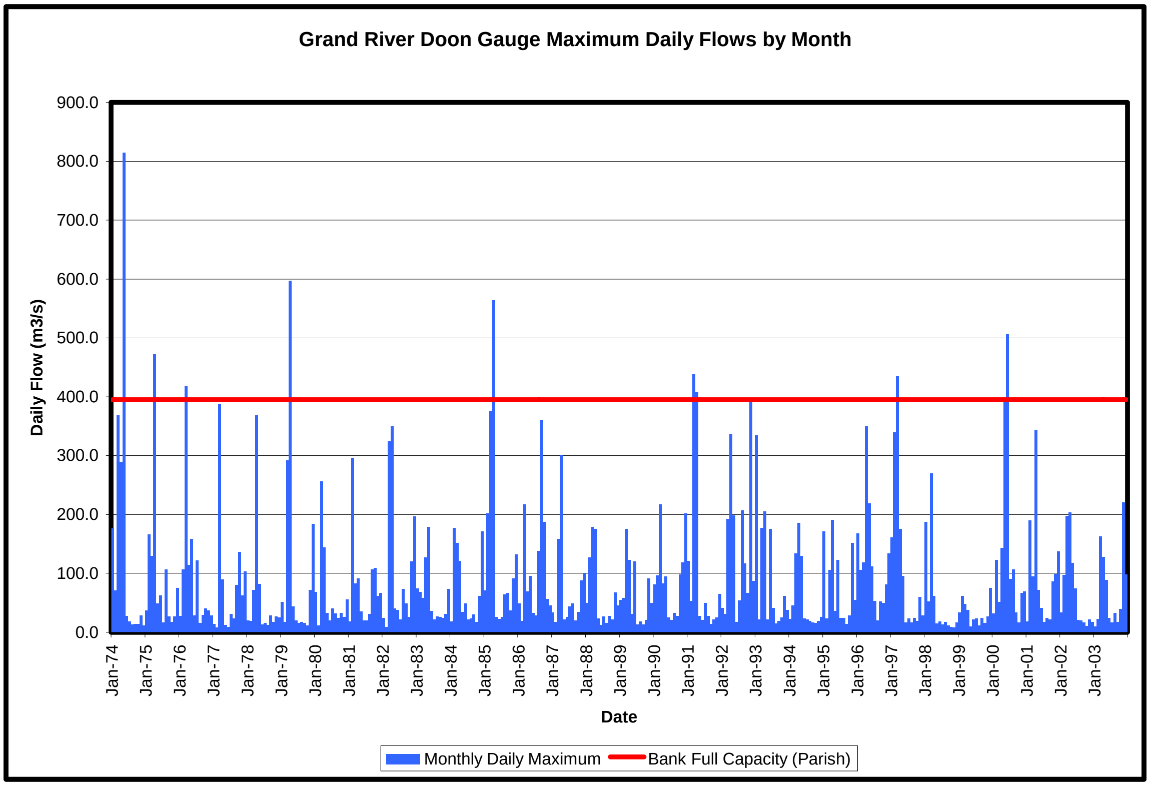

Grand River Doon Gauge Annual Maximum Instantaneous Flow
1974 - 2003
Flow (m3/s)
1500
1250
1000
750
500
250
0
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Date
Annual Daily Maximum
Bank Full Capacity (Parish)

12.


Grand River Doon Gauge Annual Daily Maximum 1974 - 2003
Daily Flow (m3/s)
900
800
700
600
500
400
300
200
100
0
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Date
Annual Daily Maximum
Bank Full Capacity (Parish)

13.

14.



15. Grand River at Doon High Flow Frequency Table (Regulated Observed Flows 1974 to 1995)

Return Period (years)	Extreme Value (m3/s)	Log Pearson (m3/s)	Three P Log Normal (m3/s)	Walkby (m3/s)
1.003	88.4	151	163	154
1.05	173	200	200	176
1.25	267	268	262	253
2	407	391	387	416
5	630	622	637	631
10	802	823	855	742
20	990	1060	1110	847
50	1270	1440	1490	1030
100	1510	1800	1840	1250
200	1780	2220	2220	1620
500	2190	2900	2810	2530

Grand River at Galt Mean Monthly Flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1974	42.75	39.20	100.42	100.05	101.25	24.98	16.72	15.38	15.53	16.27	18.61	12.90	**42.00**
1975	21.71	30.88	69.81	129.83	27.70	24.13	16.59	26.50	23.94	19.69	24.51	43.62	**38.24**
1976	22.80	64.78	188.52	72.89	50.33	19.74	30.88	22.38	27.93	32.83	29.86	21.01	**48.66**
1977	11.80	9.10	118.78	56.96	16.36	13.17	15.18	18.41	38.37	73.81	55.64	64.91	**41.04**
1978	24.13	18.65	38.51	162.48	44.54	17.19	15.72	15.16	20.31	18.23	20.14	21.60	**34.72**
1979	31.44	15.92	133.30	132.80	37.39	20.32	16.13	16.12	15.07	16.15	33.69	63.27	**44.30**
1980	43.63	15.34	58.58	88.14	27.92	20.57	20.08	20.59	19.96	24.19	24.07	35.37	**33.20**
1981	19.43	84.54	33.70	36.26	22.36	17.35	17.65	18.27	41.86	52.83	41.22	41.93	**35.62**
1982	17.26	11.33	57.37	152.41	24.24	30.04	18.22	24.59	28.77	24.12	64.44	121.79	**47.88**
1983	40.69	33.13	41.76	71.99	83.06	26.36	16.67	17.54	19.91	25.16	28.15	39.47	**36.99**
1984	18.46	97.14	74.44	72.23	25.76	24.76	18.33	19.06	20.33	14.73	32.66	69.71	**40.63**
1985	56.71	59.41	152.15	157.08	21.03	19.65	19.36	25.08	33.21	26.76	79.59	58.86	**59.07**
1986	29.72	20.47	103.06	41.78	33.81	23.32	25.19	33.07	171.17	110.22	37.17	38.80	**55.65**
1987	28.26	19.59	76.62	85.66	17.92	18.10	24.22	23.16	18.22	20.52	28.30	62.45	**35.25**
1988	30.30	41.76	66.04	61.15	22.80	14.40	17.68	16.29	17.88	19.55	46.94	27.98	**31.90**
1989	36.05	21.20	55.17	61.38	26.03	42.94	16.56	14.98	14.45	18.40	41.38	25.40	**31.16**
1990	44.00	53.09	87.96	43.60	33.15	18.42	17.78	18.22	17.92	55.98	73.28	79.23	**45.22**
1991	44.11	36.21	128.10	122.79	28.35	18.30	22.27	16.89	14.19	17.23	17.65	30.72	**41.40**
1992	28.78	20.40	59.65	98.69	42.65	19.24	30.98	64.78	63.82	45.79	149.16	56.14	**56.67**
1993	99.27	19.73	41.83	113.94	24.19	42.70	25.15	17.85	22.18	23.71	26.17	31.87	**40.72**
1994	14.22	22.98	41.54	95.90	54.11	21.22	18.73	16.96	14.97	16.83	19.31	23.07	**29.99**
1995	71.49	15.18	60.01	53.69	32.30	31.39	17.69	19.49	14.48	19.07	72.46	29.64	**36.41**
1996	63.71	45.62	64.99	136.81	79.34	55.05	29.47	21.00	29.98	36.08	45.22	77.73	**57.08**
1997	52.83	98.70	123.56	91.36	52.92	19.37	17.84	16.62	17.95	17.21	32.34	24.26	**47.08**
1998	63.88	28.83	97.79	41.06	19.03	17.41	14.01	13.05	11.49	9.33	9.01	10.38	**27.94**
1999	13.11	26.91	25.94	21.75	12.57	15.18	13.63	12.40	15.91	15.11	26.59	40.37	**19.96**
2000	20.13	32.13	29.29	46.42	85.66	99.62	42.64	34.51	23.69	18.88	23.62	34.04	**40.89**
2001	20.48	95.16	66.53	109.54	29.95	23.68	15.39	16.36	16.87	38.98	41.51	63.98	**44.87**
2002	25.99	42.74	75.95	82.38	55.99	31.83	20.03	17.20	15.23	13.16	13.68	10.91	**33.76**
2003	7.92	9.45	53.06	45.05	42.23	21.41	16.16	22.41	15.83	26.36	85.66	69.86	**34.62**
Maximum	**99.27**	**98.70**	**188.52**	**162.48**	**101.25**	**99.62**	**42.64**	**64.78**	**171.17**	**110.22**	**149.16**	**121.79**	**59.07**
Average	**34.83**	**37.65**	**77.48**	**86.20**	**39.17**	**26.40**	**20.23**	**21.14**	**27.38**	**28.91**	**41.40**	**44.38**	**40.43**
Minimum	**7.92**	**9.10**	**25.94**	**21.75**	**12.57**	**13.17**	**13.63**	**12.40**	**11.49**	**9.33**	**9.01**	**10.38**	**19.96**
Lower 10	**14.11**	**14.79**	**38.03**	**41.71**	**18.92**	**16.99**	**15.37**	**15.14**	**14.48**	**15.07**	**18.52**	**20.20**	**31.04**

2. Grand River at Galt 7-day Minimum Flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	30.50	35.71	106.44	65.56	39.80	25.21	24.07	22.29	45.84	48.96	45.44	74.20	15.73	24.04	19.56	35.51	Jan-Apr	May-Sep	Oct-Dec
Average	16.89	17.85	27.77	34.07	21.24	17.10	15.54	14.99	17.51	19.19	21.56	26.54	12.03	14.78	14.22	17.25	14	12	4
Minimum	5.30	6.78	7.68	18.04	11.00	11.06	10.54	11.13	11.04	7.97	7.56	7.69	5.30	5.30	10.54	7.56			
Lower 10 Percentile	9.50	11.22	10.88	21.13	15.97	13.92	12.19	11.82	12.29	12.87	14.06	13.27	7.67	9.50	11.76	12.28			

3. Grand River at Galt 15-day Minimum Flow (m3/s)

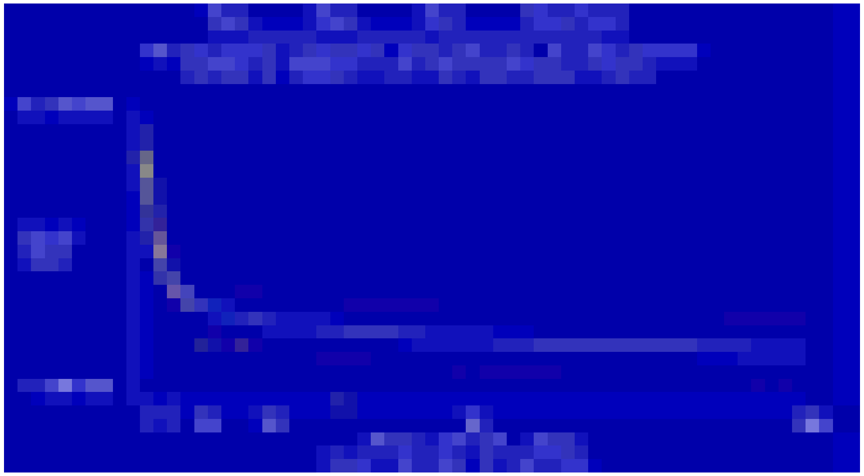
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	39.29	47.81	109.03	120.37	53.47	29.75	34.99	23.99	49.85	56.65	51.17	88.35	16.58	27.24	20.46	38.53	Jan-Apr	May-Sep	Oct-Dec
Average	19.33	19.60	31.07	49.24	26.29	18.72	16.87	15.75	18.51	20.84	22.68	30.69	12.68	16.06	15.01	18.85	15	10	5
Minimum	5.54	6.86	7.82	20.05	11.59	12.24	11.25	11.39	11.28	8.21	7.75	8.39	5.54	5.54	11.25	7.75			
Lower 10 Percentile	10.77	11.43	11.80	26.11	16.87	14.83	13.21	12.48	13.32	13.63	14.56	15.23	8.05	10.26	12.43	13.17			

4. Grand River at Galt 30-day Minimum Flow (m3/s)

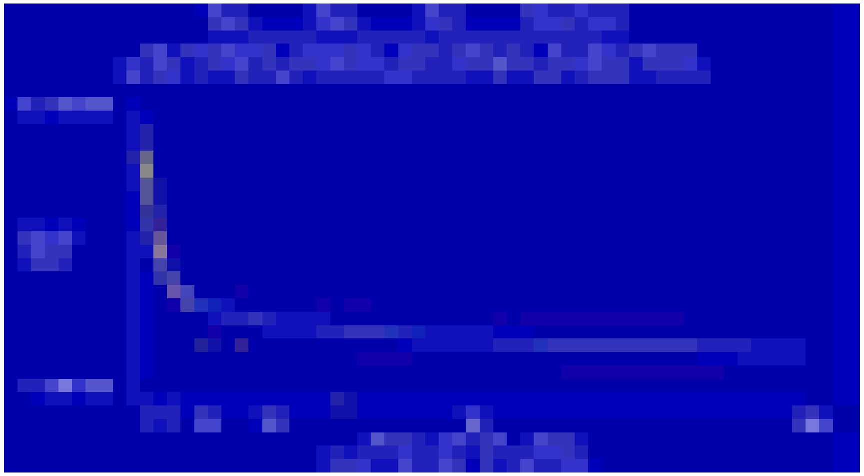
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan-Apr	May-Sep	Oct-Dec	Sum of occurances by Season		
Maximum	55.81	45.37	95.18	153.72	76.98	60.52	40.06	33.37	63.82	102.46	57.53	68.73	19.02	37.62	20.73	45.18	Jan-Apr	May-Sep	Oct-Dec
Average	25.65	22.18	32.54	62.83	34.42	22.82	18.51	17.73	19.21	22.80	24.69	33.22	13.79	18.69	15.84	20.02	13	13	4
Minimum	6.73	7.64	8.29	21.75	12.53	12.77	13.10	12.07	11.32	9.21	8.21	9.14	6.73	6.73	11.32	8.21			
Lower 10 Percentile	12.26	12.61	12.70	31.65	18.86	16.01	13.88	13.51	13.76	14.26	14.74	18.33	8.47	10.62	13.49	13.90			

5. Low Flow Frequency Plots

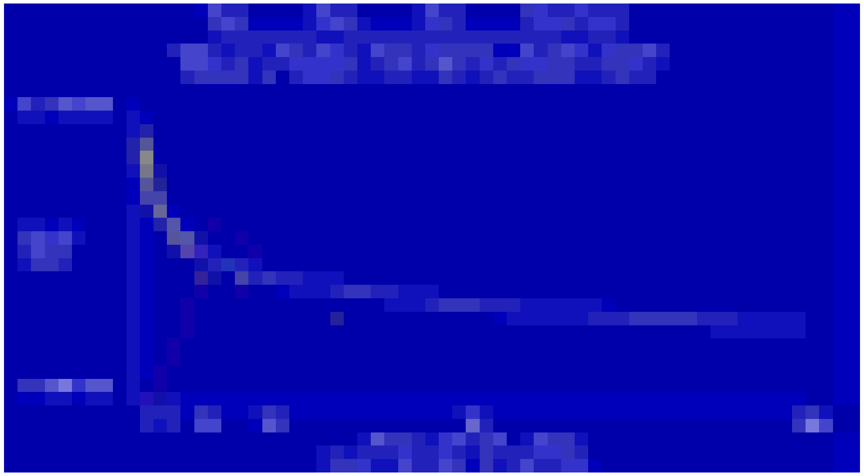
Two Parameter Log Normal Method of Moments				
Mean	12.124			
Variance	6.384			
Coefficient of Skew	-0.904			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	12.85	11.96	11.07	0.46
5	10.97	10.07	9.17	0.46
10	10.21	9.20	8.19	0.52
20	9.67	8.54	7.41	0.58
50	9.13	7.86	6.58	0.65
100	8.81	7.43	6.05	0.70



Two Parameter Log Normal Maximum Likelihood				
Mean	2.477			
Variance	6.013			
Coefficient of Skew	-1.499			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	12.85	11.96	11.07	0.46
5	10.94	10.07	9.20	0.45
10	10.13	9.20	8.28	0.47
20	9.52	8.54	7.57	0.50
50	8.89	7.86	6.82	0.53
100	8.50	7.43	6.36	0.54



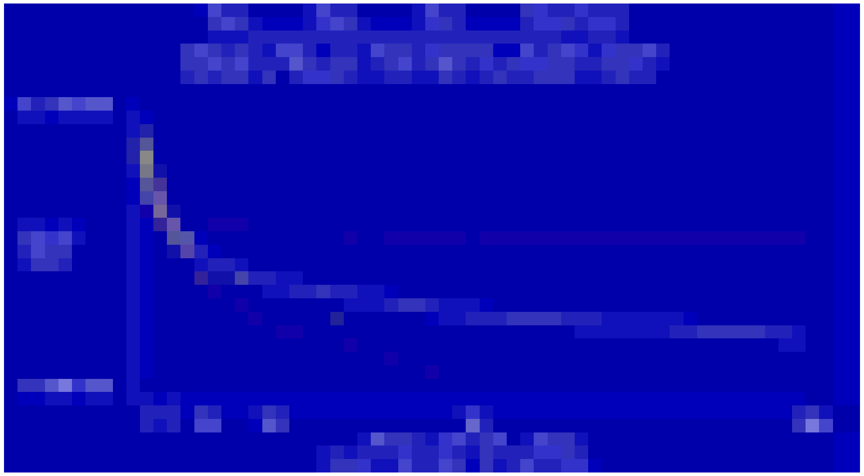
Type III External Distribution Method of Moments				
Mean	12.214		Alpha	38.43
Variance	6.164		Beta	13.39
Coefficient of Skew	-0.953		Gamma	-6.36
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	0.00	12.59	0.00	0.00
5	0.00	10.37	0.00	0.00
10	10.54	8.94	7.35	0.81
20	8.84	7.60	6.35	0.64
50	0.00	5.89	0.00	0.00
100	0.00	4.64	0.00	0.00



Pearson Type III External Distribution
Method of Moments

Mean	12.214	Alpha	1.64
Variance	6.384	Beta	2.37
Coefficient of Skew	-1.300	Gamma	8.33

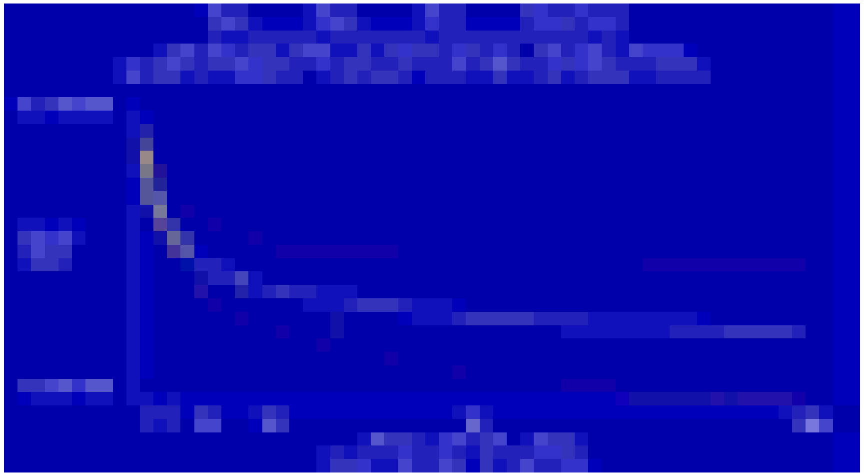
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	13.38	12.74	12.09	0.33
5	11.53	10.41	9.29	0.57
10	10.58	8.86	7.13	0.88
20	10.04	7.37	4.71	1.36
50	9.71	5.48	1.25	2.16
100	9.66	4.08	0.00	2.85



Pearson Type III External Distribution
Method of Monments (indirect)

Mean	2.477	Alpha	0.264
Variance	0.061	Beta	0.861
Coefficient of Skew	-2.156	Gamma	2.249

Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	14.49	12.86	11.23	0.83
5	12.32	10.35	8.38	1.01
10	10.72	8.74	6.75	1.01
20	9.81	7.34	4.87	1.26
50	9.18	5.80	2.41	1.73
100	8.84	4.82	0.81	2.05

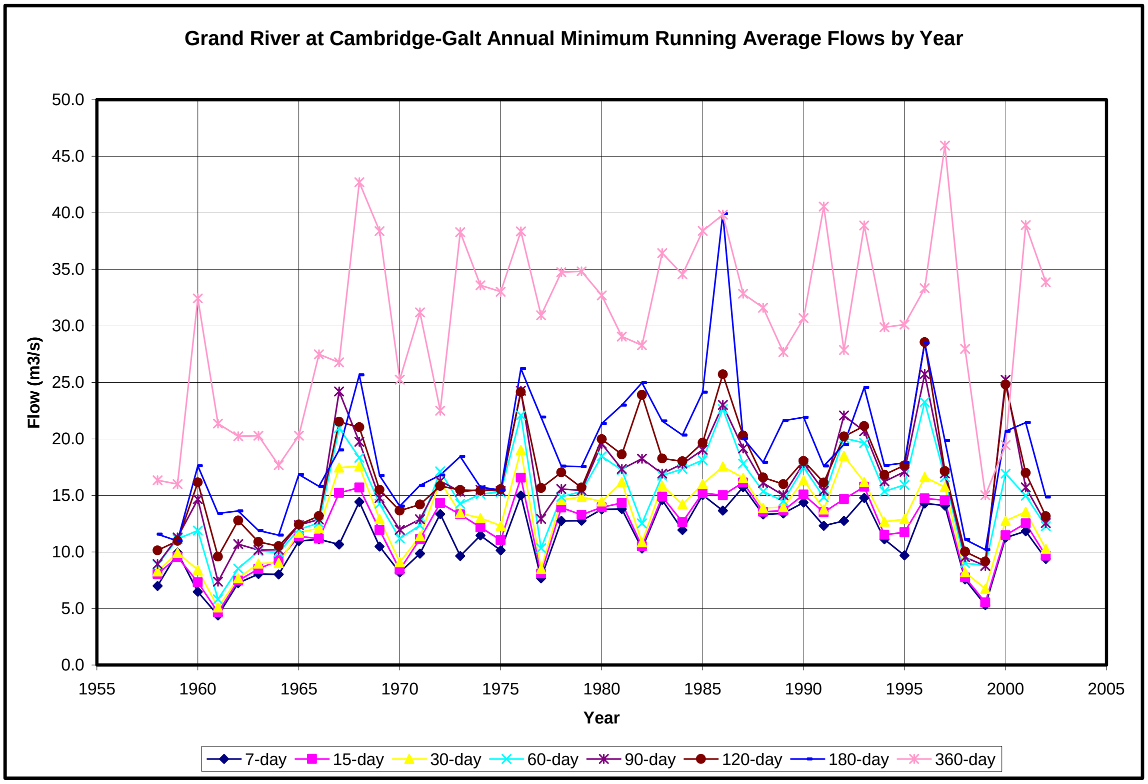


6. 7-DAY LOW FLOW STATISTICS

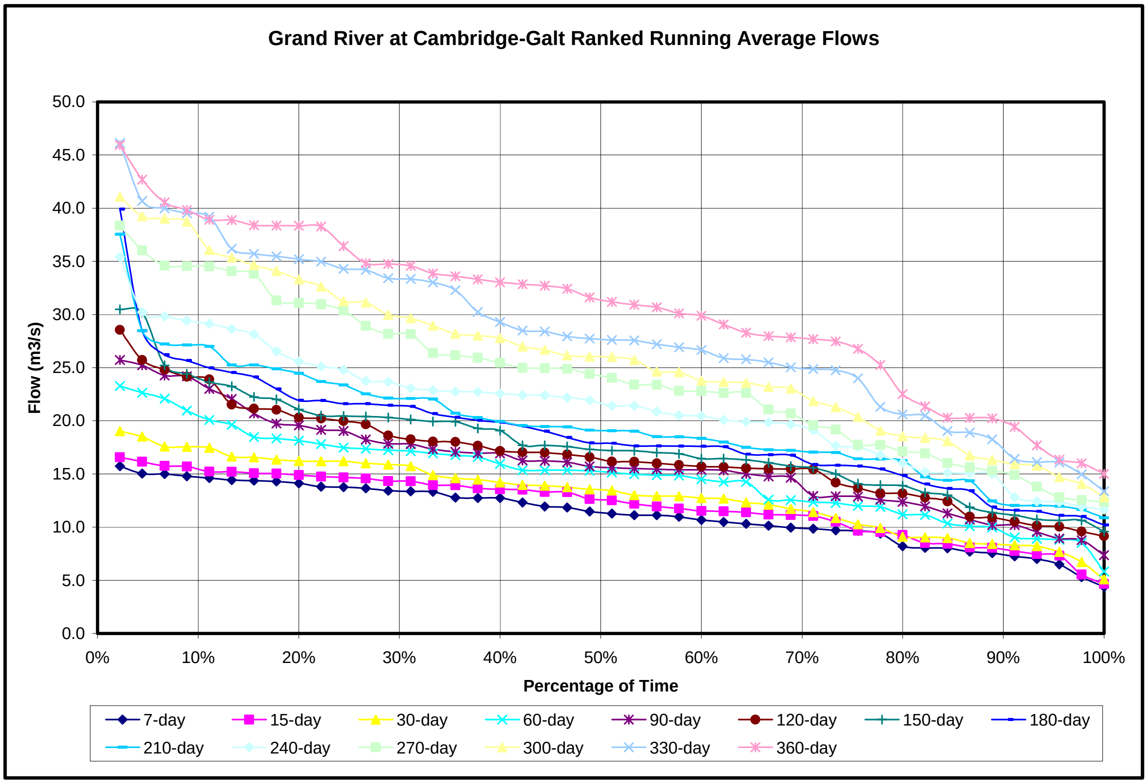
Low Flow Stastics Grand River at Cambrdige Galt Gauge Station	Annual Return Period 7-day Flow (m3/s)					
Statistical Method	**2**	**5**	**10**	**20**	**50**	**100**
Two Parameter Log Normal Method of Moments	11.961	10.068	9.201	8.541	7.855	7.429
Two Parameter Log Normal Maximum Likelihood	**11.961**	**10.068**	**9.201**	**8.541**	**7.855**	**7.429**
Three Parameter Log Normal Method of Moments						
Type III External Distribution Method of Moments	12.589	10.374	8.943	7.596	5.891	4.639
Type III External Distribution Method of Smallest Observed Drought						
Type III External Distribution Method of Maximum Likelihood						
Pearson Type III External Distribution Method of Moments	12.736	10.411	8.855	7.373	5.479	4.075
Pearson Type III External Distribution Method of Maximum Likelihood						
Pearson Type III External Distribution Method of Monments (indirect)	12.860	10.349	8.736	7.342	5.795	4.822
Maximum	12.860	10.411	9.201	8.541	7.855	7.429
Average	12.421	10.254	8.987	7.879	6.575	5.679
Minimum	11.961	10.068	8.736	7.342	5.479	4.075

7. Grand River at Cambridge-Galt Gauge Minimum Annual Running Average Flows (m3/s)

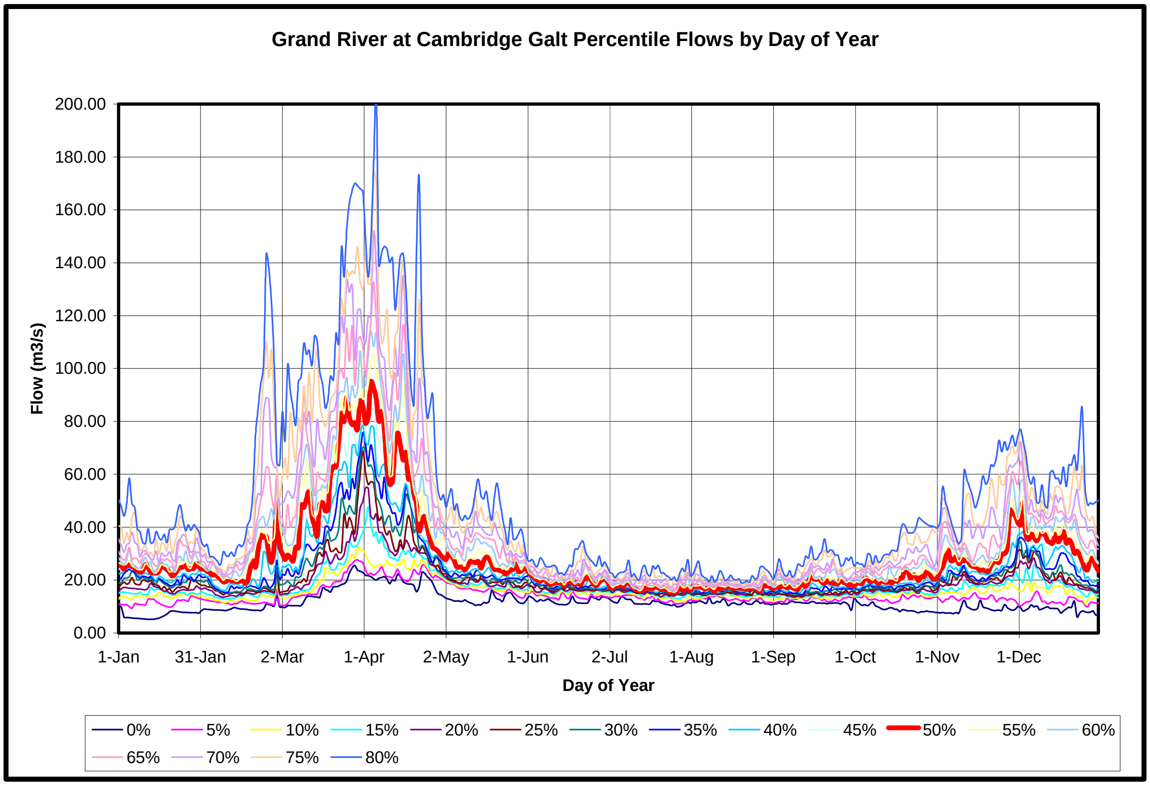
	7-day	15-day	30-day	60-day	90-day	120-day	150-day	180-day	210-day	240-day	270-day	300-day	330-day	360-day
Maximum	15.7	16.6	19.0	23.3	25.7	28.6	30.5	39.9	37.6	35.4	38.4	41.1	46.1	45.9
Average	11.2	12.0	13.0	14.9	16.0	16.8	17.7	18.8	19.6	21.2	24.1	25.9	28.1	30.4
Minimum	4.4	4.7	5.1	5.8	7.4	9.2	9.6	10.2	10.9	11.6	12.4	12.8	13.4	15.0
Lower 10 Precentile	7.4	7.9	8.3	9.4	10.2	10.7	11.2	11.7	12.2	13.7	15.1	16.1	17.2	19.8


Grand River at Cambridge-Galt Annual Minimum Running Average Flows by Year
Flow (m3/s)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year
7-day
15-day
30-day
60-day
90-day
120-day
180-day
360-day

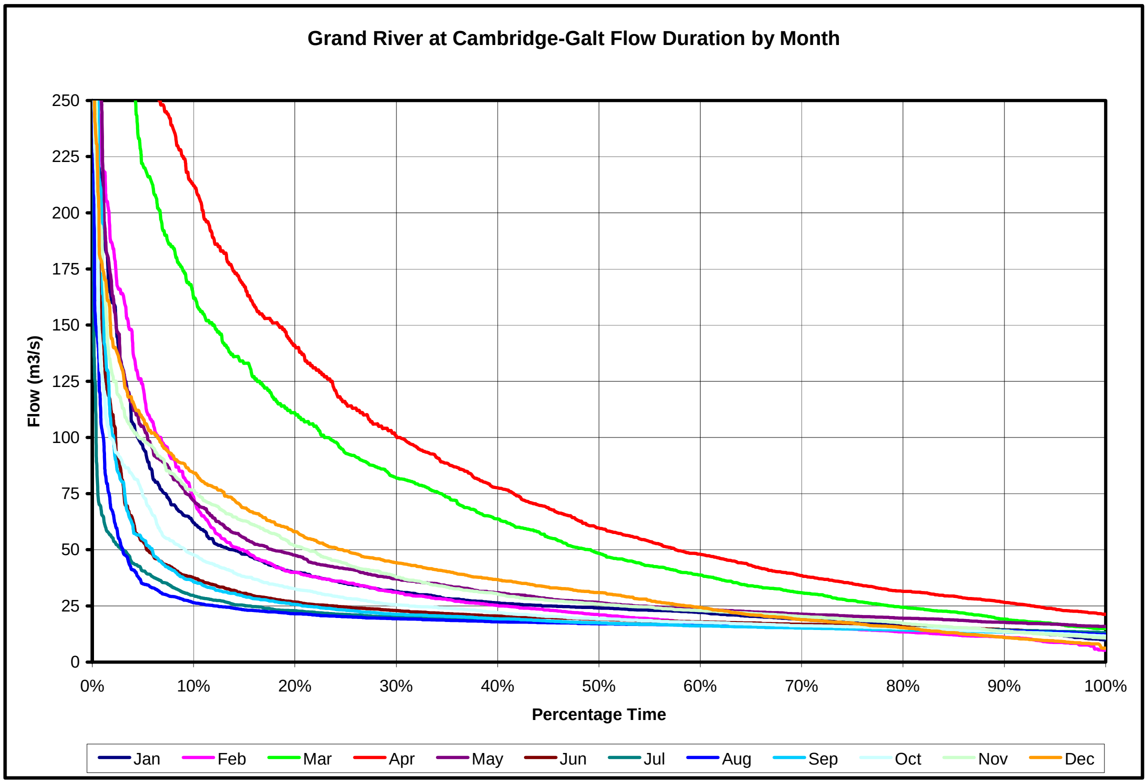
8.


Grand River at Cambridge-Galt Ranked Running Average Flows
Flow (m3/s)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentage of Time
7-day
15-day
30-day
60-day
90-day
120-day
150-day
180-day
210-day
240-day
270-day
300-day
330-day
360-day

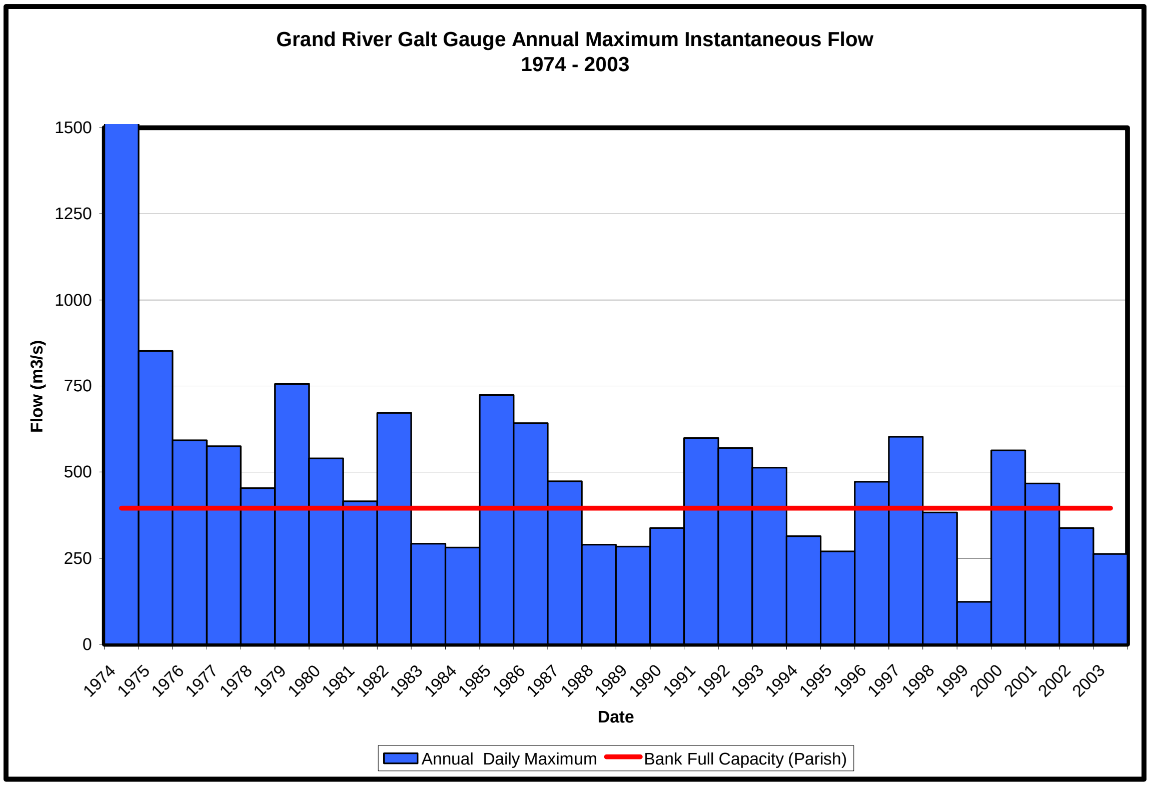
9.


Grand River at Cambridge Galt Percentile Flows by Day of Year
Flow (m3/s)
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1-Jan
31-Jan
2-Mar
1-Apr
2-May
1-Jun
2-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
Day of Year
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%

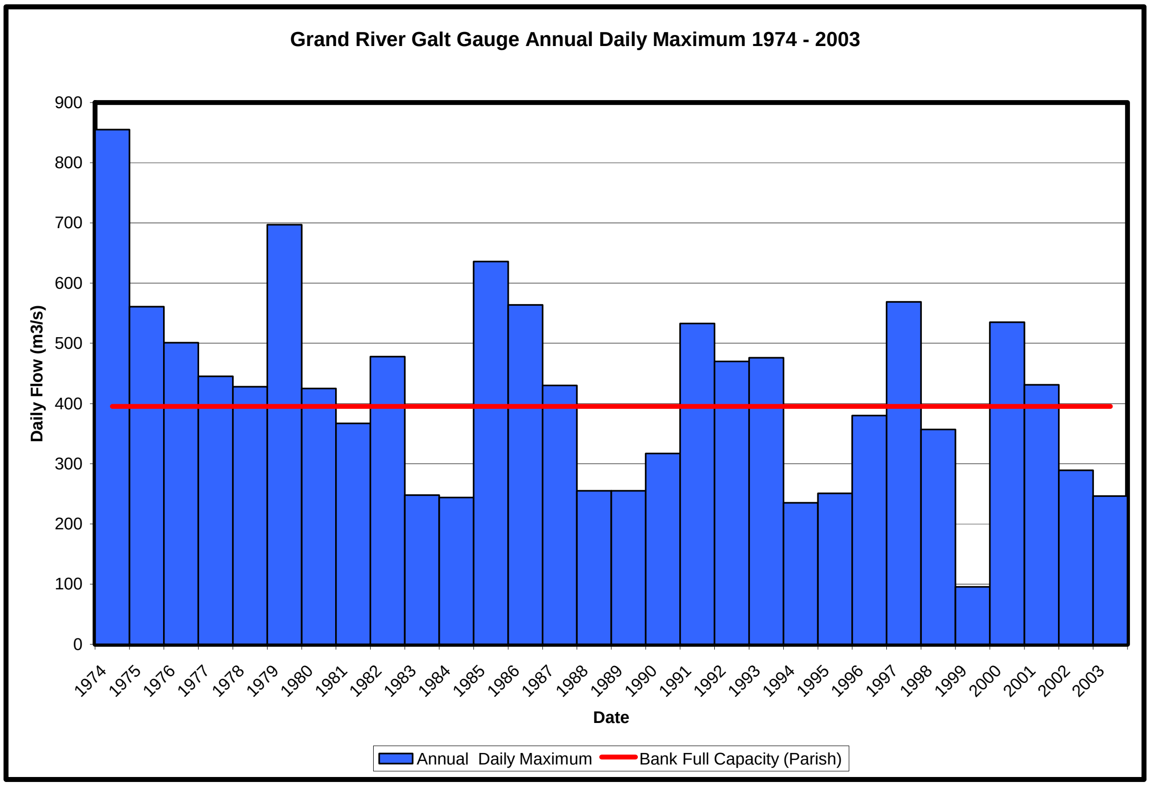
10.


Grand River at Cambridge-Galt Flow Duration by Month
Flow (m3/s)
250
225
200
175
150
125
100
75
50
25
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentage Time
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

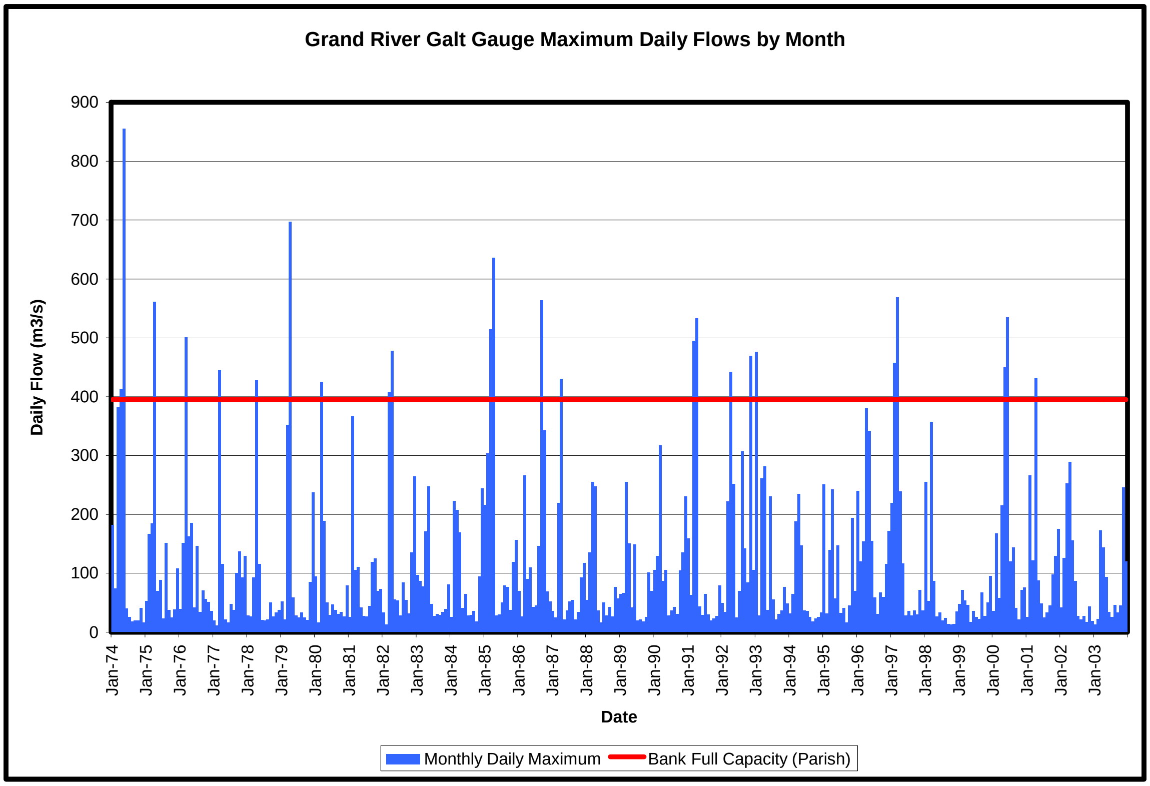
11.


Grand River Galt Gauge Annual Maximum Instantaneous Flow
1974 - 2003
Flow (m3/s)
1500
1250
1000
750
500
250
0
1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
Date
Annual Daily Maximum
Bank Full Capacity (Parish)

12.


Grand River Galt Gauge Annual Daily Maximum 1974 - 2003
Daily Flow (m3/s)
900
800
700
600
500
400
300
200
100
0
1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
Date
Annual Daily Maximum
Bank Full Capacity (Parish)

13.



14.

15. Grand River at Cambridge Galt Gauge High Flow Frequency Table (Regulated Observed Flows 1948 to 1995)

Return Period (years)	Extreme Value (m3/s)	Log Pearson (m3/s)	Three P Log Normal (m3/s)	Walkby (m3/s)
1.003	88.4	151	163	154
1.05	173	200	200	176
1.25	267	268	262	253
2	407	391	387	416
5	630	622	637	631
10	802	823	855	742
20	990	1060	1110	847
50	1270	1440	1490	1030
100	1510	1800	1840	1250
200	1780	2220	2220	1620
500	2190	2900	2810	2530

B-7: GRAND RIVER EXCEPTIONAL WATERS REACH

Grand River at Brantford Mean Monthly Flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1974	78.34	62.00	153.88	143.67	147.98	37.75	24.71	19.09	19.72	21.94	28.81	20.39	**63.19**
1975	36.48	58.92	116.36	186.93	42.15	35.97	20.86	41.16	33.34	25.89	37.04	66.68	**58.48**
1976	35.77	115.27	277.13	110.01	82.08	29.67	41.33	30.87	34.04	40.69	40.87	29.59	**72.28**
1977	19.43	18.15	198.76	87.41	28.63	20.14	22.76	26.76	63.32	107.54	76.48	103.06	**64.37**
1978	42.61	35.55	70.88	258.57	69.66	27.49	20.71	19.50	32.74	30.88	34.52	38.61	**56.81**
1979	48.46	23.32	215.92	209.05	62.06	32.13	21.93	25.67	23.14	25.88	60.30	106.48	**71.20**
1980	77.32	24.03	108.92	135.26	53.73	33.26	29.52	30.00	28.99	37.27	36.74	52.96	**54.00**
1981	28.62	153.33	57.05	60.51	44.95	26.45	23.76	26.08	69.13	83.92	64.15	58.29	**58.02**
1982	26.24	18.54	118.64	247.97	43.46	53.73	28.83	37.66	44.42	38.23	99.74	167.21	**77.06**
1983	63.05	63.43	68.01	105.49	123.01	42.18	23.60	36.63	31.82	41.35	48.85	84.15	**60.96**
1984	47.25	160.93	113.26	109.42	50.11	46.94	28.55	25.18	33.74	26.84	50.49	90.23	**65.25**
1985	62.34	96.85	240.23	216.94	36.52	34.24	31.57	35.32	54.04	48.29	133.66	90.60	**90.05**
1986	56.70	35.63	165.78	74.39	59.32	40.05	37.98	47.75	206.51	157.01	60.08	69.17	**84.20**
1987	52.15	35.23	129.90	129.95	34.94	28.85	39.59	34.56	27.62	32.91	51.10	104.93	**58.48**
1988	44.94	62.55	104.49	85.10	35.92	19.46	21.95	22.51	22.57	29.27	72.51	42.60	**46.99**
1989	56.06	34.57	92.84	91.29	33.83	56.69	20.90	18.80	18.20	23.03	54.58	32.50	**44.44**
1990	70.07	91.29	134.85	64.63	53.06	28.35	27.73	25.07	24.72	80.32	100.83	121.90	**68.57**
1991	60.89	61.63	188.38	164.64	42.84	26.92	33.24	25.15	21.20	25.71	26.33	45.81	**60.23**
1992	43.17	35.62	97.51	139.24	60.33	26.35	47.82	88.31	98.08	66.75	216.51	87.12	**83.90**
1993	146.99	29.16	70.54	163.36	36.93	57.22	35.26	25.40	31.32	35.97	40.31	49.62	**60.17**
1994	23.92	48.50	86.81	140.77	80.03	33.33	29.89	24.14	20.76	22.72	27.08	34.04	**47.66**
1995	107.02	22.88	93.62	78.02	50.17	42.02	25.27	27.79	20.05	27.90	107.53	50.09	**54.36**
1996	103.83	97.59	98.57	182.03	120.91	84.56	42.77	28.77	47.42	55.84	65.23	110.85	**86.53**
1997	86.16	163.50	173.70	115.13	80.08	34.94	34.76	25.38	26.70	26.65	49.95	40.59	**71.46**
1998	99.75	56.45	137.54	64.49	30.81	25.93	22.69	19.31	17.05	15.47	15.50	18.35	**43.61**
1999	22.11	51.28	47.52	40.77	23.65	30.18	23.16	22.99	34.03	30.82	70.17	77.87	**39.54**
2000	32.26	57.34	50.94	66.71	108.71	119.02	57.41	46.14	31.82	26.52	35.08	54.73	**57.22**
2001	31.19	140.88	102.22	137.06	48.40	35.08	19.99	19.86	20.76	48.16	51.08	88.63	**61.94**
2002	40.63	69.88	102.71	112.95	75.16	46.25	30.61	27.48	22.07	20.75	24.86	22.27	**49.63**
2003	19.56	16.26	94.22	74.77	64.05	32.28	23.08	32.57	24.33	39.94	118.53	98.38	**53.17**
Maximum	**146.99**	**163.50**	**277.13**	**258.57**	**147.98**	**119.02**	**57.41**	**88.31**	**206.51**	**157.01**	**216.51**	**167.21**	**90.05**
Average	**55.44**	**64.68**	**123.71**	**126.55**	**60.78**	**39.58**	**29.74**	**30.53**	**39.46**	**43.15**	**63.30**	**68.59**	**62.13**
Minimum	**19.43**	**16.26**	**47.52**	**40.77**	**23.65**	**19.46**	**19.99**	**18.80**	**17.05**	**15.47**	**15.50**	**18.35**	**39.54**
Lower 10	**23.74**	**22.44**	**66.92**	**64.61**	**33.53**	**26.31**	**20.90**	**19.48**	**20.02**	**22.64**	**27.00**	**28.86**	**46.73**

2. Brantford Gauge Lowflows Minimum 7 day Running Average Flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max	55.36	71.10	160.29	131.86	67.50	39.43	37.29	34.20	65.09	69.63	62.16	89.77	24.40
Mean	26.00	27.37	41.27	55.54	32.01	23.18	20.72	19.06	21.53	23.06	27.42	32.65	15.68
Min	6.00	6.24	11.39	25.59	14.54	13.07	9.92	8.26	10.04	5.31	8.35	8.00	5.31
Lower 10 Percentile	14.07	14.75	19.27	33.03	18.84	16.42	15.51	13.64	13.17	12.97	13.21	14.64	10.48

3. Brantford Gauge Lowflows Minimum 15 day Running Average Flow (m3/s)

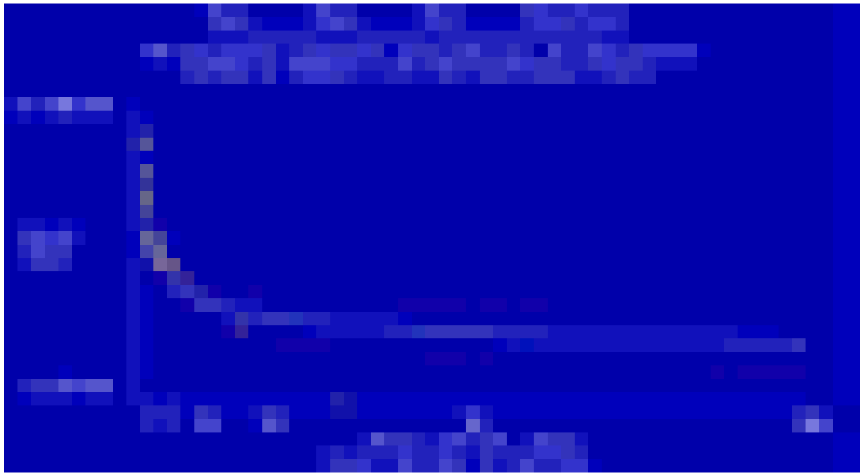
Max	112.92	72.03	198.22	174.75	90.51	48.31	47.77	36.79	75.47	80.62	81.78	105.56	26.91
Mean	29.82	30.00	45.81	75.06	38.41	26.01	22.81	20.38	23.10	24.94	30.11	38.43	16.73
Min	6.10	6.18	11.41	28.85	14.73	14.09	10.81	8.74	9.75	6.82	8.74	9.07	6.10
Lower 10 Percentile	14.48	16.11	19.72	40.59	22.07	17.42	16.54	14.63	14.47	13.55	13.64	15.08	11.16

4. Brantford Gauge Lowflows Minimum 30 day Running Average Flow (m3/s)

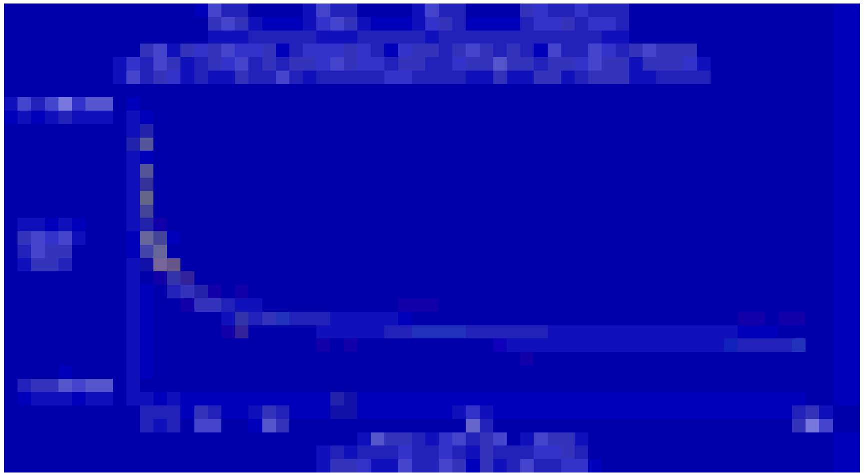
Max	115.90	113.97	140.05	216.94	152.85	121.32	100.38	49.48	103.66	142.84	117.08	106.73	31.71
Mean	51.34	52.54	80.65	108.23	79.98	38.06	27.19	22.78	26.20	29.88	38.46	51.99	18.38
Min	10.28	10.11	11.76	40.77	18.78	14.97	13.26	10.50	10.01	10.11	10.21	10.86	10.01
Lower 10 Percentile	15.45	17.44	24.10	54.99	29.21	18.94	17.46	16.08	14.78	14.07	13.97	15.54	11.84

5. Low Flow Frequency Plots

Two Parameter Log Normal Method of Moments				
Mean	18.397			
Variance	10.550			
Coefficient of Skew	-0.723			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	19.27	17.98	16.96	0.59
5	16.82	15.47	14.45	0.60
10	15.81	14.30	13.14	0.68
20	15.07	13.40	12.09	0.76
50	14.32	12.45	10.96	0.86
100	13.87	11.86	10.24	0.93

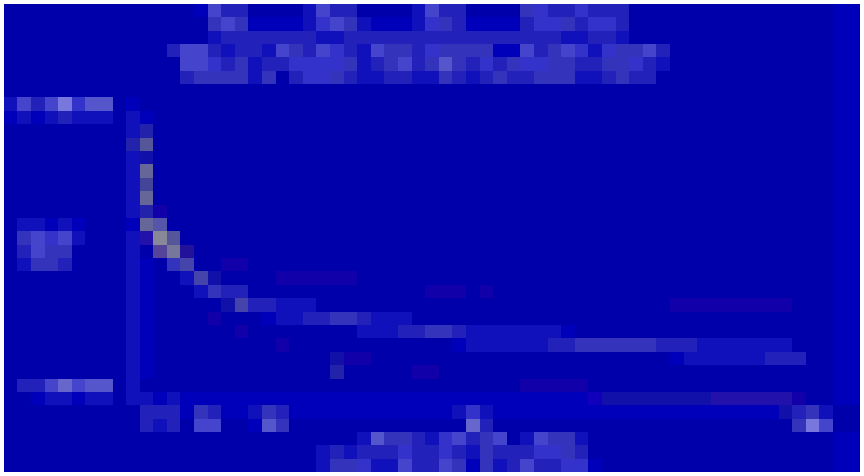


Two Parameter Log Normal Maximum Likelihood				
Mean	2.894			
Variance	4.213			
Coefficient of Skew	-1.786			
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	19.27	17.98	16.96	0.59
5	16.79	15.47	14.47	0.59
10	15.72	14.30	13.23	0.64
20	14.91	13.40	12.25	0.68
50	14.06	12.45	11.22	0.73
100	13.53	11.86	10.57	0.76



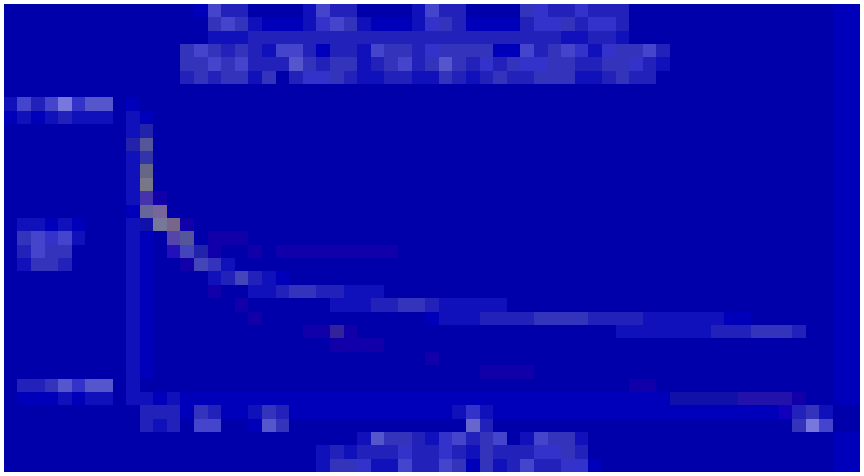
Type III External Distribution Method of Moments

Mean	18.397		Alpha	14.24
Variance	10.186		Beta	19.78
Coefficient of Skew	-0.762		Gamma	-18.73
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	19.90	18.80	17.71	0.56
5	17.51	15.93	14.35	0.81
10	16.23	14.15	12.07	1.06
20	15.10	12.53	9.96	1.31
50	13.69	10.55	7.41	1.60
100	12.62	9.15	5.68	1.77

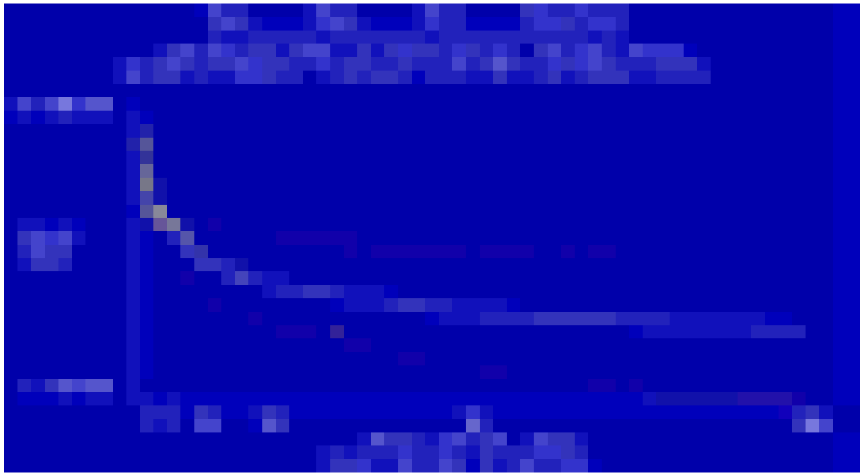


Pearson Type III External Distribution Method of Moments

Mean	18.397		Alpha	1.69
Variance	10.550		Beta	3.70
Coefficient of Skew	-1.040		Gamma	12.15
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	19.66	18.94	18.23	0.37
5	17.26	15.97	14.67	0.66
10	16.10	14.06	12.02	1.04
20	15.38	12.29	9.21	1.57
50	14.83	10.08	5.33	2.42
100	14.63	8.47	2.31	3.14



Pearson Type III External Distribution Method of Monments (indirect)				
Mean	2.894		Alpha	0.264
Variance	4.213		Beta	0.606
Coefficient of Skew	-2.569		Gamma	2.734
Return Period Flows (m3/s)	**Upper 95%**	**Mean**	**Lower 95%**	**Std Error**
2	21.54	19.43	17.32	1.08
5	19.52	16.34	13.15	1.63
10	17.14	14.11	11.08	1.55
20	15.68	12.07	8.48	1.84
50	14.92	9.72	4.52	2.66
100	14.46	8.18	1.72	3.30

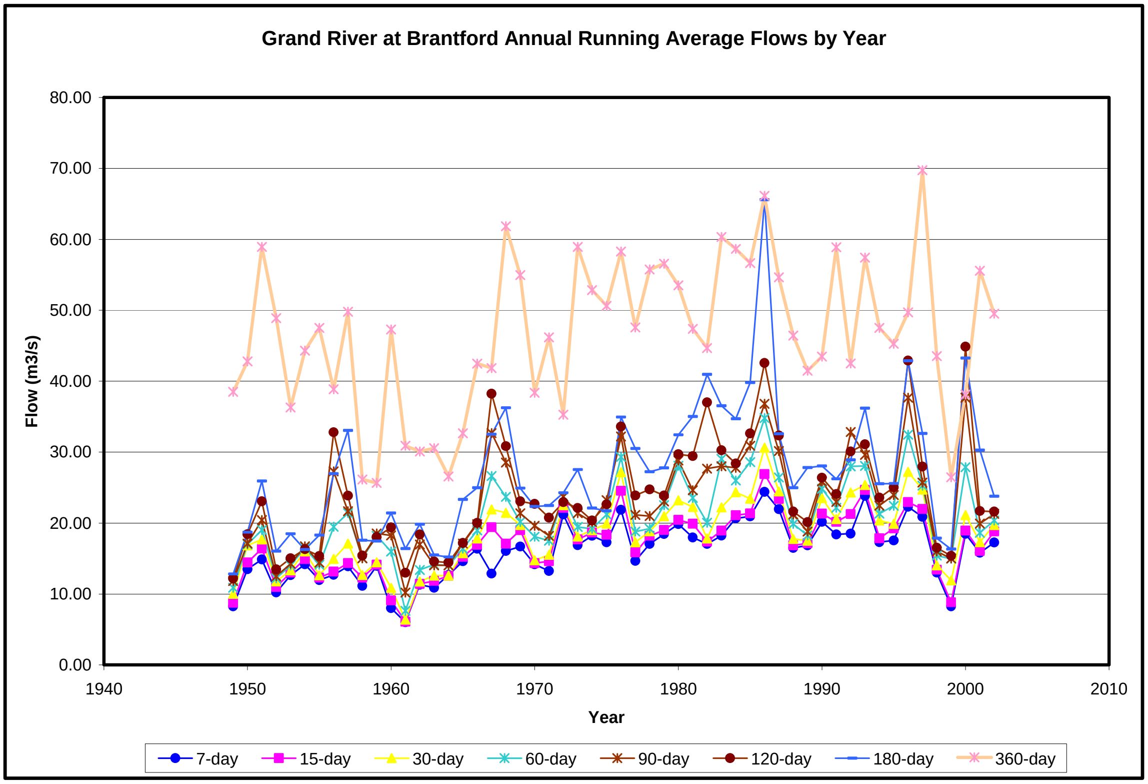


6. 7-DAY LOW FLOW STATISTICS

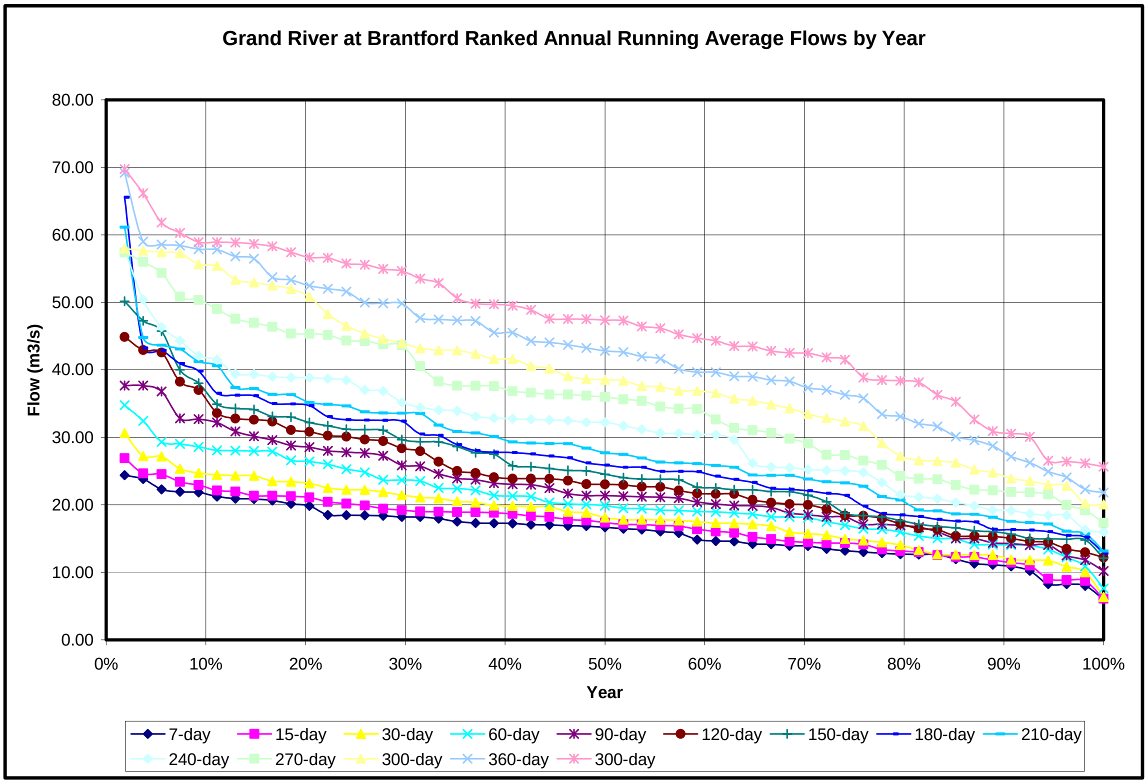
Low Flow Stastics Grand River at Brantford Gauge Station Statistical Method	**Annual Return Period 7-day Flow (m3/s)**					
	2	**5**	**10**	**20**	**50**	**100**
Two Parameter Log Normal Method of Moments	17.982	15.469	14.298	13.399	12.454	11.861
Two Parameter Log Normal Maximum Likelihood	**17.982**	**15.469**	**14.298**	**13.399**	**12.454**	**11.861**
Three Parameter Log Normal Method of Moments						
Type III External Distribution Method of Moments	18.803	15.931	14.152	12.531	10.551	9.149
Type III External Distribution Method of Smallest Observed Drought						
Type III External Distribution Method of Maximum Likelihood						
Pearson Type III External Distribution Method of Moments	18.944	15.966	14.062	12.294	10.082	8.469
Pearson Type III External Distribution Method of Maximum Likelihood						
Pearson Type III External Distribution Method of Monments (indirect)	19.431	16.335	14.113	12.071	9.721	8.182
Maximum	19.431	16.335	14.298	13.399	12.454	11.861
Average	18.628	15.834	14.185	12.739	11.052	9.904
Minimum	17.982	15.469	14.062	12.071	9.721	8.182

7. Grand River at Brantford Gauge Station Minimum Annual Running Average Flows (m3/s)

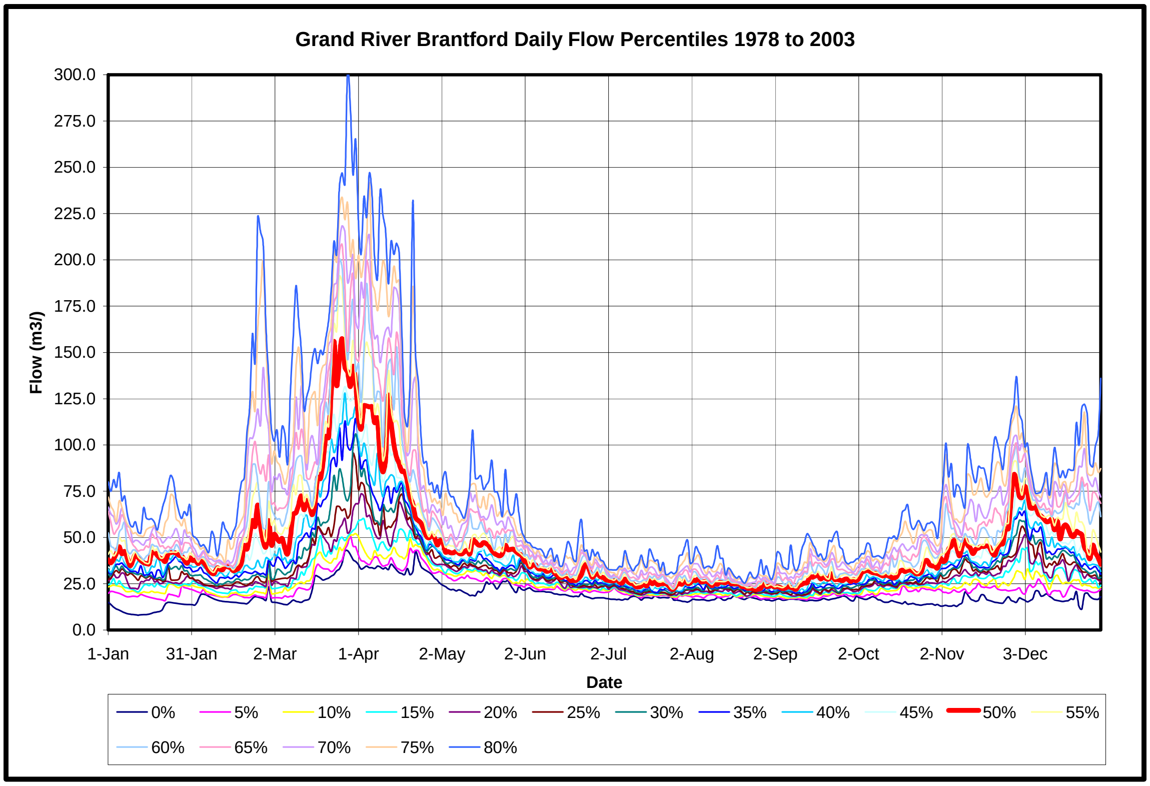
	7-day	15-day	30-day	60-day	90-day	120-day	150-day	180-day	210-day	240-day	270-day	300-day	330-day	360-day
Maximum	24.4	26.9	30.6	34.8	37.7	44.9	50.2	65.6	61.1	57.9	57.4	58.0	69.2	69.8
Average	16.0	17.0	18.4	20.6	22.4	24.2	25.7	27.0	28.5	31.0	35.3	38.8	42.6	46.6
Minimum	6.0	6.1	6.4	7.6	10.2	12.2	12.1	12.8	13.2	16.0	17.3	20.0	21.8	25.7
Lower 10 Percentile	11.0	11.5	12.1	14.1	14.3	15.1	15.8	16.3	17.7	19.2	22.0	24.2	27.7	30.7


Grand River at Brantford Annual Running Average Flows by Year
Flow (m3/s)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1940
1950
1960
1970
1980
1990
2000
2010
Year
7-day
15-day
30-day
60-day
90-day
120-day
180-day
360-day

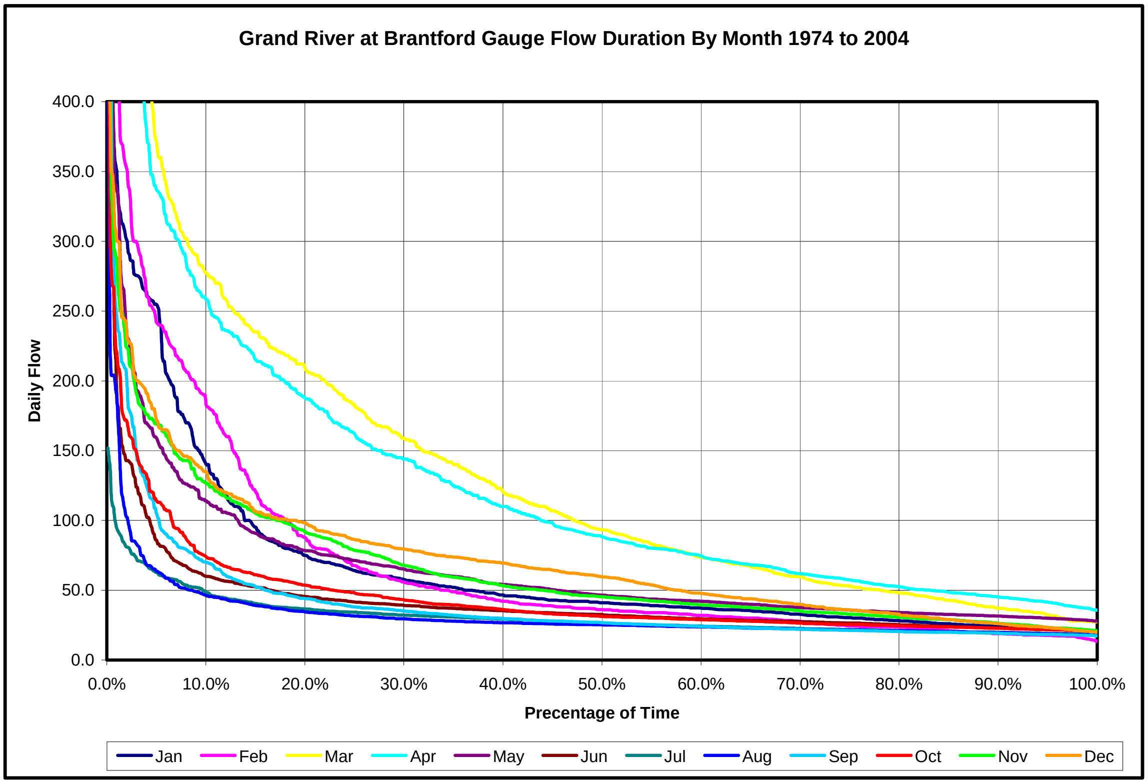
8.


Grand River at Brantford Ranked Annual Running Average Flows by Year
Flow (m3/s)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Year
7-day
15-day
30-day
60-day
90-day
120-day
150-day
180-day
210-day
240-day
270-day
300-day
360-day
300-day

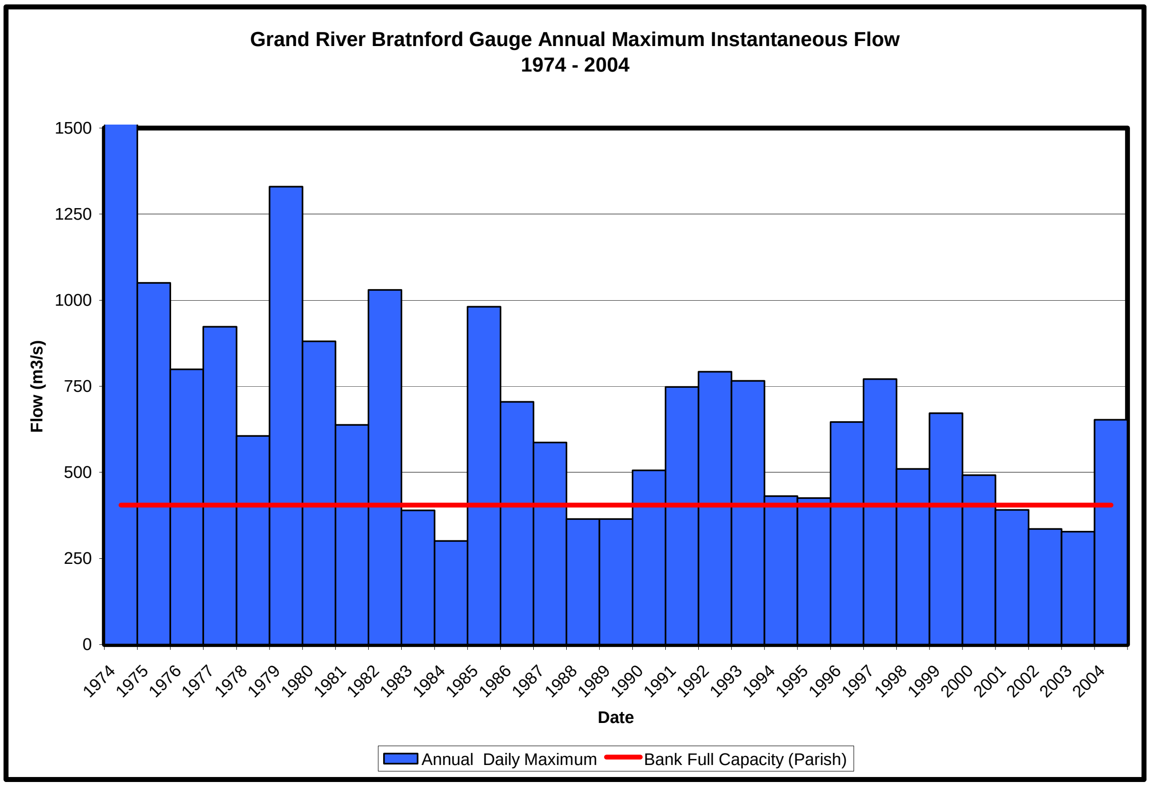
9.


Grand River Brantford Daily Flow Percentiles 1978 to 2003
Flow (m3/)
300.0
275.0
250.0
225.0
200.0
175.0
150.0
125.0
100.0
75.0
50.0
25.0
0.0
1-Jan
31-Jan
2-Mar
1-Apr
2-May
2-Jun
2-Jul
2-Aug
2-Sep
2-Oct
2-Nov
3-Dec
Date
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
80%

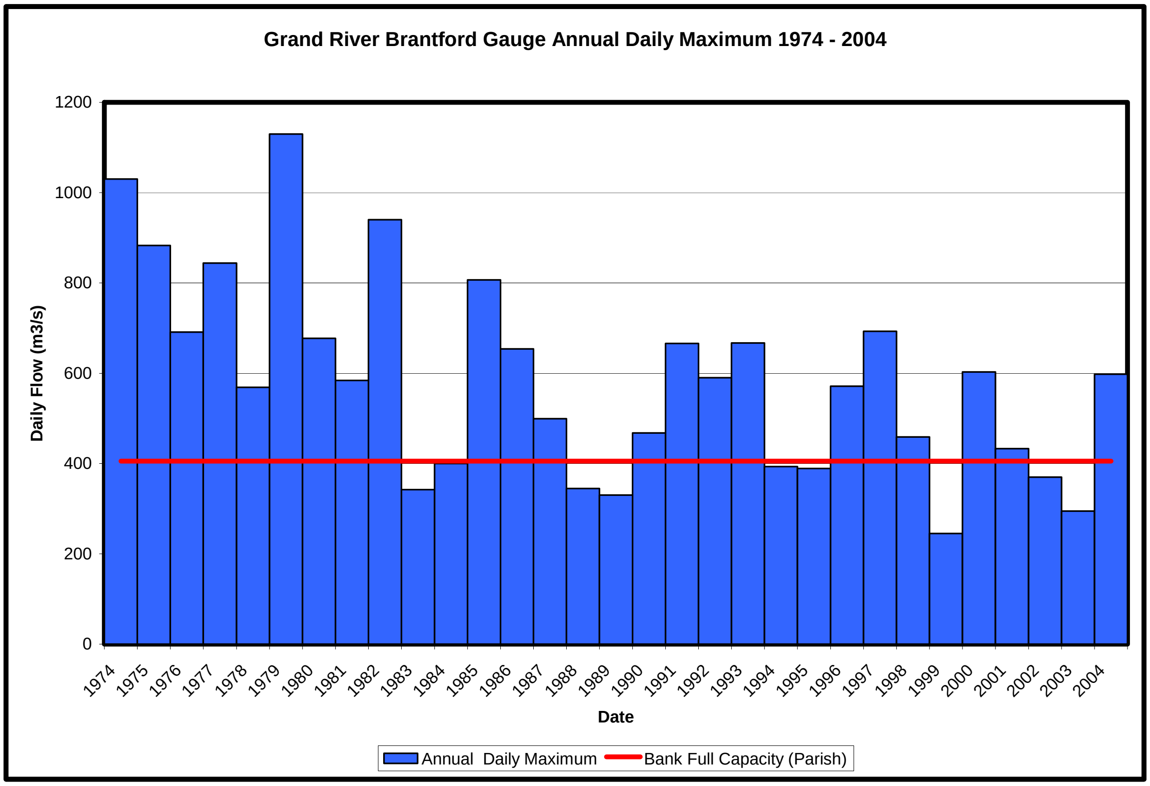
10.


Grand River at Brantford Gauge Flow Duration By Month 1974 to 2004
Daily Flow
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%
Precentage of Time
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

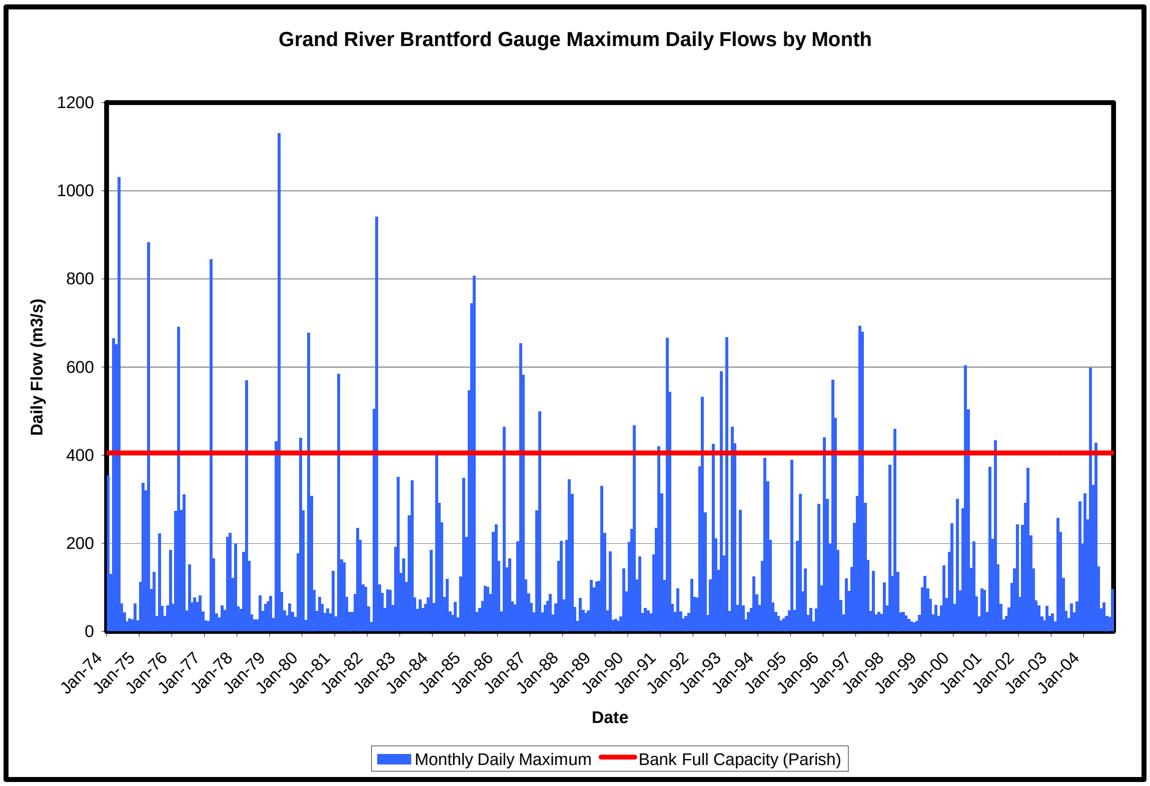
11.


Grand River Bratnford Gauge Annual Maximum Instantaneous Flow
1974 - 2004
Flow (m3/s)
1500
1250
1000
750
500
250
0
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Date
Annual Daily Maximum
Bank Full Capacity (Parish)

12.


Grand River Brantford Gauge Annual Daily Maximum 1974 - 2004
Daily Flow (m3/s)
1200
1000
800
600
400
200
0
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Date
Annual Daily Maximum
Bank Full Capacity (Parish)

13.



14.

15. Brantford Gauge Regulated High Flow Frequency Table

Return Period (years)	Extreme Value (m3/s)	Log Pearson (m3/s)	Three P Log Normal (m3/s)	Walkby (m3/s)
1.003	77.7	263	173	na
1.05	261	305	293	na
1.25	438	434	436	na
2	667	632	648	na
5	964	951	957	na
10	1160	1180	1170	na
20	1330	1410	1380	na
50	1560	1730	1660	na
100	1720	1990	1880	na
200	1880	2260	2100	na
500	2090	2640	2390	na

B-8: CARROLL CREEK REACH

Not included due to unstable rating at gauge location.

APPENDIX C: EFFECTS OF CHANNEL SHAPE

The shape of the cross section of a channel is an important consideration with respect to water takings. This shape refers to the outline of the channel bed at one single cross sectional point (see Figure C.1). This outline can take on an infinite number of shapes, but there are some general similarities that can resemble certain parts of a river, such as a riffle, pool or run. With respect to water takings, riffles are the most sensitive since they are the shallower sections of a river. Hence, the change in water levels is most pronounced in riffle sections.

Riffles in a river are the key location to be considered for the maintenance of flows, as they are the first to be affected by the diminishment of flows in a river. If the water levels in the riffles of a stream are maintained, then it is probable that other sections, such as runs and pools, will be maintained. However, if the riffle water level drops, then this may also mean that fringe areas of runs and pools are affected, which are also critical areas for aquatic habitat that should be submerged (Armstrong *et al*., 2003).

Within the stream sections, there is a critical habitat that needs the flows to be maintained for the success of aquatic habitats (Stanford and Ward, 1979; Ward and Stanford, 1989; Poff *et al*., 1997). The littoral zone (see Figure C.1), is the zone inhabited with emergent and floating leaved aquatic macrophytes, and is used extensively by aquatic organisms (Mackie, 2001). The maintenance of flows in this littoral region relates to life stage habitat requirements and thus the survival of fish populations (Armstrong *et al*., 2003). Water surface levels should be kept above this littoral zone during the season, to prevent detriment to the aquatic habitats (Imhof, 2002).

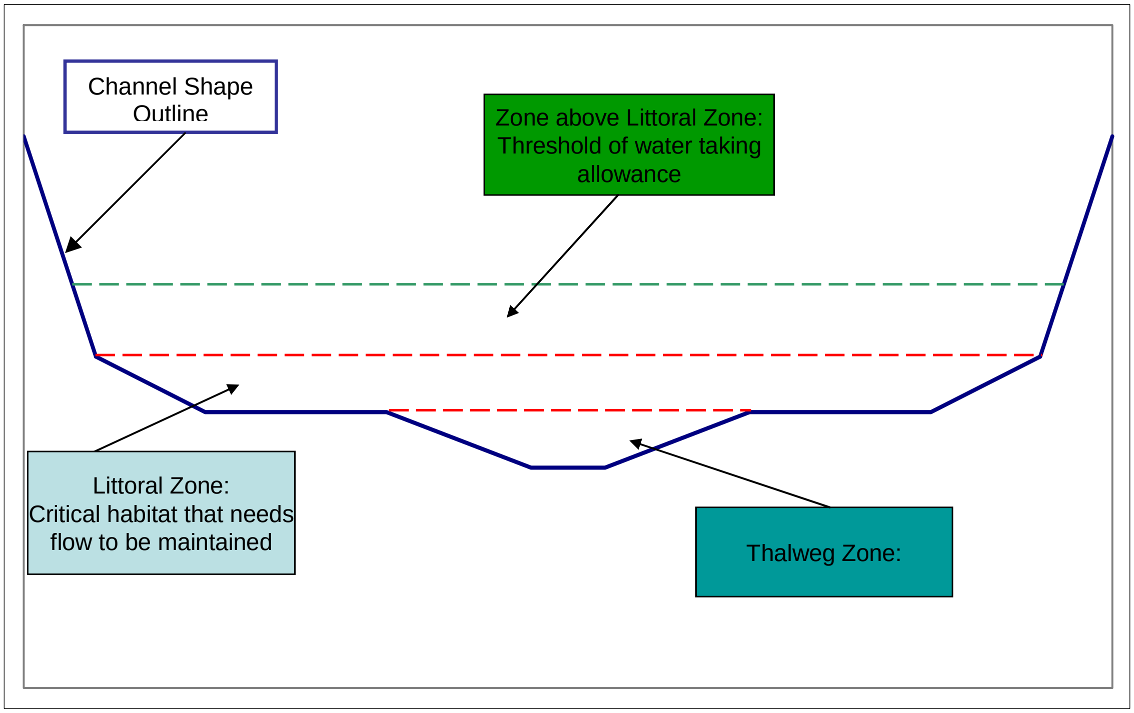


Figure C.1 Cross sectional view of the littoral zone of a riffle

Rosgen, Flow Depth and Wetted Perimeter

When considering the shape of the sections of a river, the cross-sectional view of channel shape can vary quite a bit, thus changing the size and requirement of the littoral zone. Rosgen (1996) has defined several channel shapes within a classification scheme, which describes characteristics associated with each type. Please see Table 1 and Rosgen (1996) for further detail on the characteristics of each channel type.

The flow depth of a river channel and its associated wetted perimeter are surrogates for determining the amount of available aquatic habitat in a reach. Wetted perimeter is the distance along the bottom and sides of a river channel that is in contact with water (PPWB, 1999).

A hydraulic rating method called the Wetted Perimeter Inflection Point Method uses the concept of wetted perimeter as an indicator of aquatic habitat availability. The basic assumption of this model is that the rate of change of the discharge (and flow depth) is a function of its wetted perimeter, and that wetted perimeter depends on channel geometry. When plotting the wetted perimeter against a flow rate or a flow depth (water elevation), distinct changes in the wetted perimeter are seen as distinct changes in the slope of the line; this change is called an inflection point. The inflection points that are most relevant to study correspond to pronounced changes in the wetted perimeter for a minimal change in flow. For instance, if flow decreases by a unit, the wetted perimeter might decrease more drastically and significantly reduce the amount of aquatic habitat for fish and other aquatic organisms. The slope change is a critical point of interest can be predicted by knowing the shape of the channel. Thus, when modeling habitat availability, inflection points can indicate where significant losses to habitat availability would occur at differing flow levels.

The littoral zone, however, often does not coincide with an inflection point, when plotting flow level versus wetted perimeter, depending on the shape of the channel. Often, there must be a consideration of leaving some depth above the littoral zone that needs to be maintained for the habitat to be useable.

The general channel shapes classified and described by Rosgen (1996) are replicated in the figures below to show the relationship of wetted perimeter to flow at differing water levels. The Rosgen classification types will be the basis for the analysis of the effects of channel shapes on aquatic habitat.

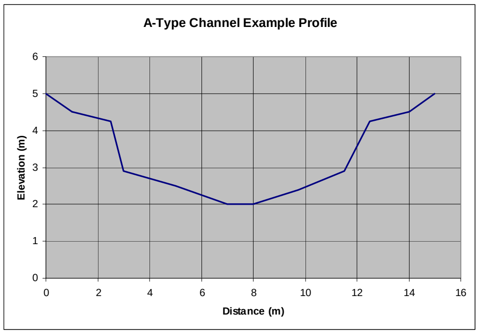
Table C.1. Rosgen Single-Thread Channel Types and Characteristics

	Aa+	A	B	C	E	F	G
Common name	Pocket water stream		Pocket water stream	Riffle: pool stream, point-bar	Meandering stream, spring creek	Riffle: pool stream	Pocket water stream; riffle: pool stream
Geog. Location	Typical mountain or escarpment streams			most typical of S.Ontario	Wide shallow valleys		
Sequence	Repeating Step:pool sequence			Riffle:pool sequences		Riffle:pool sequences	
Pattern	Vertical steps, deep scour pools, waterfalls	Confined with cascading reaches	Rapids predominate with scour pools	Deep pools, point bars, mild meanders	Extreme looping meanders	Entrenched, meandering	Gully, entrenched, moderate sinuosity
Long Profile	Steep slope, high relief		Steep, less than A	Low relief	Low gradient	Relatively low relief	Gentle slopes, down-cut gullies
Cross Section Profile	deeply entrenched V-shaped	Narrow profile	Bowl-shaped channel	Well-defined floodplain, right-angled triangle	Very deep channel for width; square-shaped	Wide, shallow Rectangular-shaped	U-shaped
Control	Structural contact zones like faults, joints	Structural contact zones like faults, joints	Valley side slopes, structural contact zones		Controlled by vegetation on banks		
Sediment Movement	High energy high sediment				Most stable		High bank erosion rates, high supply
Fish Habitat			Most usable habitat for fish	Few, but increases with woody debris	As much linear habitat, more volume than B		
Example				Eramosa River	Mill Creek	Grand River at Elora Gorge	

To illustrate the effects of channel shape on habitat availability, below are a variety of different stream cross section shapes plotted on a grid, and their respective flow level versus wetted perimeter plots. Notice that the changes in slope occur in where there are changes in the shape or slope of the channel. Elevation is used as the surrogate for flow level in the channel, and can be applied, depending on the size of the channel, to correspond with a flow rate. All these figures following are normalized for comparison purposes using a depth instead of a flow rate. Also, the width to depth ratio is maintained at a value of 5, except for the B-type and F-type channel, as the ratio is a key characteristic of these channel types.

Under each channel type is a description of its characteristics as they relate to aquatic habitat.

A-Type Channel



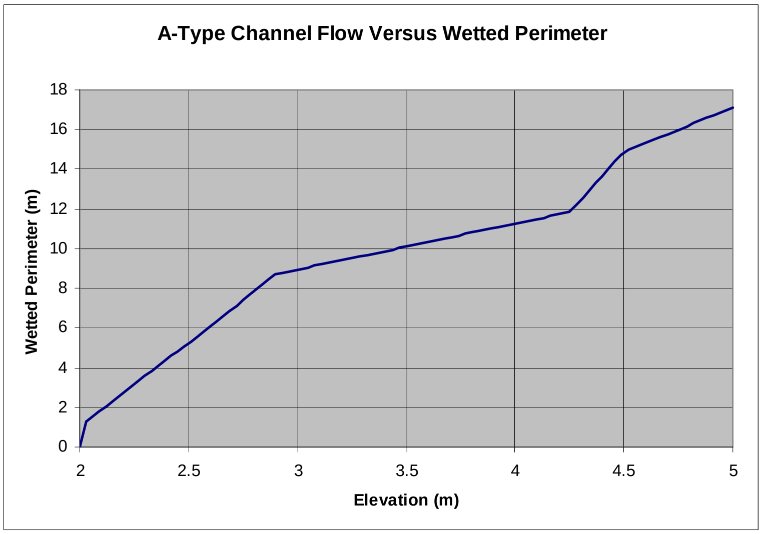
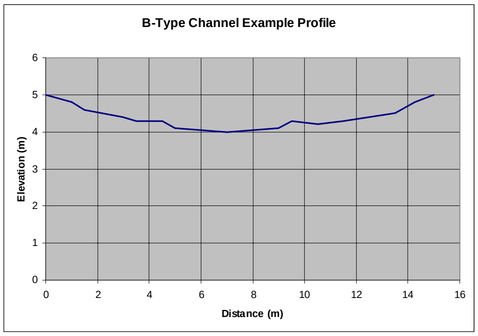


Figure C.2(a) A-TYPE Channel shape; and C.2(b) Flow elevation versus wetted perimeter plot

The A-type channel is generally found on mountain sides or escarpments. The shape of an A-type channel is due to the fast-flowing nature of the river due to a high longitudinal gradient. There is a slight thalweg in this example, which shows a point of inflection at the bottom of Figure C.2b. The change in slope seen in the flow vs. wetted perimeter graph for this channel shape (Figure C.2b), defines the top of the littoral zone, just below the 3m elevation mark. The 'A' channel generally has low width to depth ratios and are entrenched, which leave little space for fish habitat. Fast flows also are less suitable habitat for many fish.

B-Type Channel



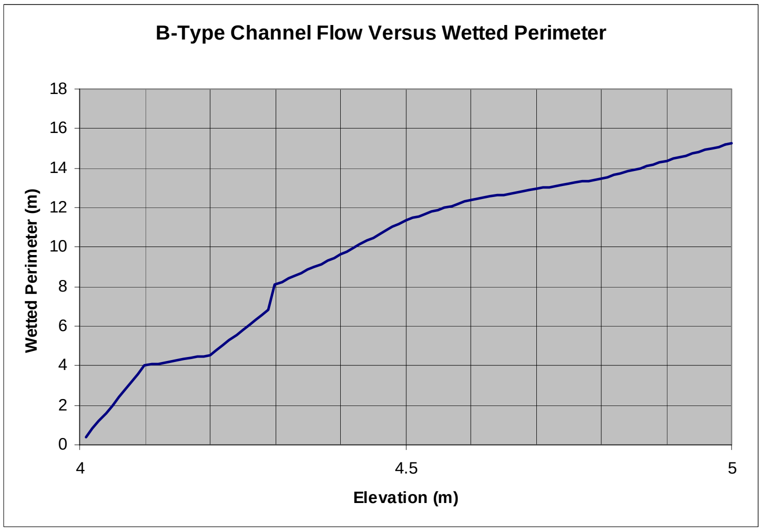
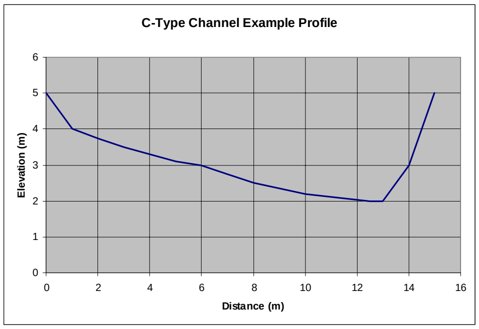


Figure C.3(a) B-TYPE Channel shape; and C.3(b) Flow elevation versus wetted perimeter plot
W:D RATIO: 15

B-type channels are shallow and wide, having a high width to depth ratio. A slight change in the water surface elevation will drastically change the wetted perimeter, especially if the bottom is not flat, but undulating, as can been seen by Figure C.3a and C.3b.

The point of inflection at a depth of 4.3m is important to note on Figure C.3b, as it shows where a small change in flow depth will result in a much larger change in wetted perimeter, diminishing the habitat possibilities for fish. The channel is generally dominated by rapids as the gradient is still fairly high, but less than an A-type channel. Large woody debris in the channel is an important component for fish habitat. B channels with alluvial soils of clay and silt often have dense riparian vegetation which can be a source of organic input to the stream for the macroinvertebrates and fish. The B-type channel likely has the most useable habitat for juvenile and adult fish along the bed than any other channel. Fish can be found almost anywhere in this type of stream (Imhof, 2002).

C-Type Channel



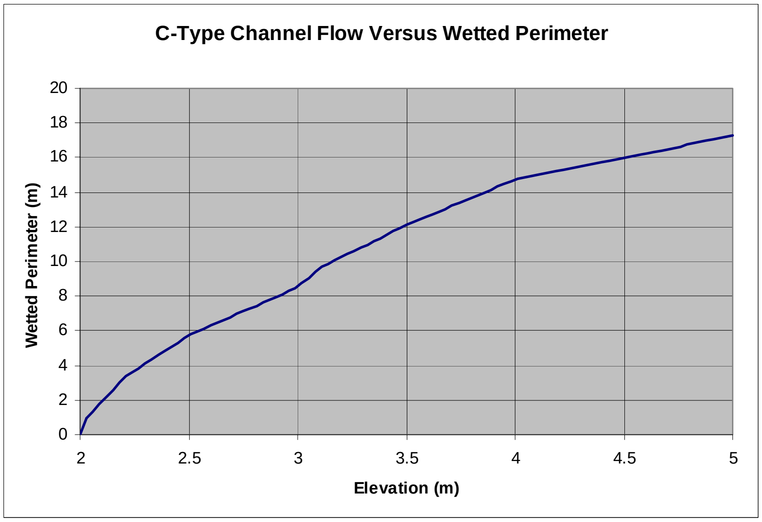


Figure C.4(a) C-TYPE channel shape; and C.4(b) Flow elevation versus wetted perimeter plot

C-type channels are point-bar streams dominated by rapids with deep scour pools. Figure C.4a shows a deep scour pool on the right side of the stream. These channels are the most common river class in southern Ontario. Characteristics include meandering with high width to depth ratio, and well-developed floodplains. The lateral movement of the stream is influenced by the amount and condition of riparian vegetation. There are many edge habitats available when boulders and large woody debris are present. The pools provide good cover for trout and shallower areas are suitable for smaller fish especially if cover is present. The riffle-pool sequence repeats itself along the length of the channel, the pools generally found on the outside bend and riffles halfway between the pools. This type of channel provides good habitat for spawning and early nursery habitat for trout and bass. The plot of wetted perimeter and water depth does not show a distinct point of inflection, however, the diminishment of habitat could occur rapidly if flow is decreased. The pools would remain but they are susceptible to erosion.

D-Type Channel

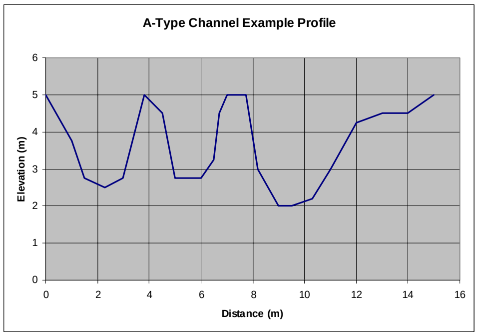
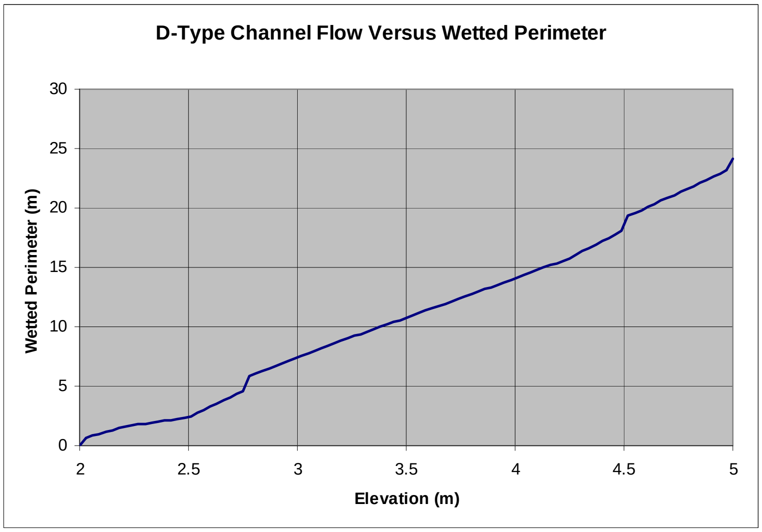


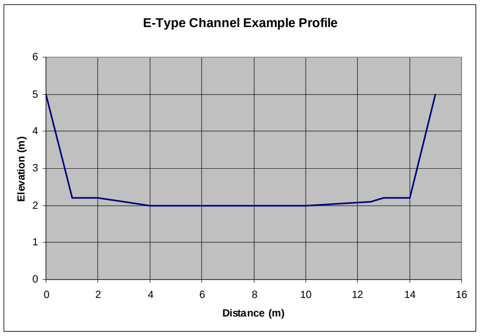
Figure C.5(a) D-TYPE channel shape; and C.5(b) Flow elevation versus wetted perimeter plot



The D-type channel is a braided stream channel, and can have multiple channels of flow at any one cross section. They are generally made up of interconnected channels with deposits of sediment (i.e. cobbles to gravels to sands, alluvial material) separating them. The channels are constantly changing, with high sediment supply and high erosion and deposition rates.

It is unlikely that there is much suitable habitat in these channel types for fish due to the constant altering of the channel form and shape.

E-Type Channel



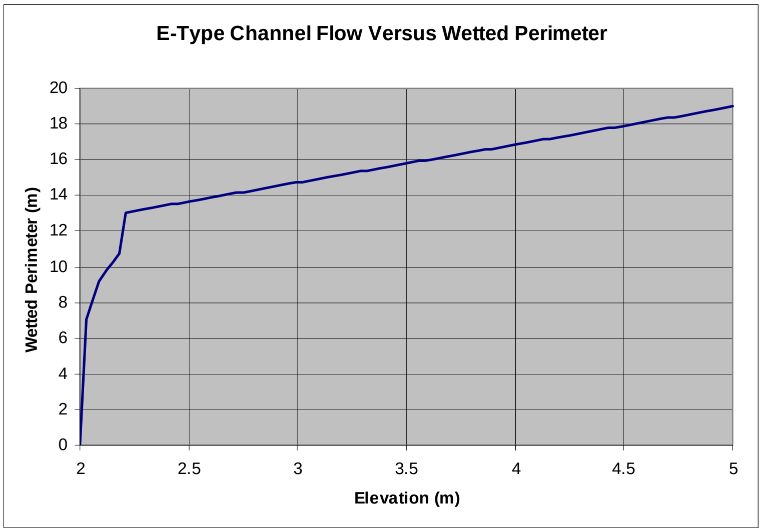
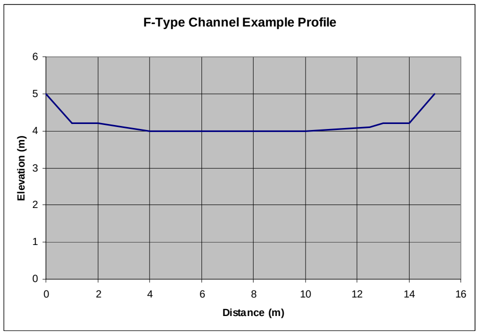


Figure C.6(a) E-TYPE channel shape; and C.6(b) Flow elevation versus wetted perimeter plot

The E-type channel is characterized by a stable square-shaped cross section. They are meandering, have moderate sinuosity and low width to depth ratios. Riparian vegetation has a strong influence to keep these channels stable and prevent plan form adjustment. Often they are deeper and narrow, confined by the riparian vegetation.

The key to ecological flow requirements in this type of channel is the maintenance of flows to the rooting depth of the riparian vegetation, to prevent desiccation. If the vegetation is allowed to dry up, then bank erosion and destabilization of the channel could result. These channels often have as much useable habitat as a B-type channel, but more volume as the E-type channel is deeper.

F-Type Channel



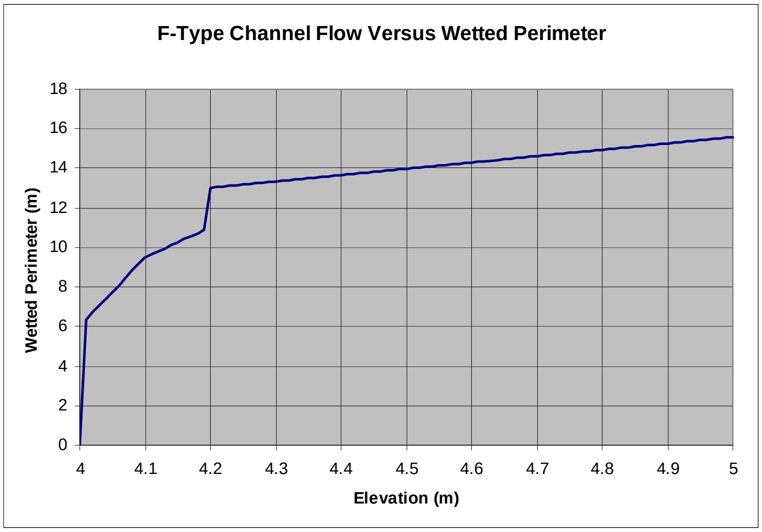
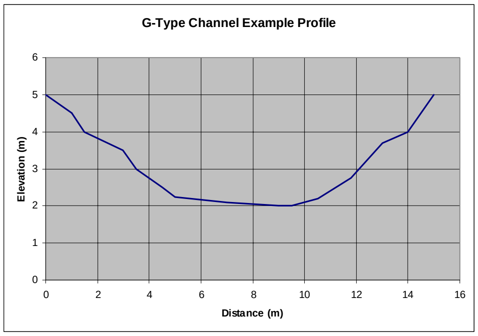


Figure C.7(a) F-TYPE channel shape; and C.7(b) Flow elevation versus wetted perimeter plot
W:D RATIO: 15

F-type channels have similar characteristics to an E-type channel, however the width-to-depth ratio is higher, and thus having a shallower channel. The channel is entrenched, meandering and generally does not have developed floodplains. They can be found deeply incised in valleys of relatively low relief.

G-Type Channel



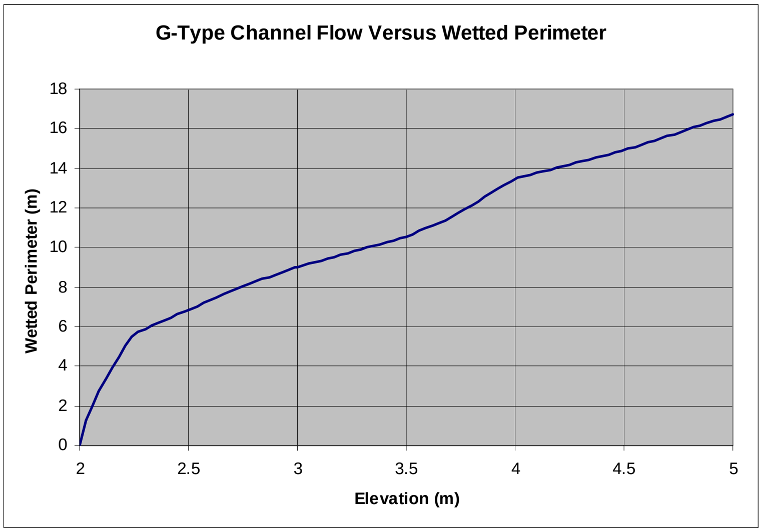
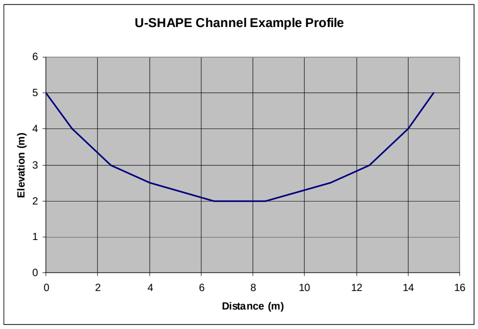


Figure C.8(a) G-TYPE channel shape; and C.8(b) Flow elevation versus wetted perimeter plot

The G-type channel is described as a “gully” stream that is entrenched, narrow and deep. They are similar to A-type channels, but not as steep, with low width to depth ratios and step/pool sequences. Sediment supply and bank erosion rates are high and thus the channel is unstable, both laterally and vertically.

U-Shaped Channel



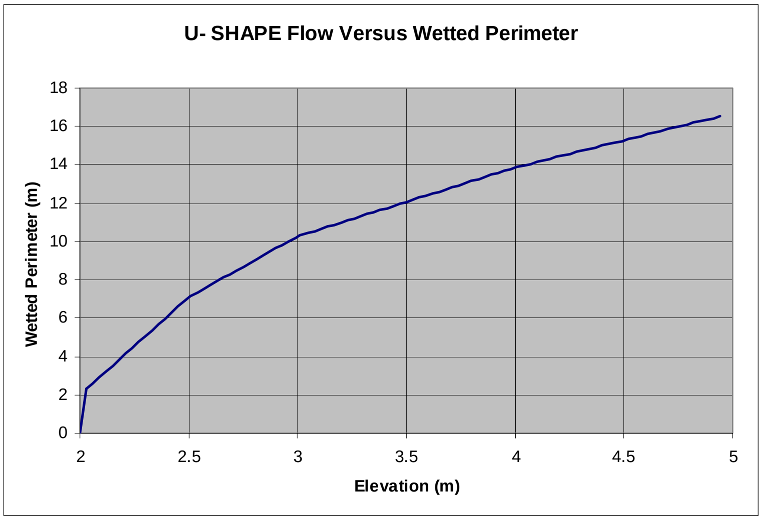


Figure C.9(a) U-SHAPE channel shape; and C.9(b) Flow elevation versus wetted perimeter plot

The U-shaped channel as seen in Figure C.9 is a shape that is typically not common in stream shapes and is not in the Rosgen classification. However, this shape can be used for comparison purposes to the other Rosgen type channel shapes. The associated wetted perimeter has no inflection points other than the very bottom of the channel where it drops down to zero. This shape shows that diminishing flows result in smooth, gradual changes in wetted perimeter.

Shape Comparisons Summary

The comparison of similar channel cross section shape types can visualize the effects shape has on the wetted perimeter. In Figures C.10a and C.11a, slight changes were made to simple channel shapes, and their associated wetted perimeter versus flow depth were plotted (Figures C.10b and C.11b, respectively).

In Figure C.10, the width of the thalweg changes to show the differences that occur to the littoral zone, from a more confined (narrower in the deepest part) portion of the channel cross section (blue line), to a wider, more gradual change (yellow line) and finally to a flatter channel bed with a slight thalweg. These slight differences result in more dramatic changes in their wetted perimeter inflection points, however. The critical inflection point changes from 3 m flow depth to 2.5 m, which could result in a substantial difference regarding fish migration ability.

The changes in the channel bed have less affect when the general channel shape is U-shaped, as in Figure C.11a. Slight alterations in the channel shape don't show dramatic inflection points in wetted perimeter as do the general shapes in C.10, which has a wider channel bed and steeper sides.

In summary, slight changes in both the general shape and the details of the channel bed can noticeably change the wetted perimeter inflection points, and hence the availability of aquatic habitat for fish. Changes in flow depth as the stream is approaching low flows have consequences for fish migration and life cycle requirements. An important consideration, thus, must be the shape of the channel, as well as other hydraulic habitat considerations to fully quantify ecological flow requirements in a river reach.

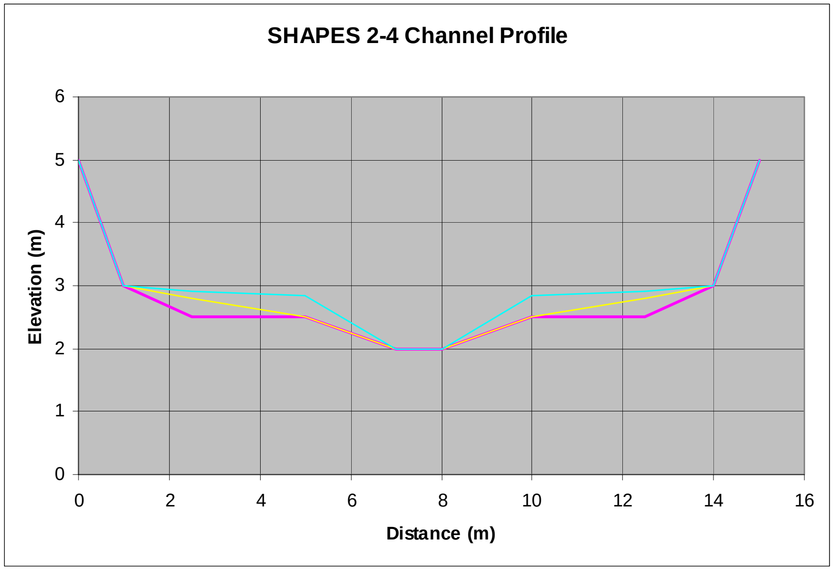


Figure C.10a Channel cross section comparison for Shapes 2-4

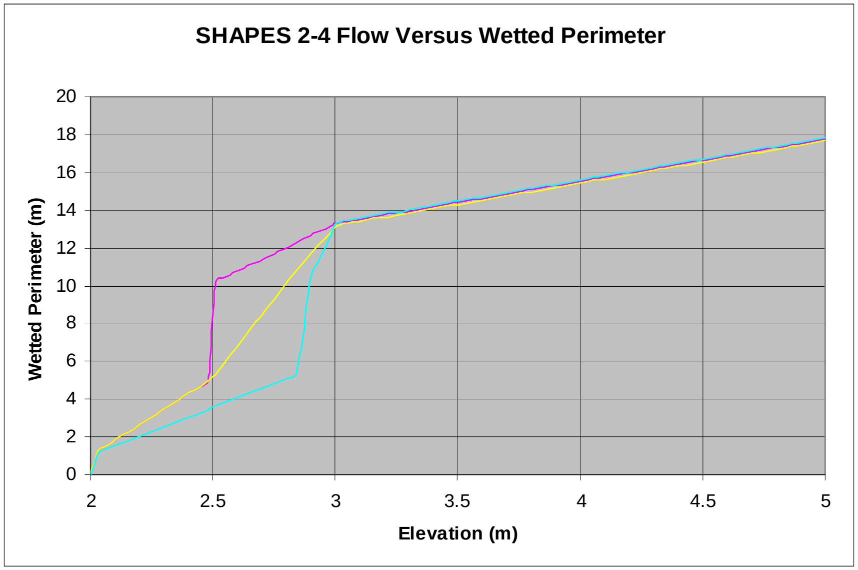


Figure C.10b Wetted perimeter comparison for shapes 2-4

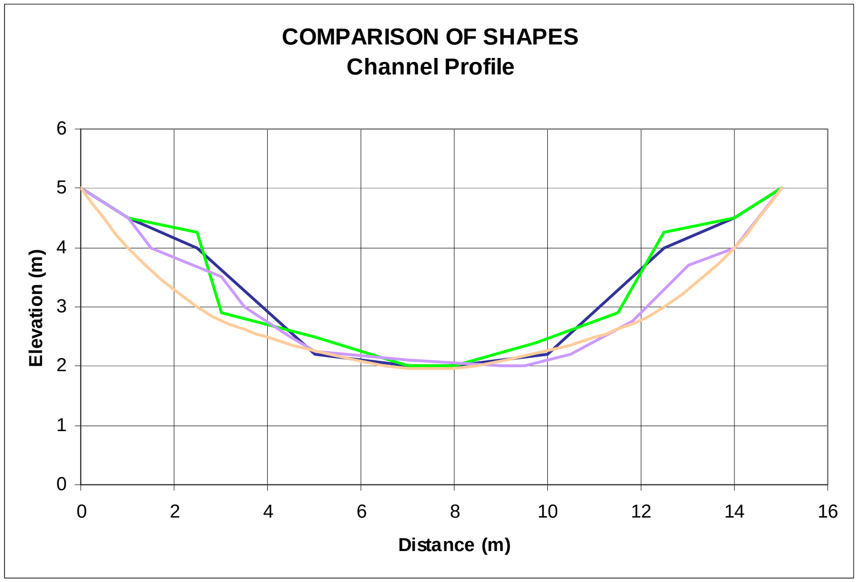


Figure C.11a Comparison of cross sections

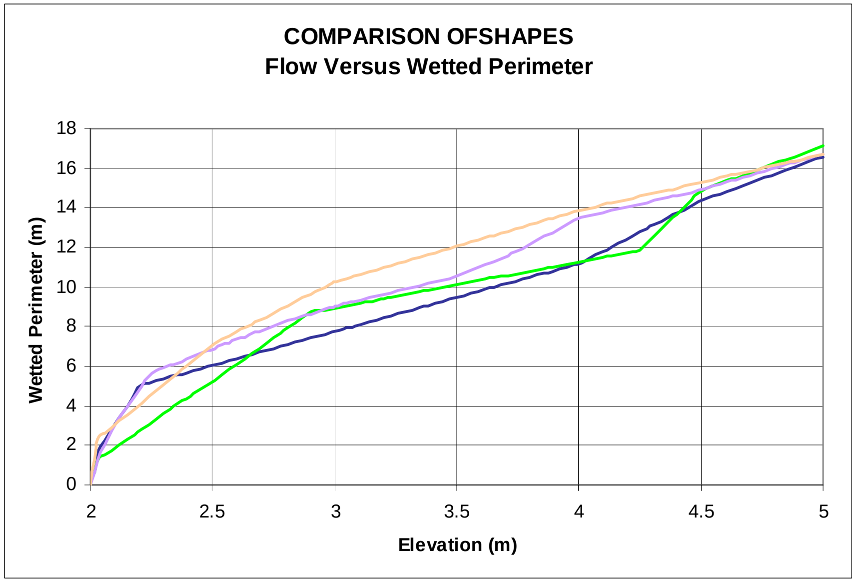


Figure C.11b Wetted perimeter comparison

APPENDIX D: HYDRAULIC MODELLING RESULTS

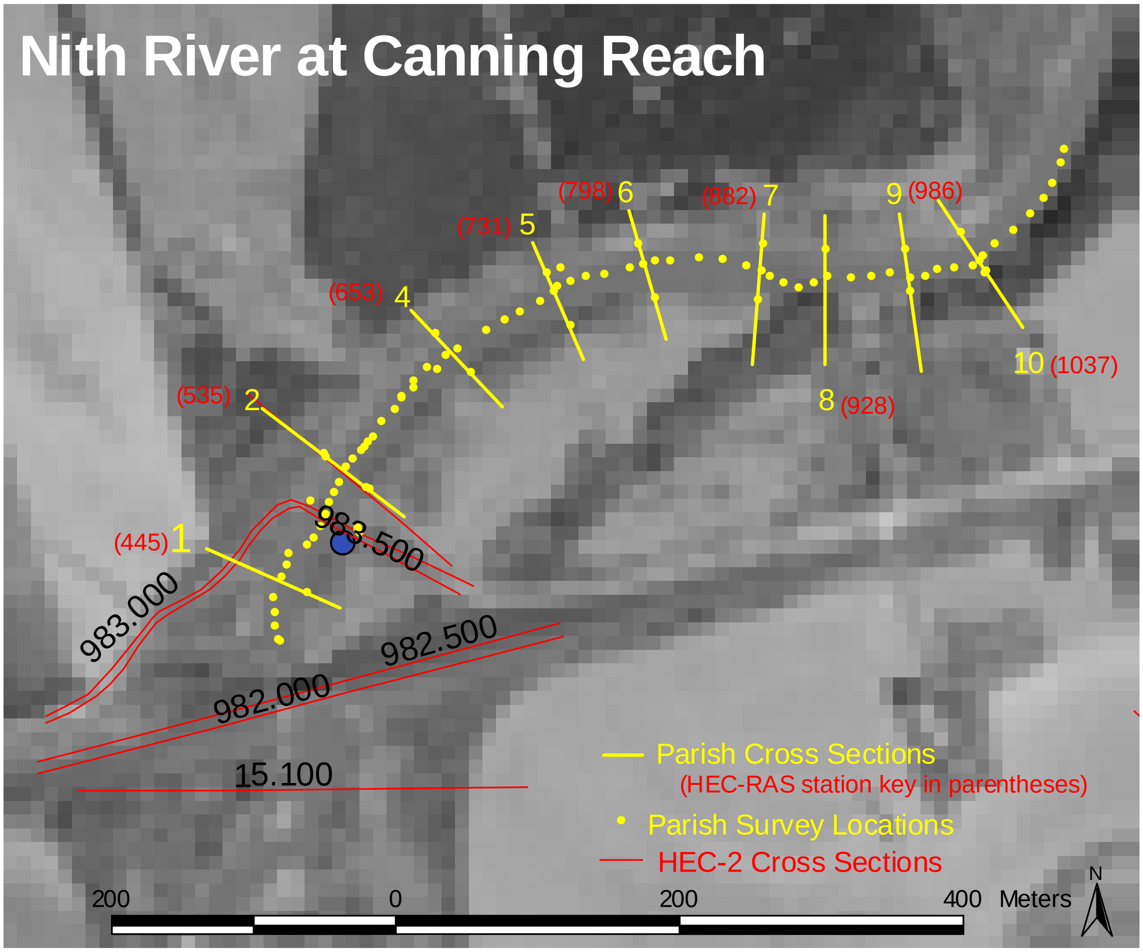
For each study site, this appendix includes:

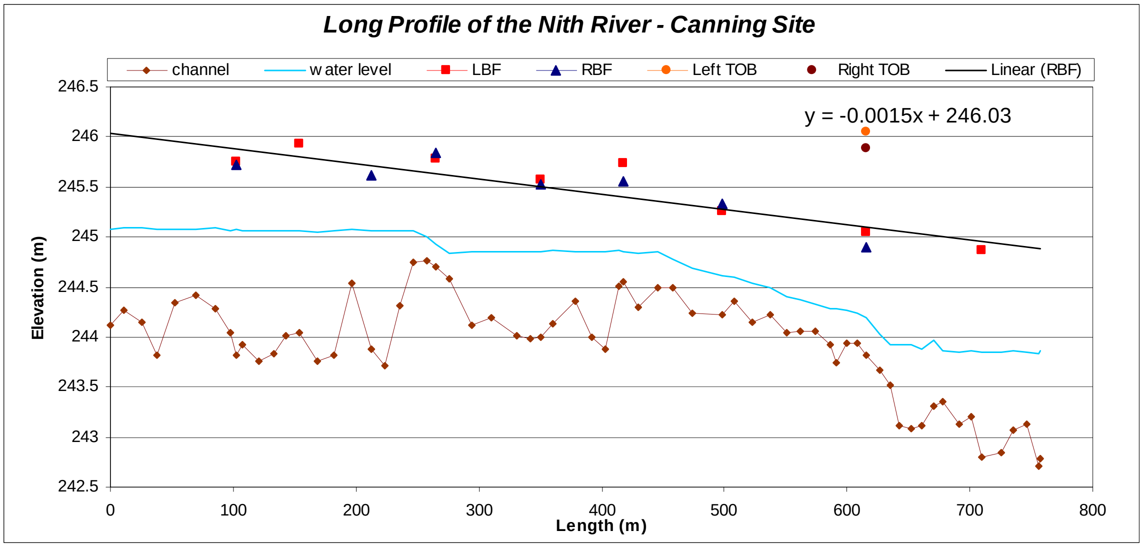
1. Ortho Map of Cross Section Locations
2. Longitudinal Profile of Study Reach
3. Cross Sections (10 in total)
4. Rating Curves
5. Calibration Results
    a) Rating Curve: Difference Between Estimated and Observed Water Elevations (not available for all reaches)
    b) Long Profile
    c) Comparison of Calibration to Long Profile (not available for all reaches)
6. Hydraulic Figures: (yellow background)

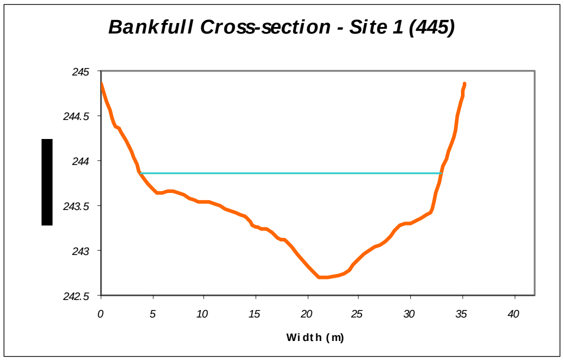
Flow vs.	**Definition of Terms (for any given flow rate):**
a) Depth	Maximum depth of flow
b) Area	Cross sectional area
c) Wetted Perimeter	Cross-sectional area in contact with the water
d) Top Width	Span across the cross section water surface
e) Hydraulic Radius	(not available for all reaches)
f) Froude Number	Describes open channel flow 0 = slow tranquil flow; 1 = shallow, fast flow
g) Channel Velocity	Average cross sectional velocity
h) Width-to-Depth Ratio	Channel width by maximum depth

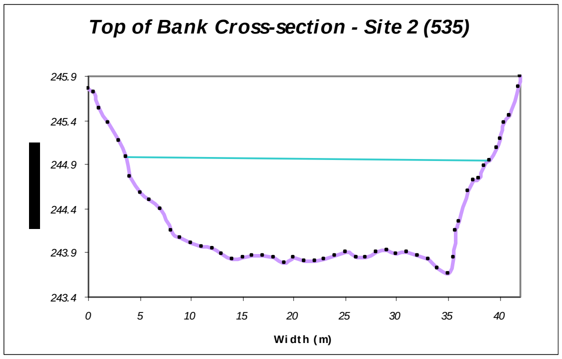
Note: Cross section colour scheme matches the colour scheme of the hydraulic plots for ease of comparison.

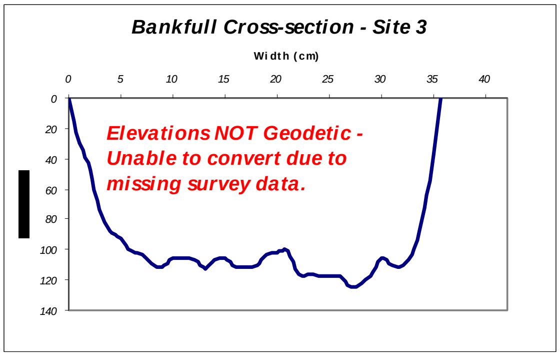
D-1: NITH RIVER AT CANNING REACH

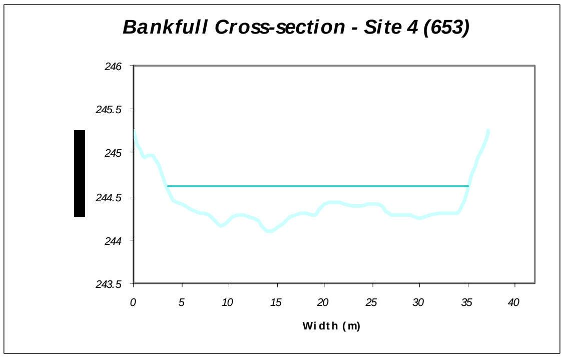


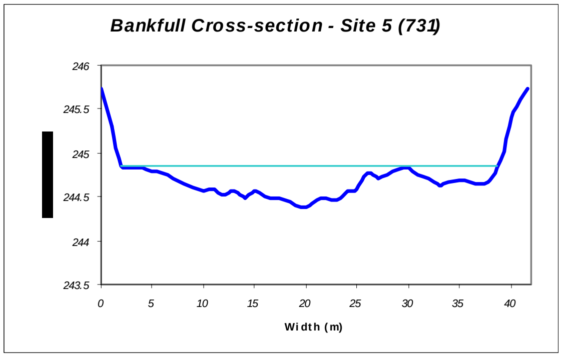


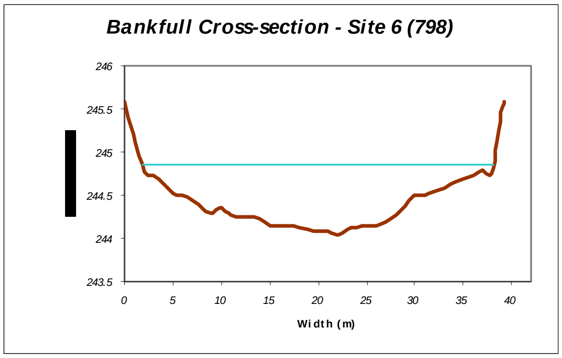

Bankfull Cross-section - Site 1 (445)

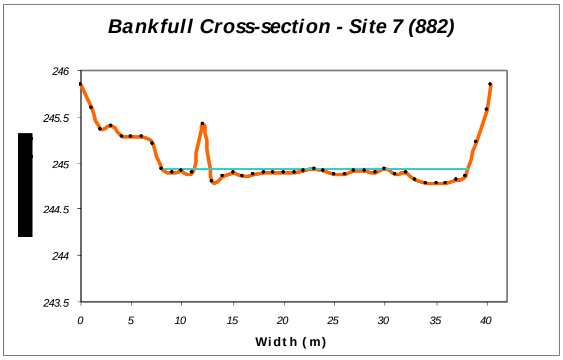

Top of Bank Cross-section - Site 2 (535)

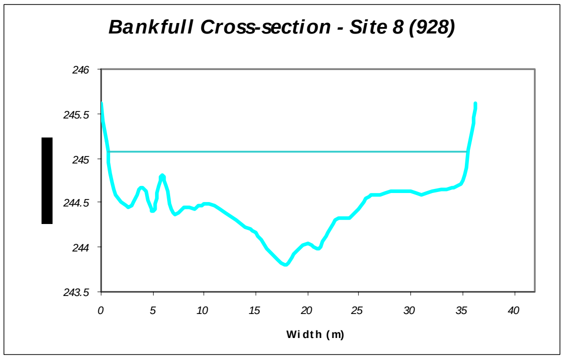

Bankfull Cross-section - Site 3

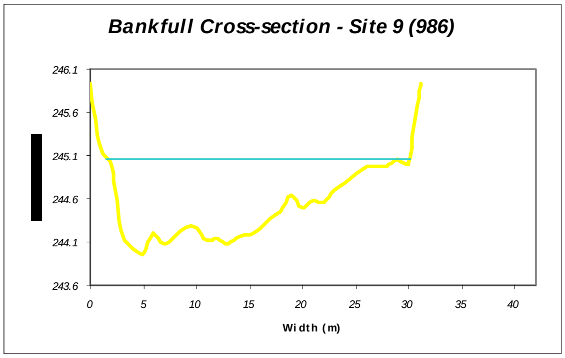

Bankfull Cross-section - Site 4 (653)

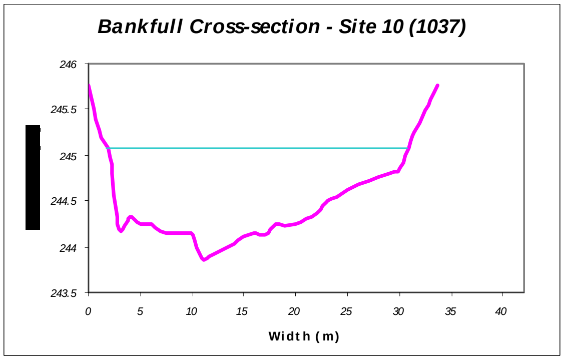

Bankfull Cross-section - Site 5 (731)

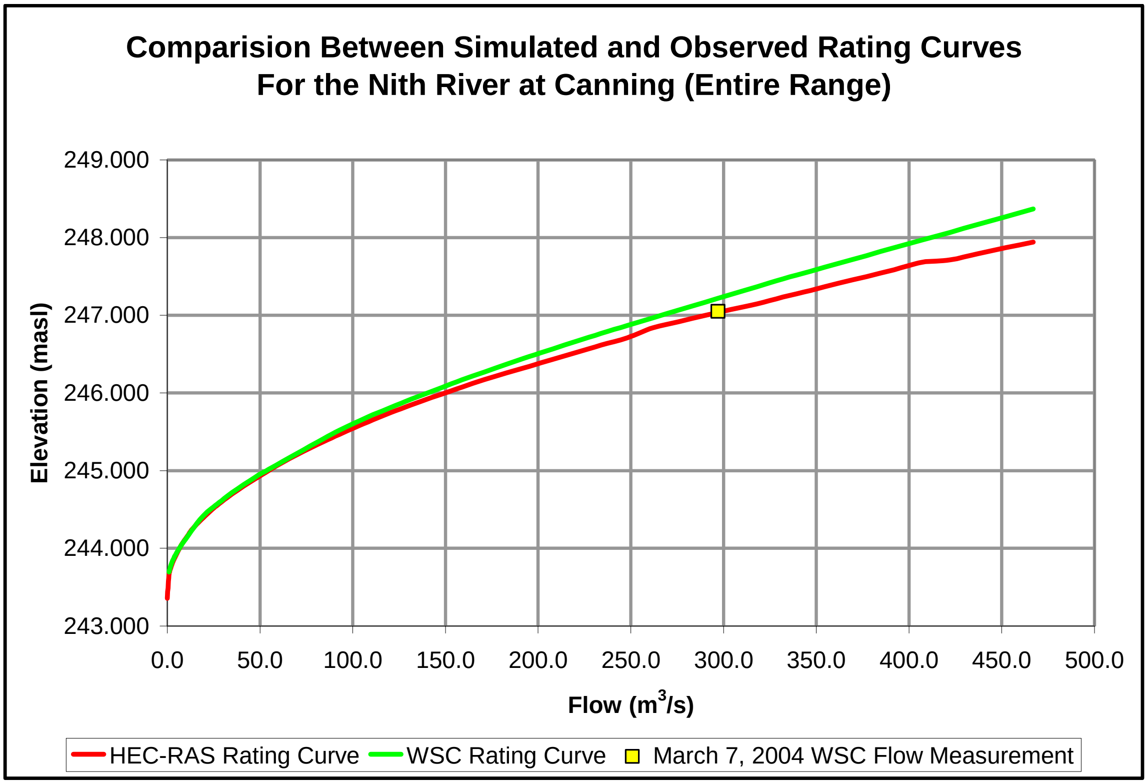

Bankfull Cross-section - Site 6 (798)

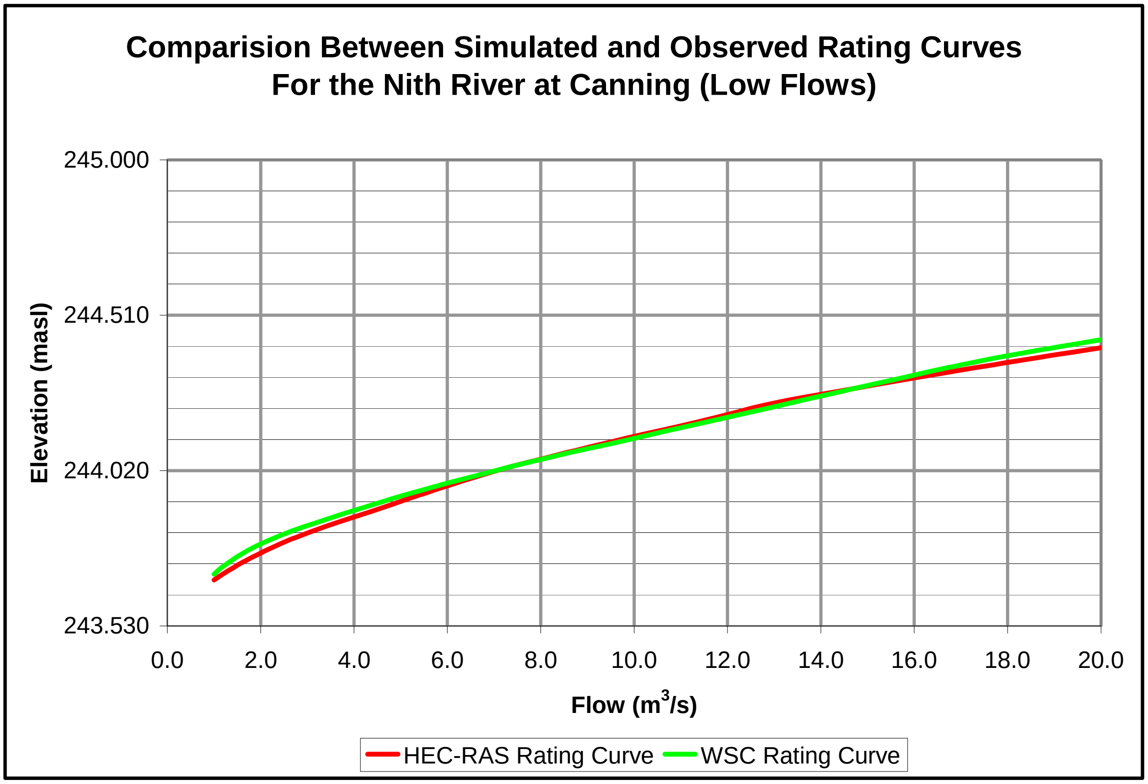

Bankfull Cross-section - Site 7 (882)

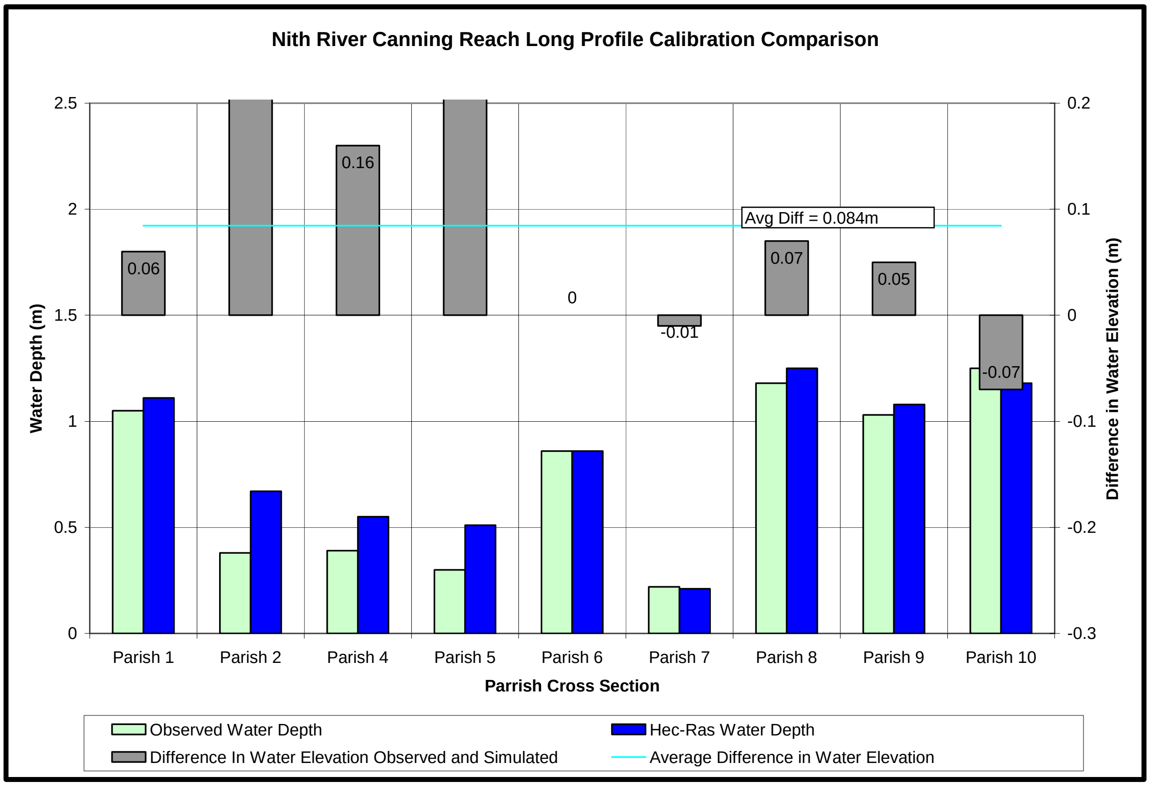

Bankfull Cross-section - Site 8 (928)

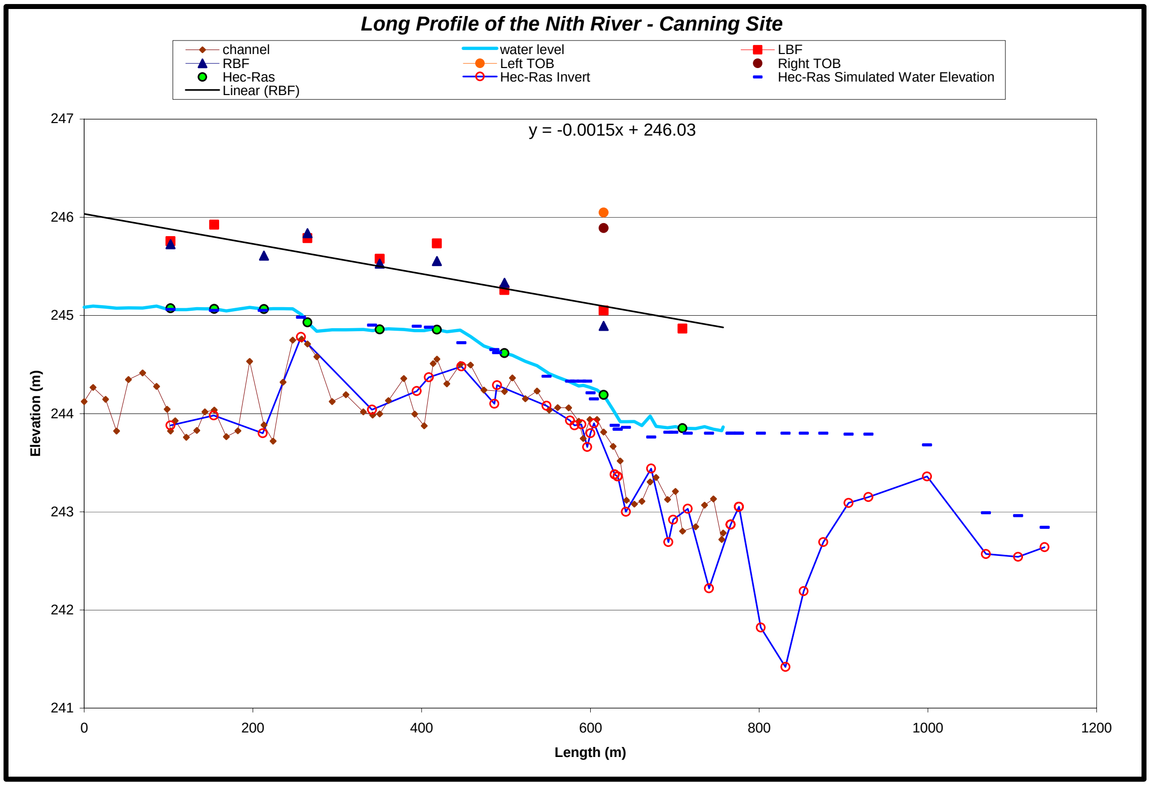

Bankfull Cross-section - Site 9 (986)
246.1
245.6
245.1
244.6
244.1
243.6
0
5
10
15
20
25
30
35
40
Width (m)

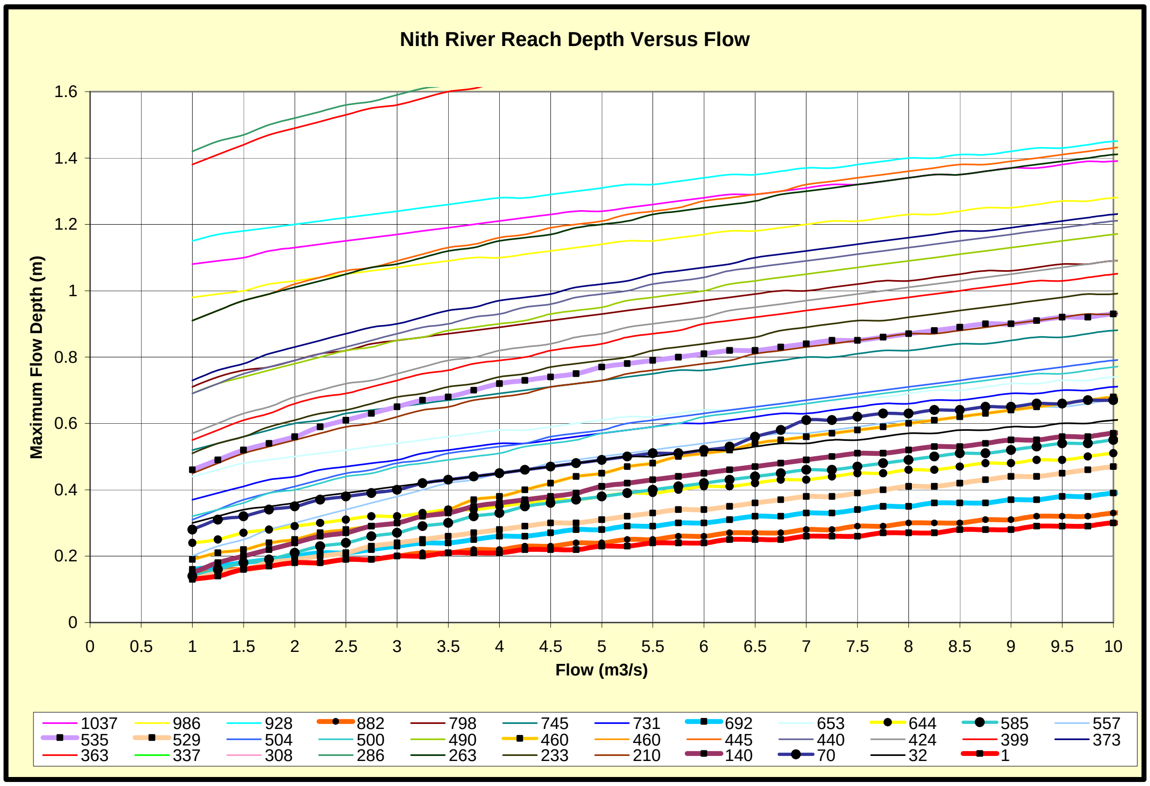

Bankfull Cross-section - Site 10 (1037)
246
245.5
245
244.5
244
243.5
0
5
10
15
20
25
30
35
40
Width (m)

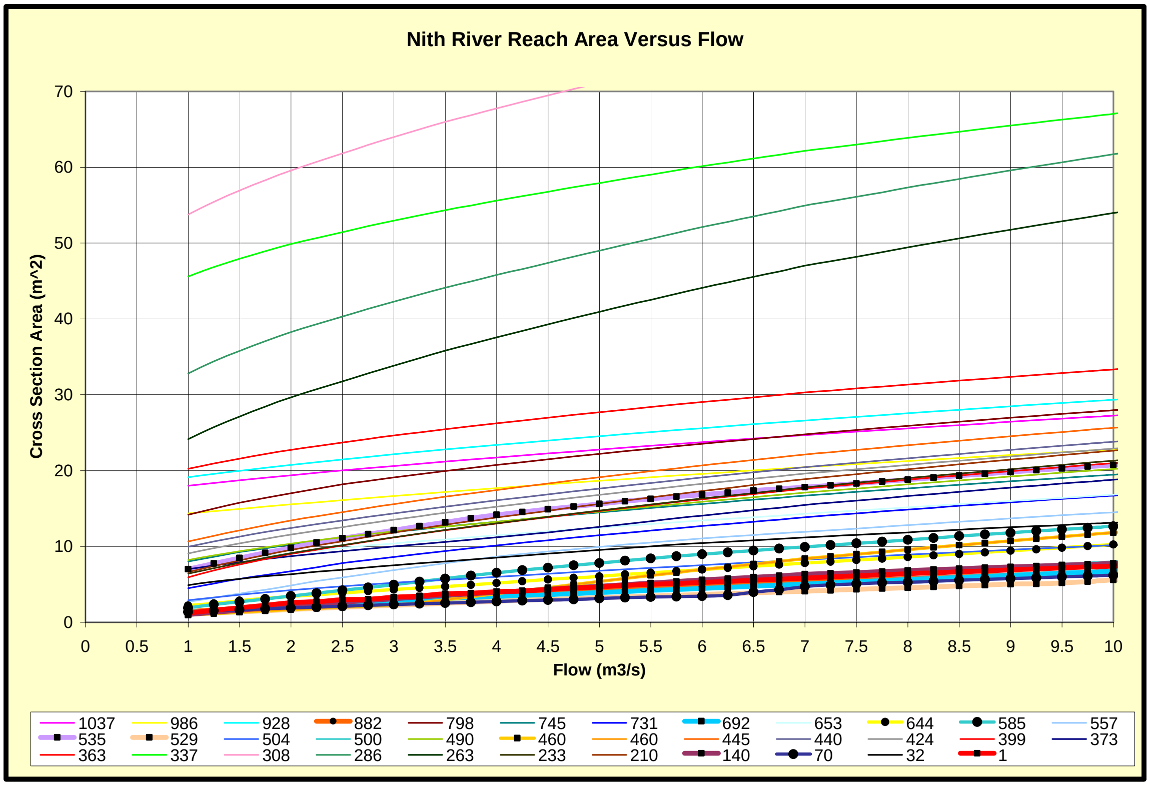

Comparision Between Simulated and Observed Rating Curves For the Nith River at Canning (Entire Range)
249.000
248.000
247.000
246.000
245.000
244.000
243.000
Elevation (masl)
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
Flow (m3/s)
HEC-RAS Rating Curve
WSC Rating Curve
March 7, 2004 WSC Flow Measurement

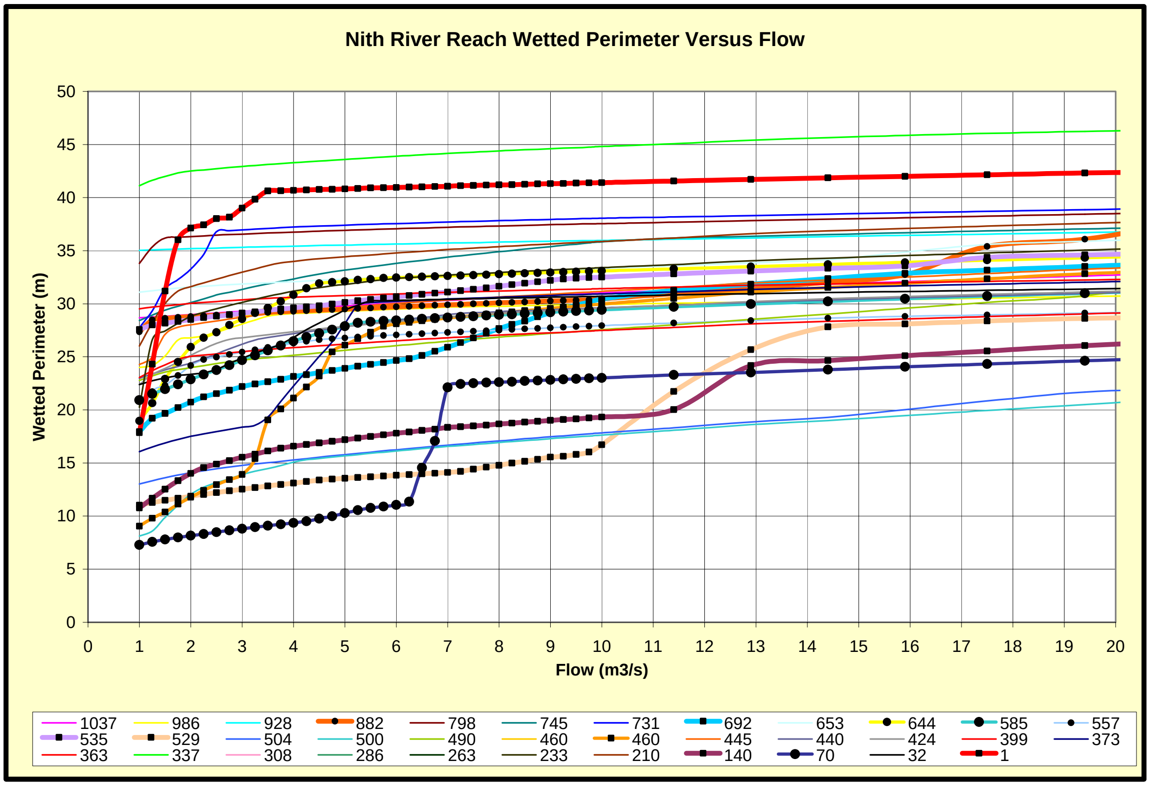

Comparision Between Simulated and Observed Rating Curves
For the Nith River at Canning (Low Flows)
Elevation (masl)
245.000
244.510
244.020
243.530
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Flow (m³/s)
HEC-RAS Rating Curve
WSC Rating Curve

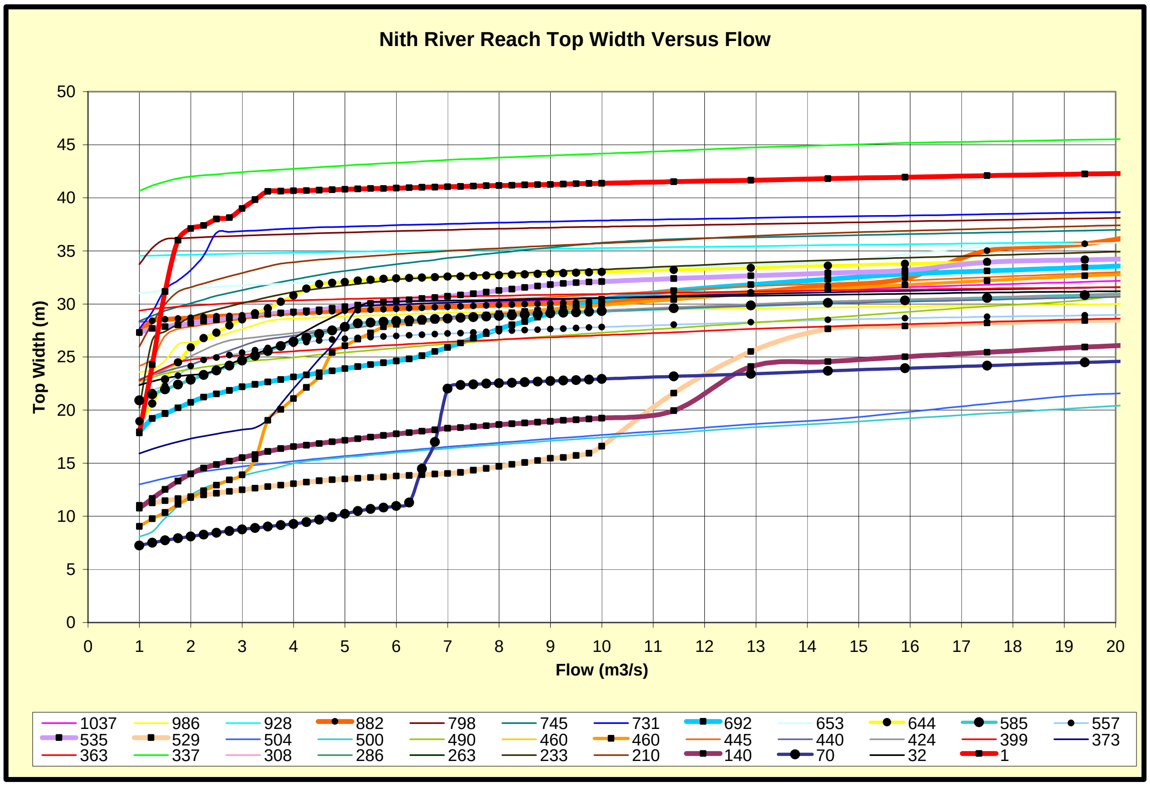

Nith River Canning Reach Long Profile Calibration Comparison
Water Depth (m)
2.5
2
1.5
1
0.5
0
Difference in Water Elevation (m)
0.2
0.1
0
-0.1
-0.2
-0.3
0.06
0.16
0
-0.01
0.07
0.05
-0.07
Avg Diff = 0.084m
Parish 1
Parish 2
Parish 4
Parish 5
Parish 6
Parish 7
Parish 8
Parish 9
Parish 10
Parrish Cross Section
Observed Water Depth
Hec-Ras Water Depth
Difference In Water Elevation Observed and Simulated
Average Difference in Water Elevation

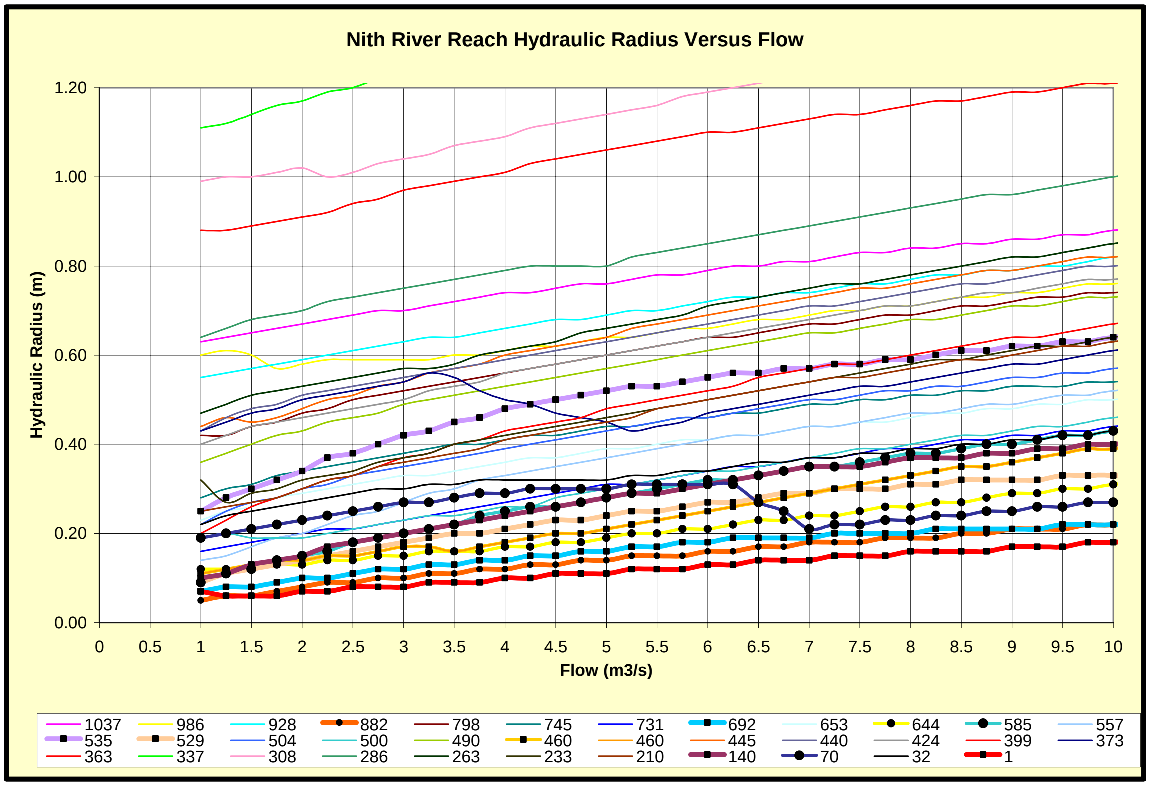

Long Profile of the Nith River - Canning Site
channel
water level
LBF
RBF
Left TOB
Right TOB
Hec-Ras
Hec-Ras Invert
Hec-Ras Simulated Water Elevation
Linear (RBF)
y = -0.0015x + 246.03
Elevation (m)
247
246
245
244
243
242
241
0
200
400
600
800
1000
1200
Length (m)

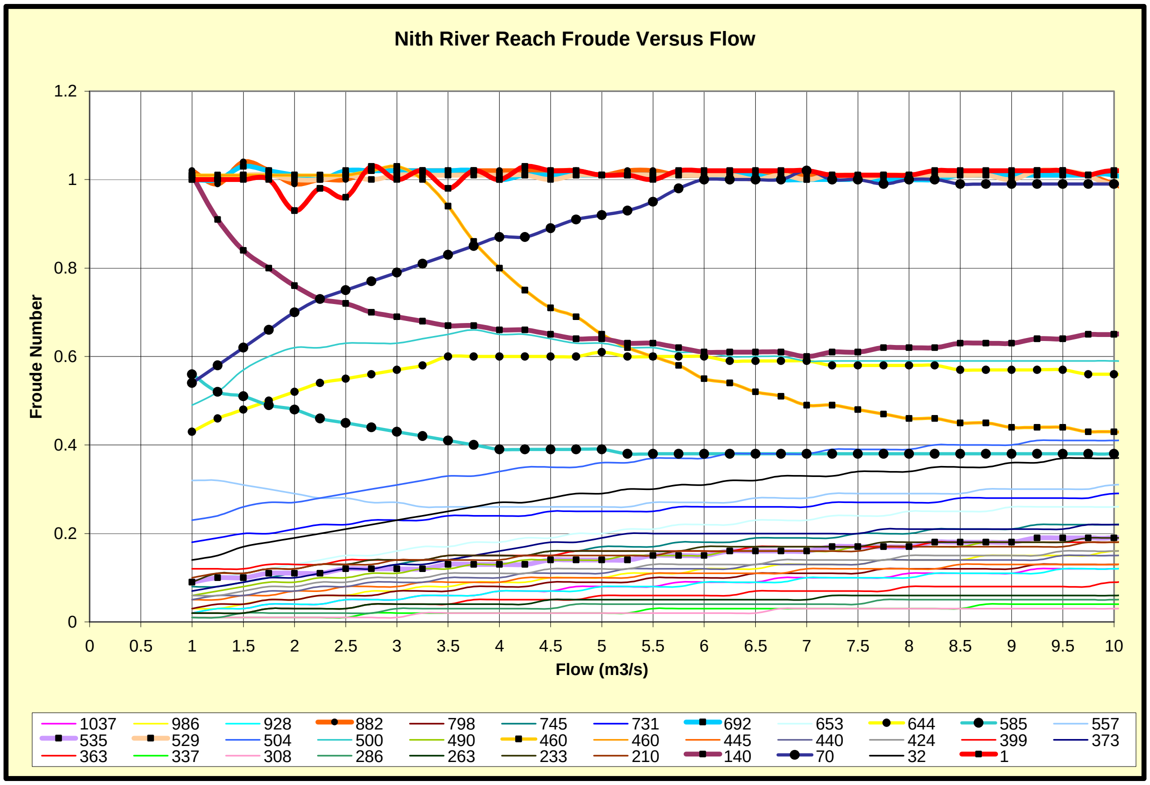

Nith River Reach Depth Versus Flow
Maximum Flow Depth (m)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
Flow (m3/s)
1037
986
928
882
798
745
731
692
653
644
585
557
535
529
504
500
490
460
460
445
440
424
399
373
363
337
308
286
263
233
210
140
70
32
1

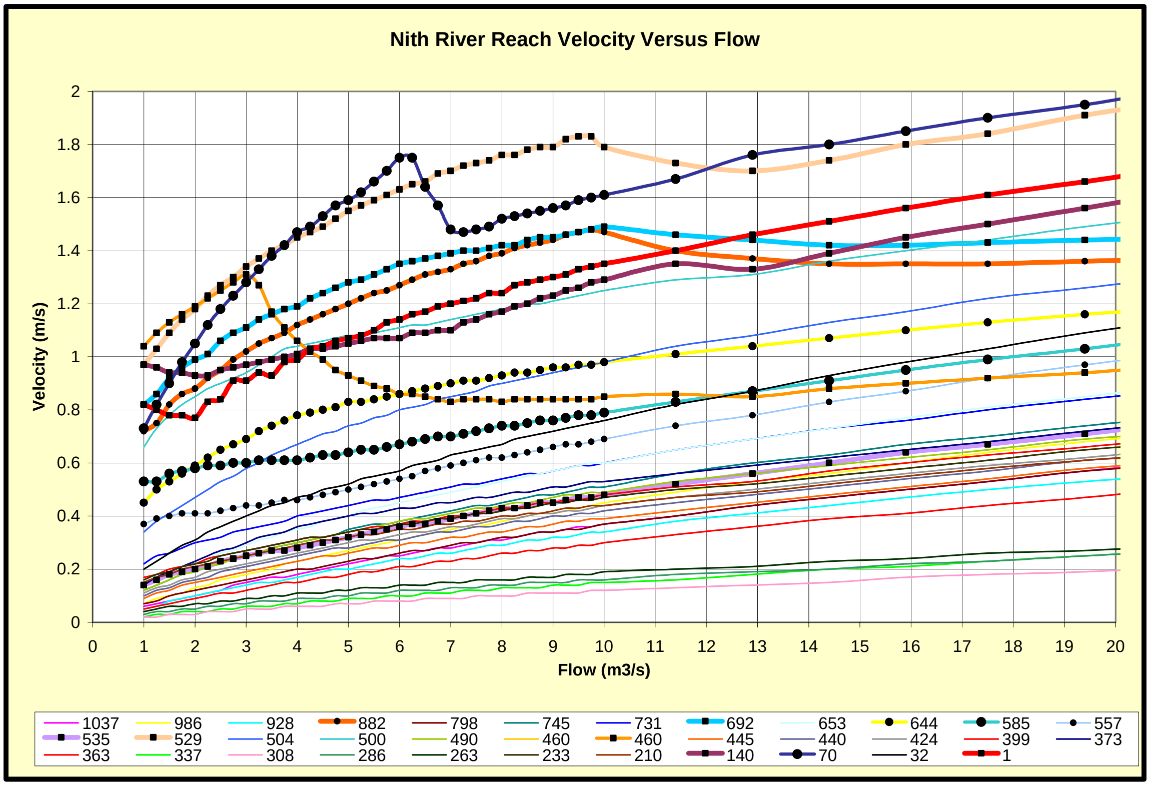

Nith River Reach Area Versus Flow
Cross Section Area (m^2)
Flow (m3/s)
0
10
20
30
40
50
60
70
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
1037
986
928
882
798
745
731
692
653
644
585
557
535
529
504
500
490
460
460
445
440
424
399
373
363
337
308
286
263
233
210
140
70
32
1

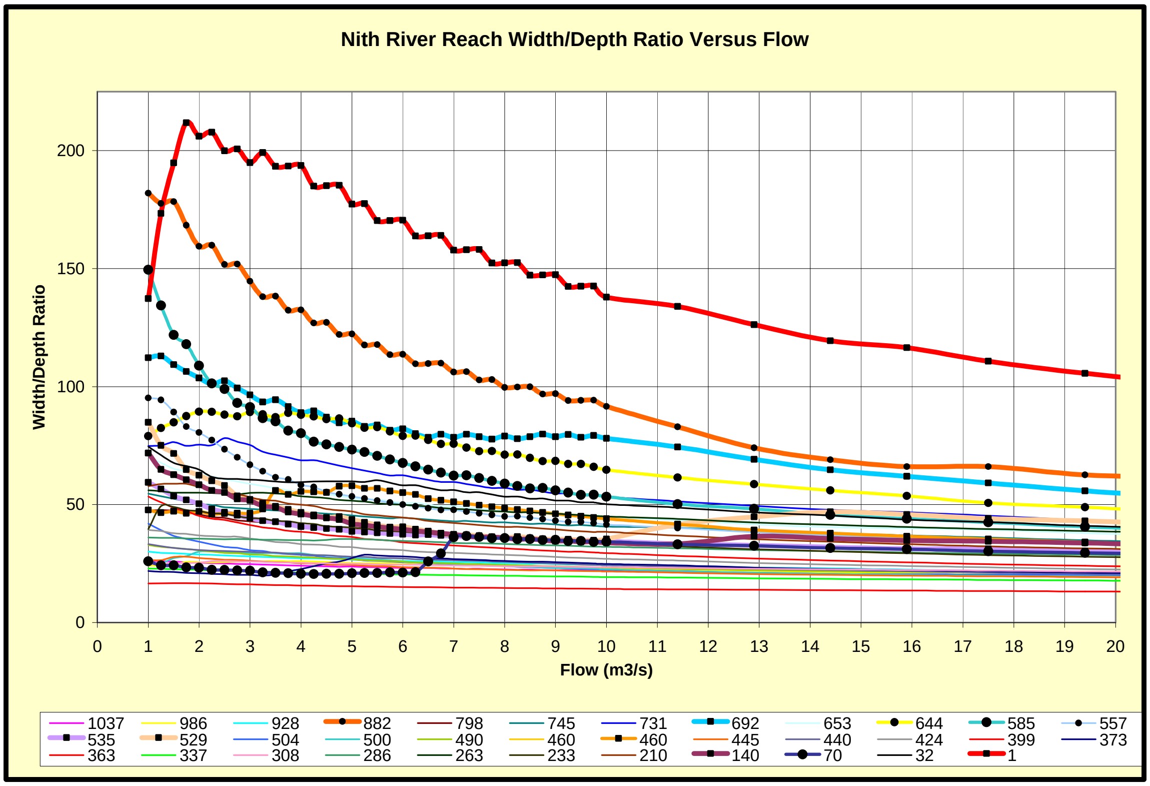

Nith River Reach Wetted Perimeter Versus Flow
Wetted Perimeter (m)
0
5
10
15
20
25
30
35
40
45
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Flow (m3/s)
1037
986
928
882
798
745
731
692
653
644
585
557
535
529
504
500
490
460
460
445
440
424
399
373
363
337
308
286
263
233
210
140
70
32
1


Nith River Reach Top Width Versus Flow
Top Width (m)
0
5
10
15
20
25
30
35
40
45
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Flow (m3/s)
1037
986
928
882
798
745
731
692
653
644
585
557
535
529
504
500
490
460
460
445
440
424
399
373
363
337
308
286
263
233
210
140
70
32
1

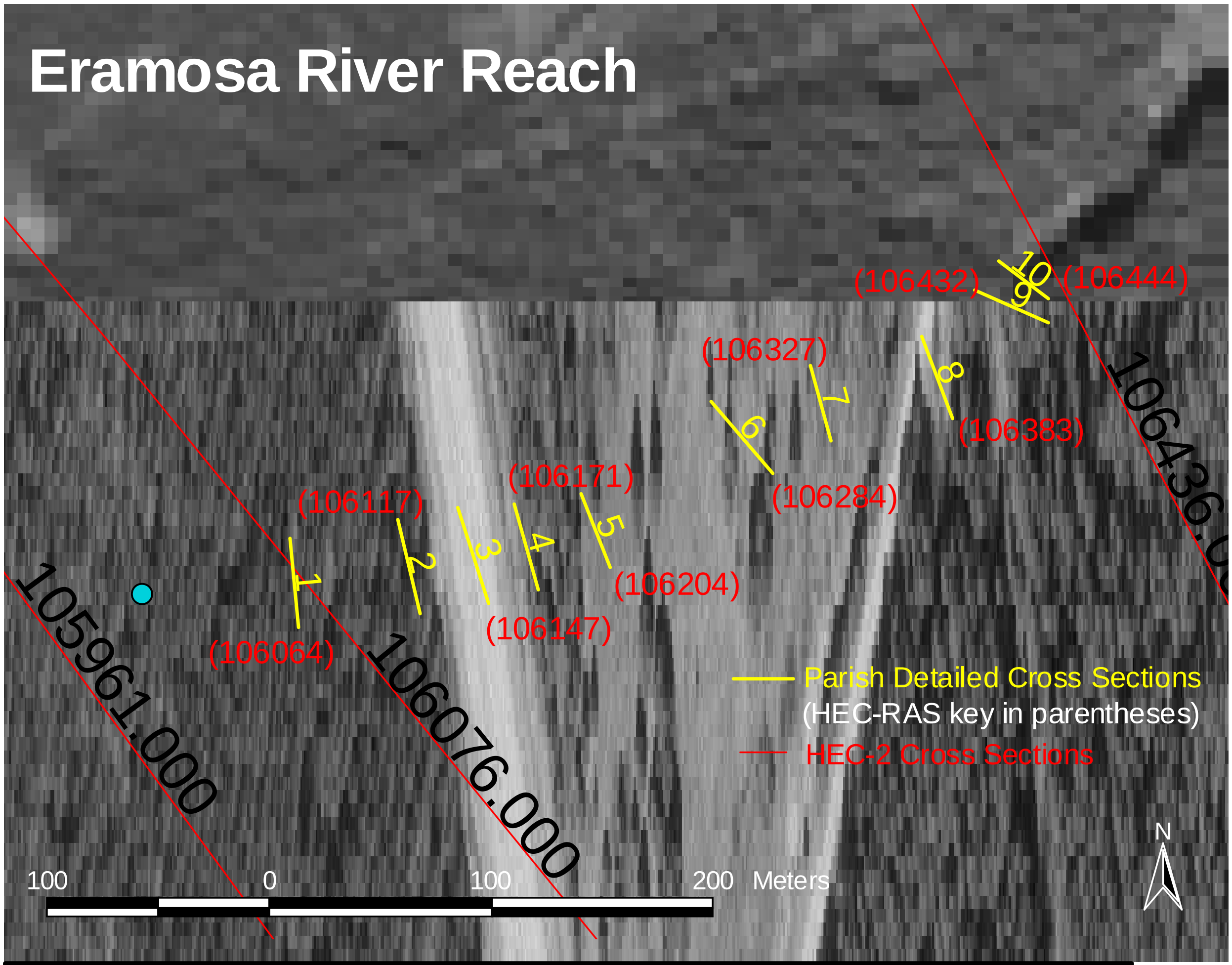

Nith River Reach Hydraulic Radius Versus Flow
Hydraulic Radius (m)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
Flow (m3/s)
1037
986
928
882
798
745
731
692
653
644
585
557
535
529
504
500
490
460
460
445
440
424
399
373
363
337
308
286
263
233
210
140
70
32
1

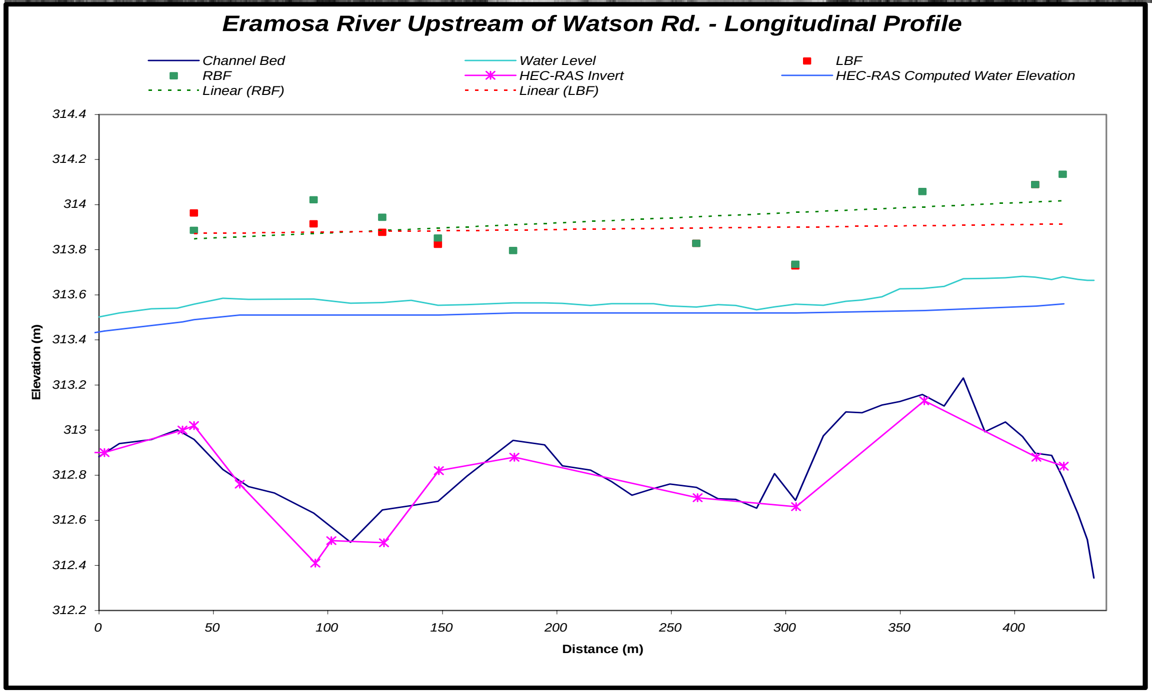

Nith River Reach Froude Versus Flow
Froude Number
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
Flow (m3/s)
1037
986
928
882
798
745
731
692
653
644
585
557
535
529
504
500
490
460
460
445
440
424
399
373
363
337
308
286
263
233
210
140
70
32
1

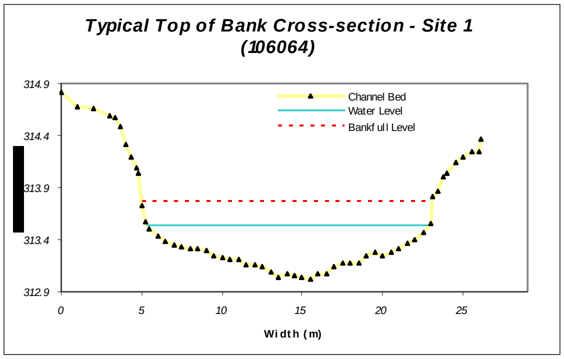

Nith River Reach Velocity Versus Flow
Velocity (m/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Flow (m3/s)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
1037 986 928 882 798 745 731 692 653 644 585 557
535 529 504 500 490 460 460 445 440 424 399 373
363 337 308 286 263 233 210 140 70 32 1

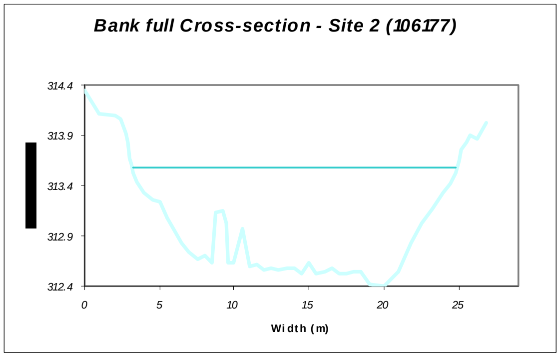

Nith River Reach Width/Depth Ratio Versus Flow
Width/Depth Ratio
0
50
100
150
200
Flow (m3/s)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
1037 986 928 882 798 745 731 692 653 644 585 557
535 529 504 500 490 460 460 445 440 424 399 373
363 337 308 286 263 233 210 140 70 32 1

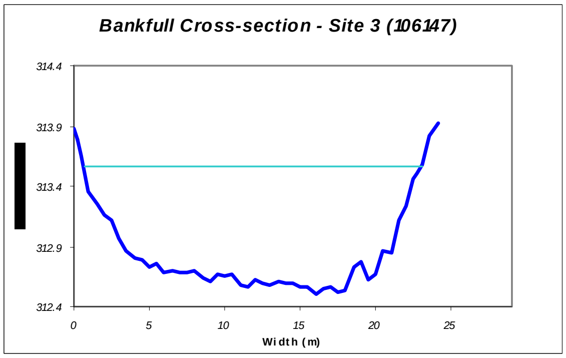
D-2: ERAMOSA RIVER REACH

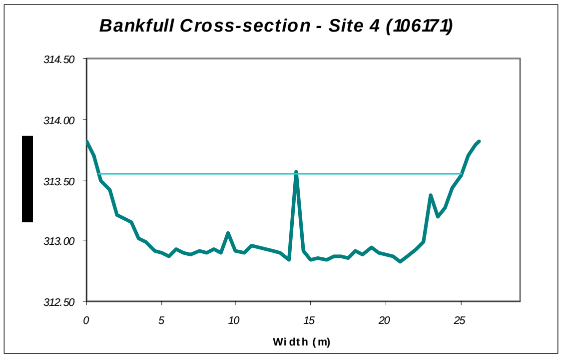


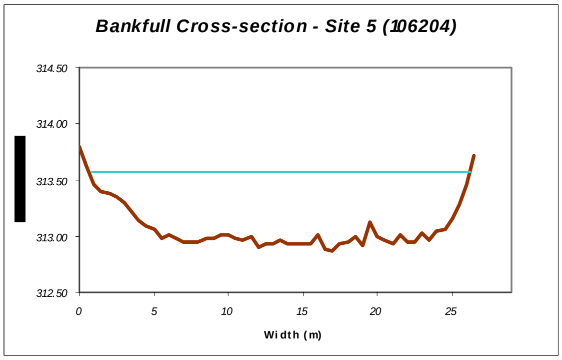


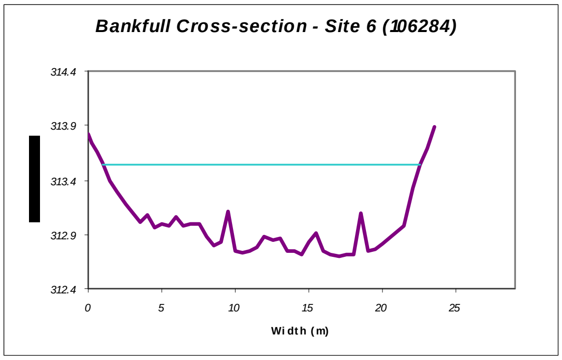

Typical Top of Bank Cross-section - Site 1 (106064)

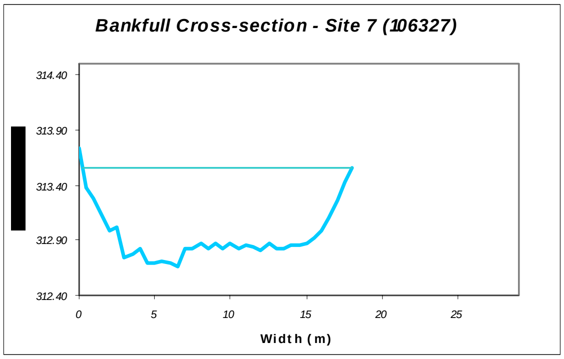

Bank full Cross-section - Site 2 (106177)

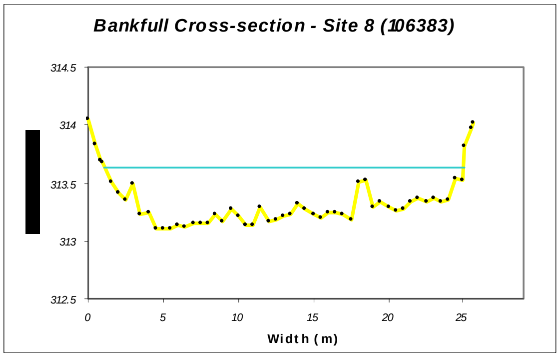

Bankfull Cross-section - Site 3 (106147)

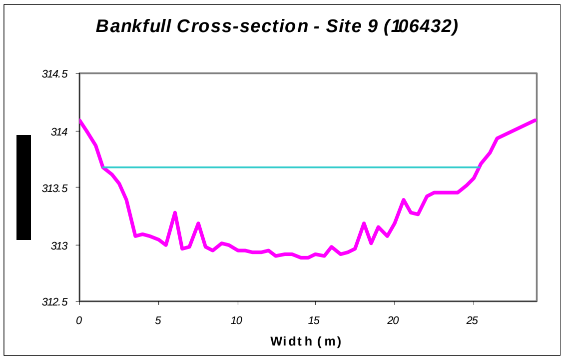

Bankfull Cross-section - Site 4 (106171)

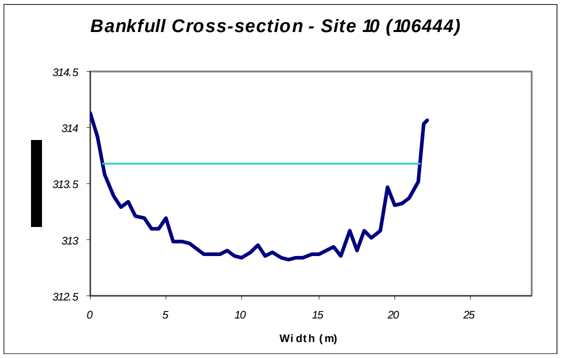

Bankfull Cross-section - Site 5 (106204)

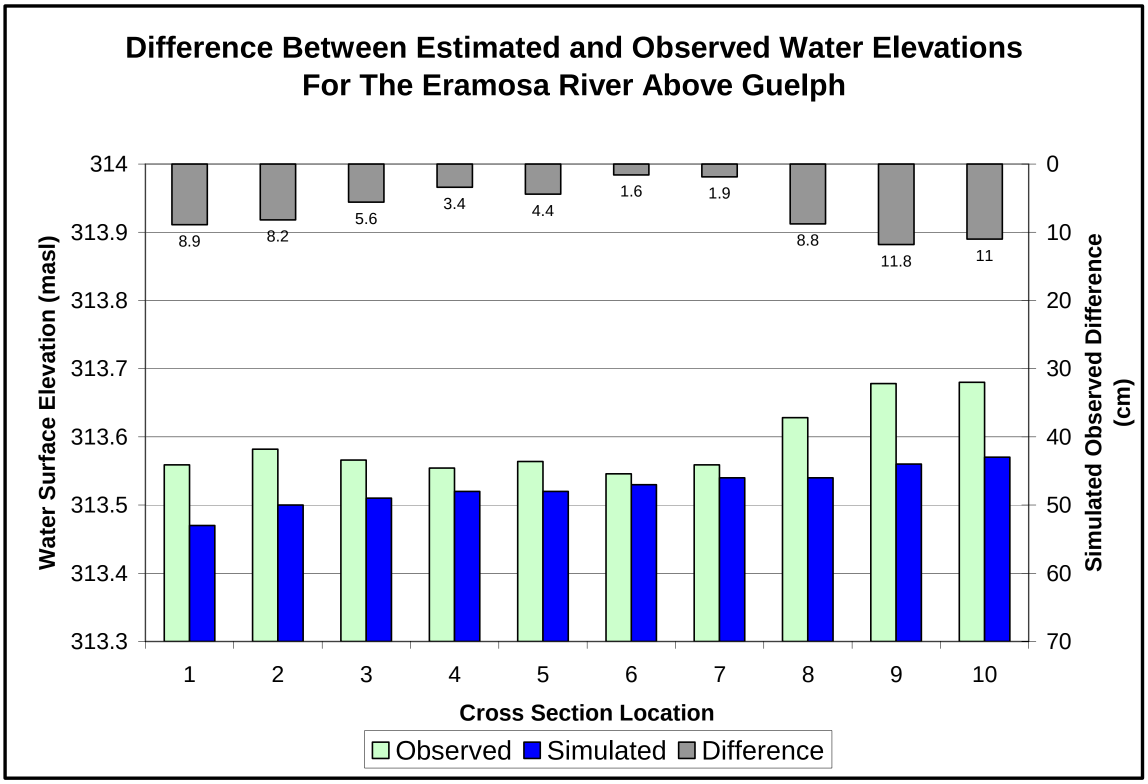

Bankfull Cross-section - Site 6 (106284)

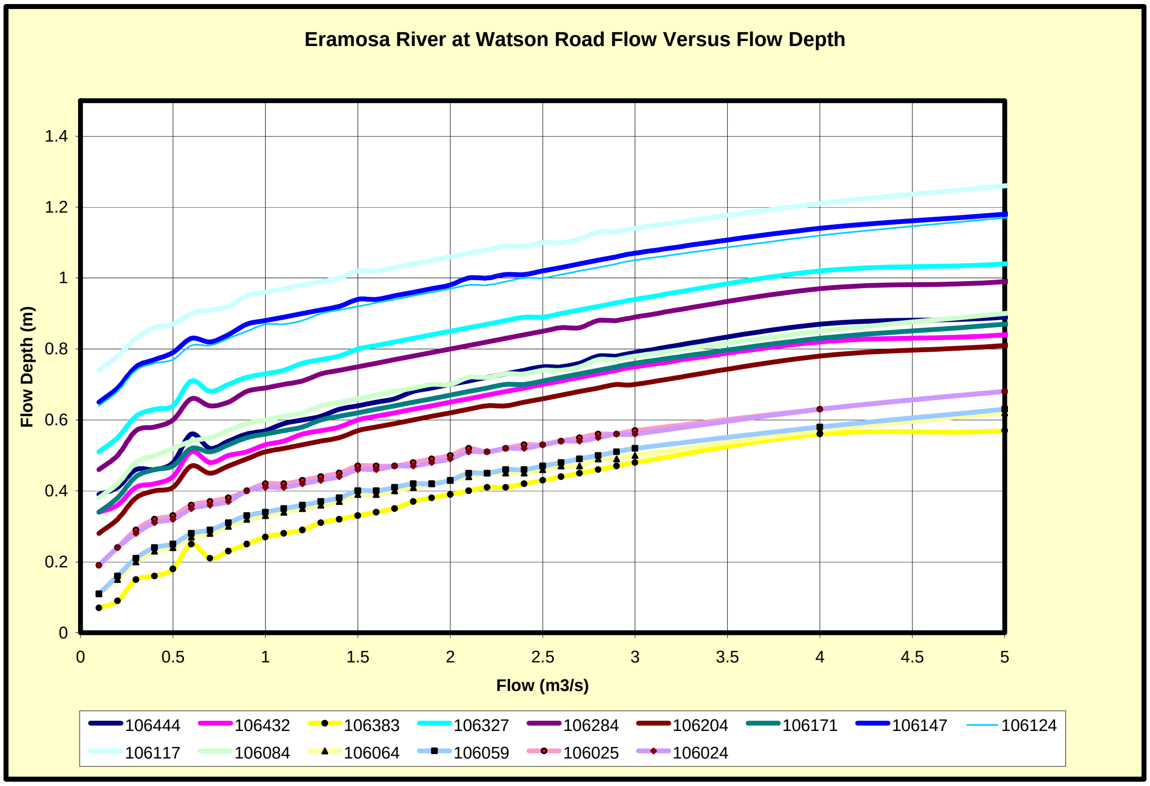

Bankfull Cross-section - Site 7 (106327)

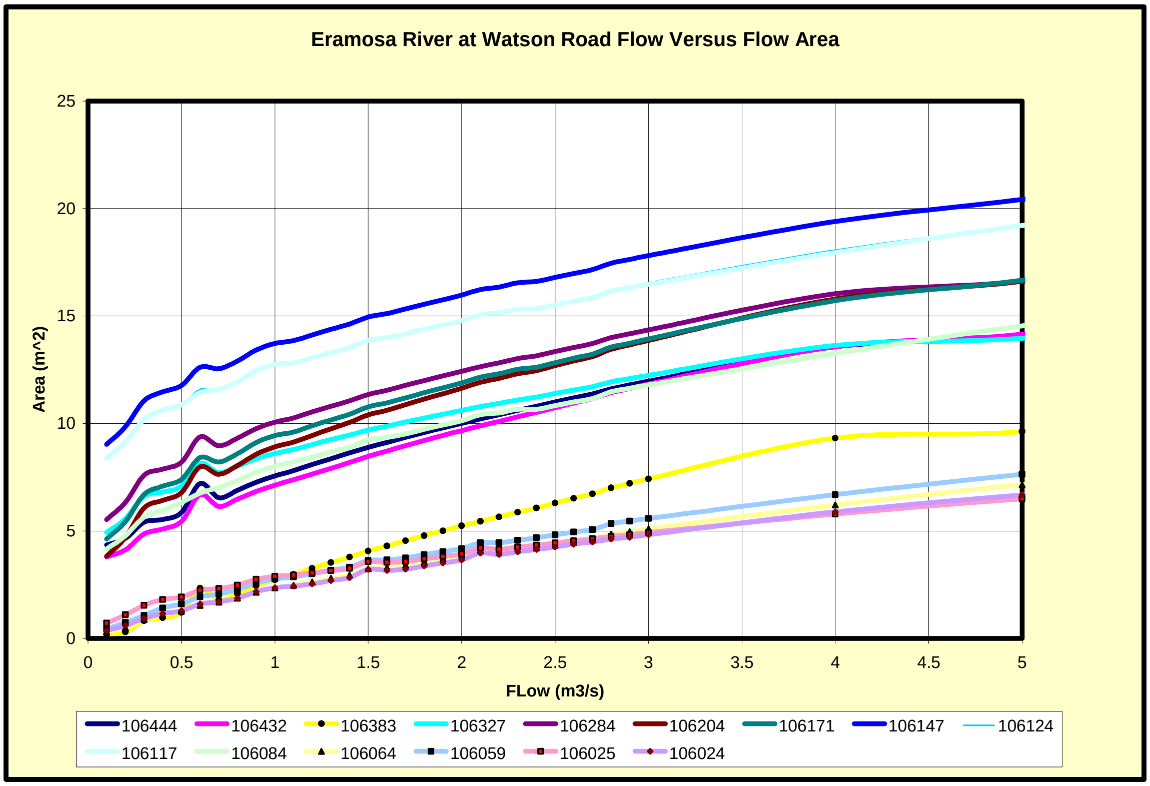

Bankfull Cross-section - Site 8 (106383)

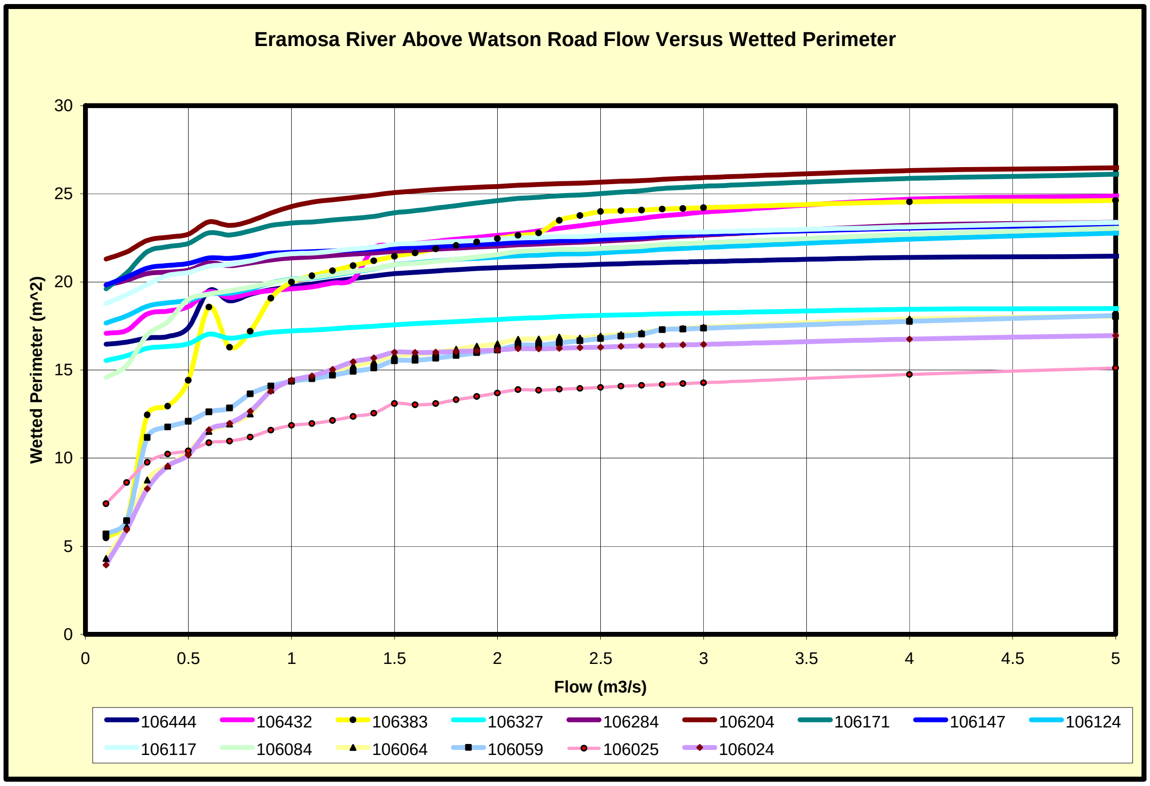

Bankfull Cross-section - Site 9 (106432)
314.5
314
313.5
313
312.5
0
5
10
15
20
25
Width (m)

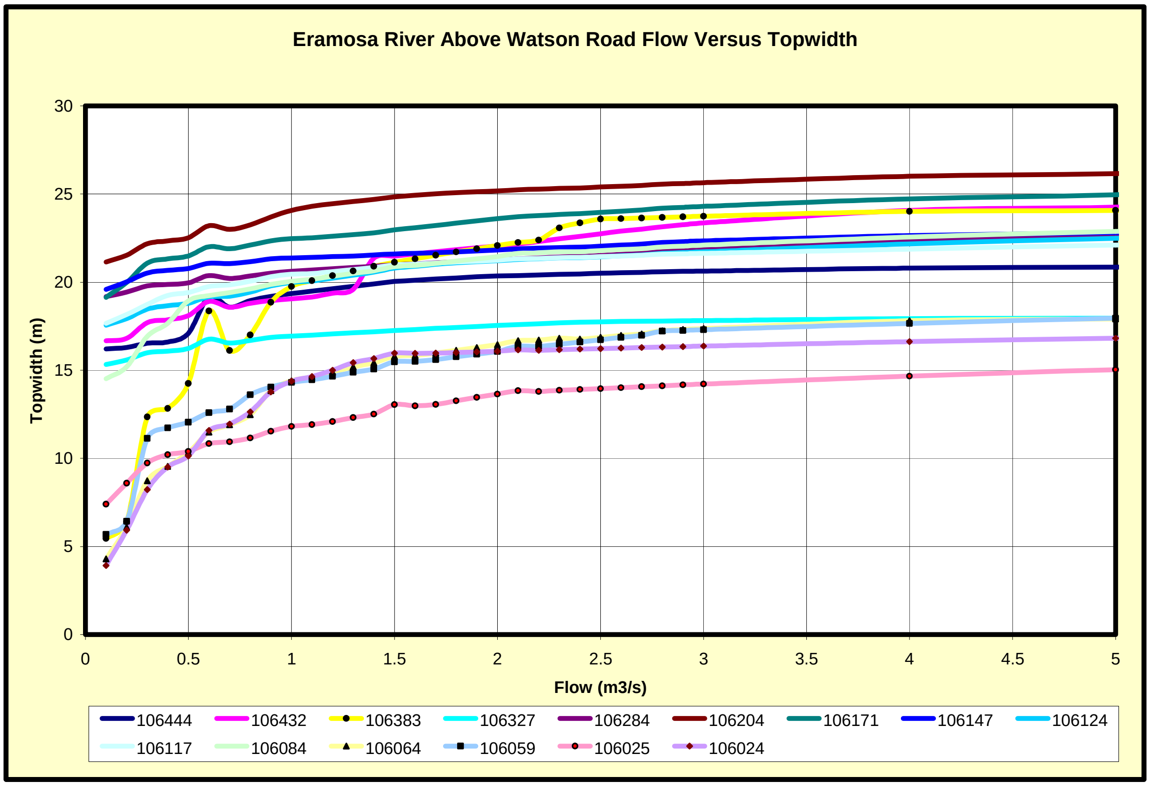

Bankfull Cross-section - Site 10 (106444)
314.5
314
313.5
313
312.5
0
5
10
15
20
25
Width (m)

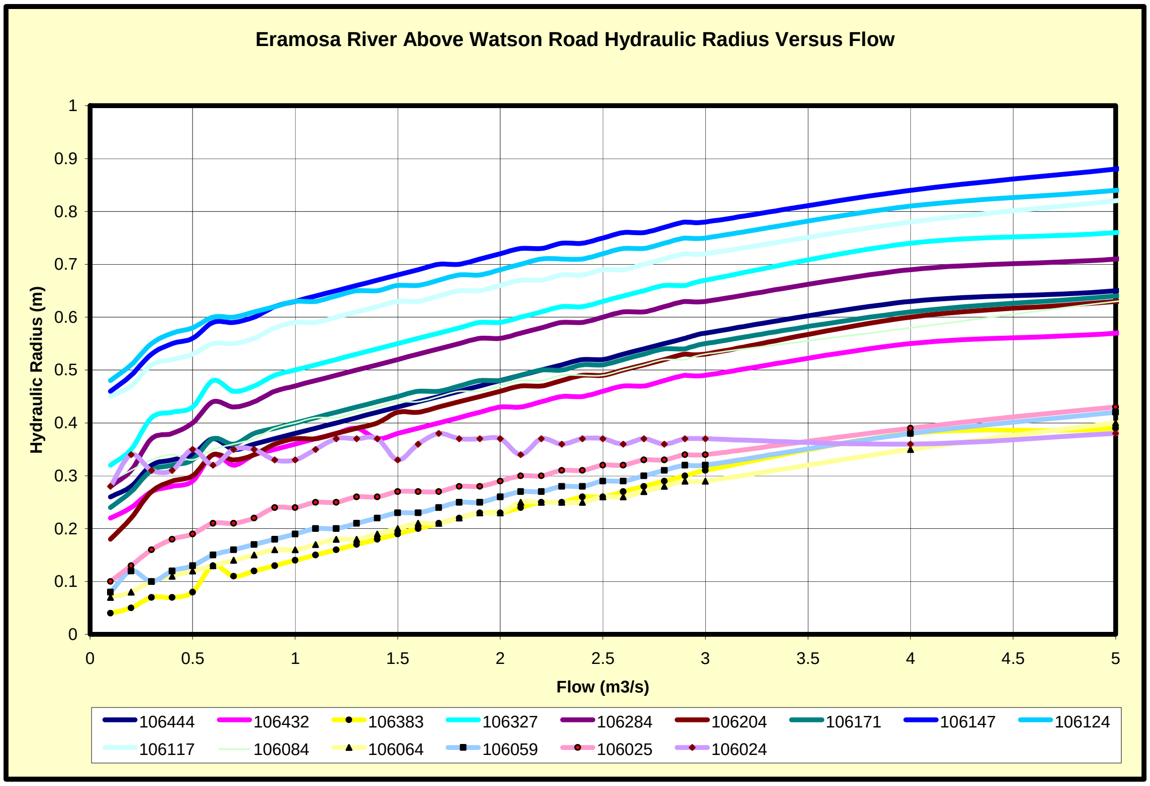

Difference Between Estimated and Observed Water Elevations
For The Eramosa River Above Guelph
Water Surface Elevation (masl)
314
313.9
313.8
313.7
313.6
313.5
313.4
313.3
Simulated Observed Difference (cm)
0
10
20
30
40
50
60
70
8.9
8.2
5.6
3.4
4.4
1.6
1.9
8.8
11.8
11
1
2
3
4
5
6
7
8
9
10
Cross Section Location
Observed
Simulated
Difference

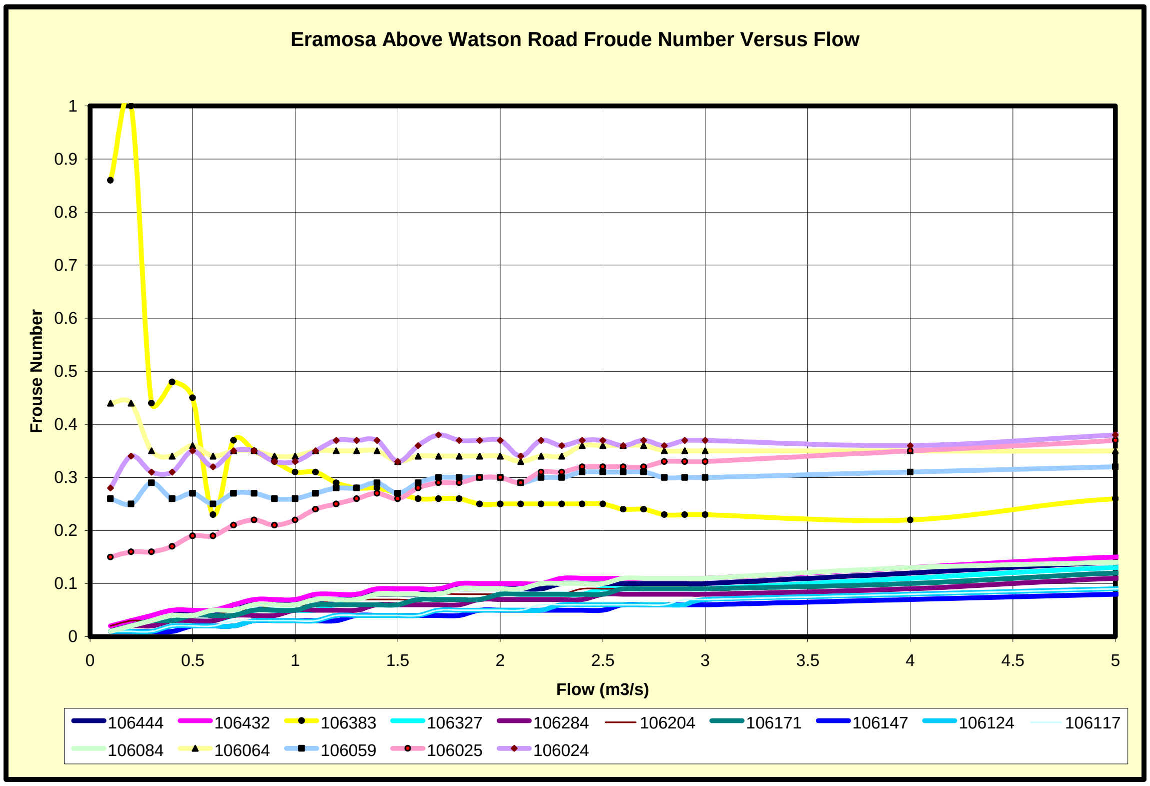

Eramosa River at Watson Road Flow Versus Flow Depth
Flow Depth (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
106444
106432
106383
106327
106284
106204
106171
106147
106124
106117
106084
106064
106059
106025
106024

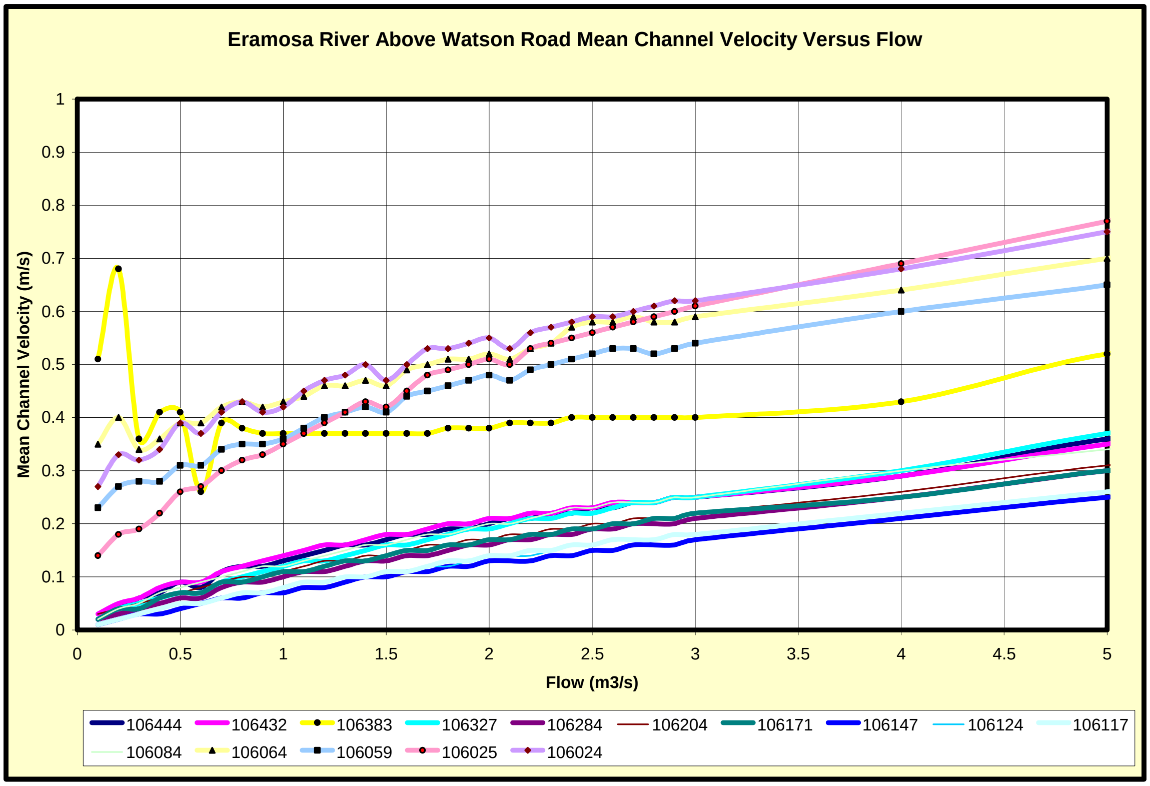

Eramosa River at Watson Road Flow Versus Flow Area
Area (m^2)
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
FLow (m3/s)
106444
106432
106383
106327
106284
106204
106171
106147
106124
106117
106084
106064
106059
106025
106024

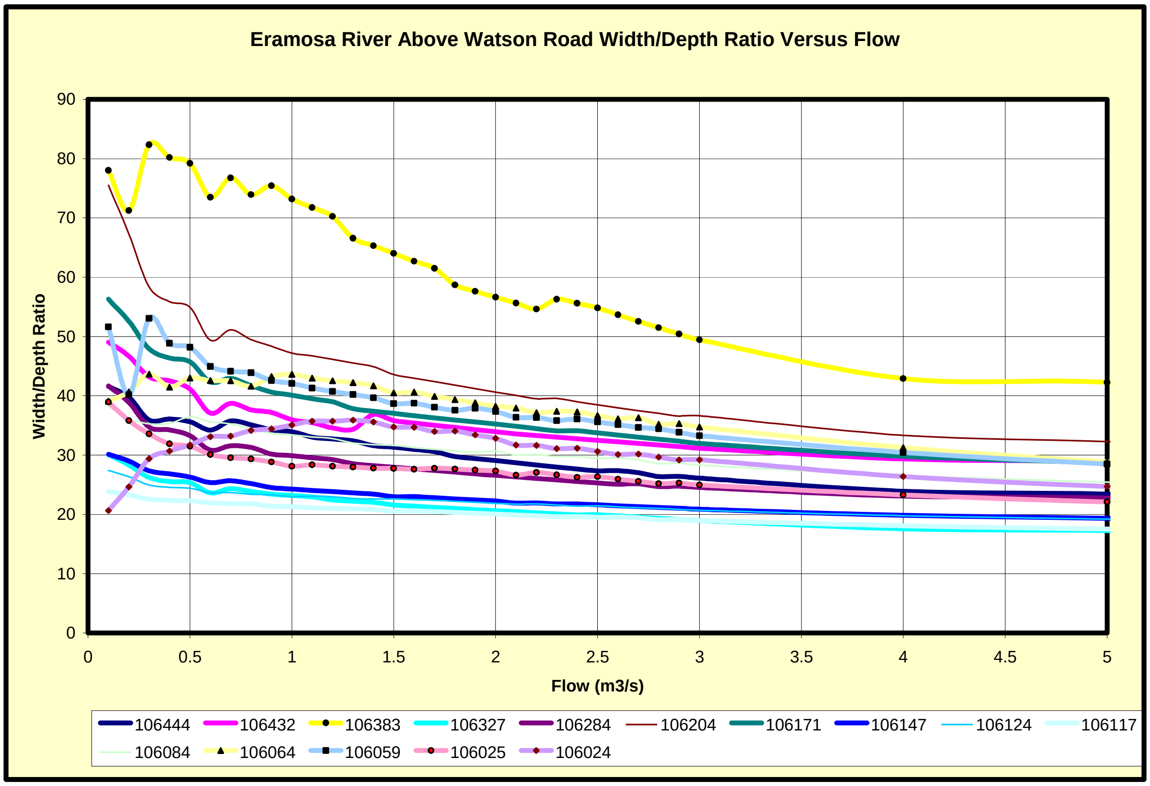

Eramosa River Above Watson Road Flow Versus Wetted Perimeter
Wetted Perimeter (m^2)
Flow (m3/s)
0
5
10
15
20
25
30
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
106444
106432
106383
106327
106284
106204
106171
106147
106124
106117
106084
106064
106059
106025
106024


Eramosa River Above Watson Road Flow Versus Topwidth
Topwidth (m)
Flow (m3/s)
0
5
10
15
20
25
30
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
106444
106432
106383
106327
106284
106204
106171
106147
106124
106117
106084
106064
106059
106025
106024

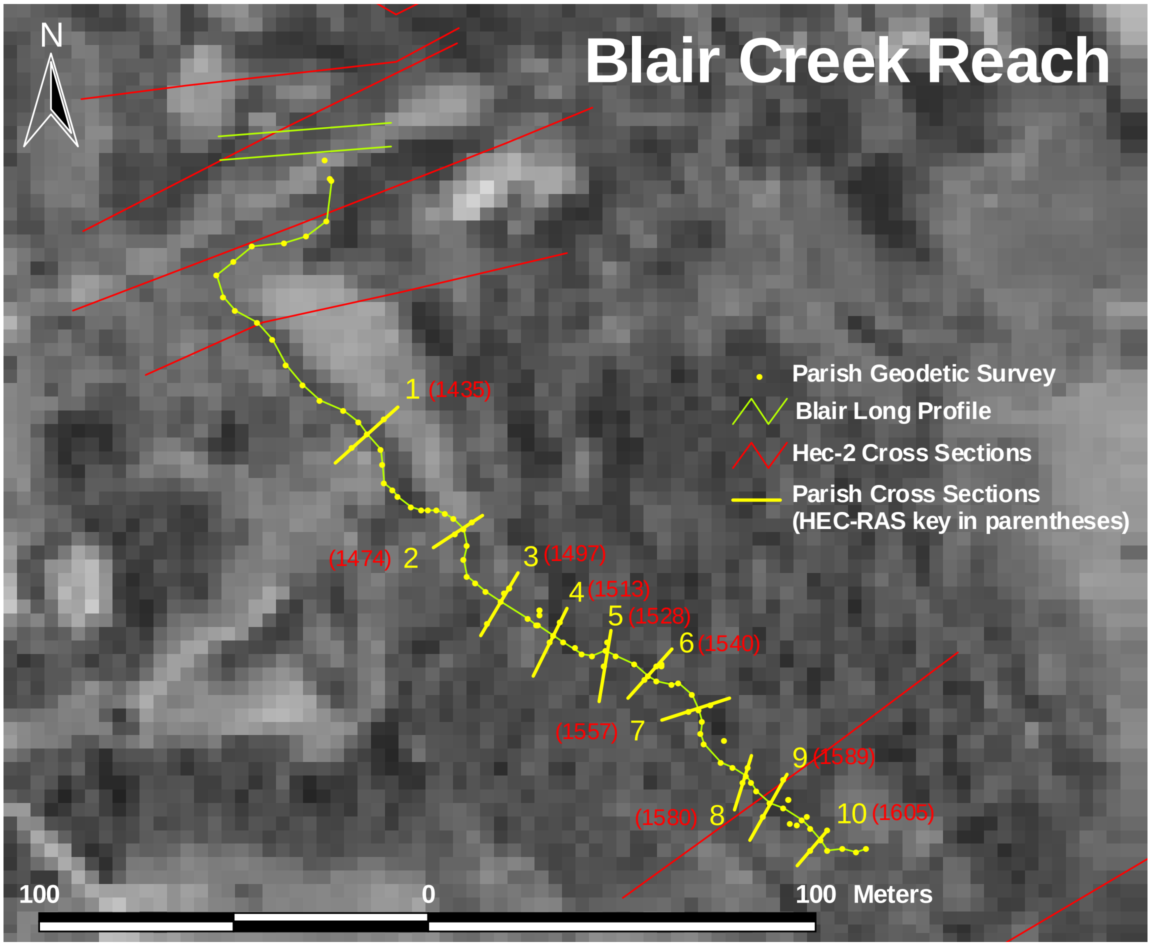

Eramosa River Above Watson Road Hydraulic Radius Versus Flow
Hydraulic Radius (m)
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
106444
106432
106383
106327
106284
106204
106171
106147
106124
106117
106084
106064
106059
106025
106024

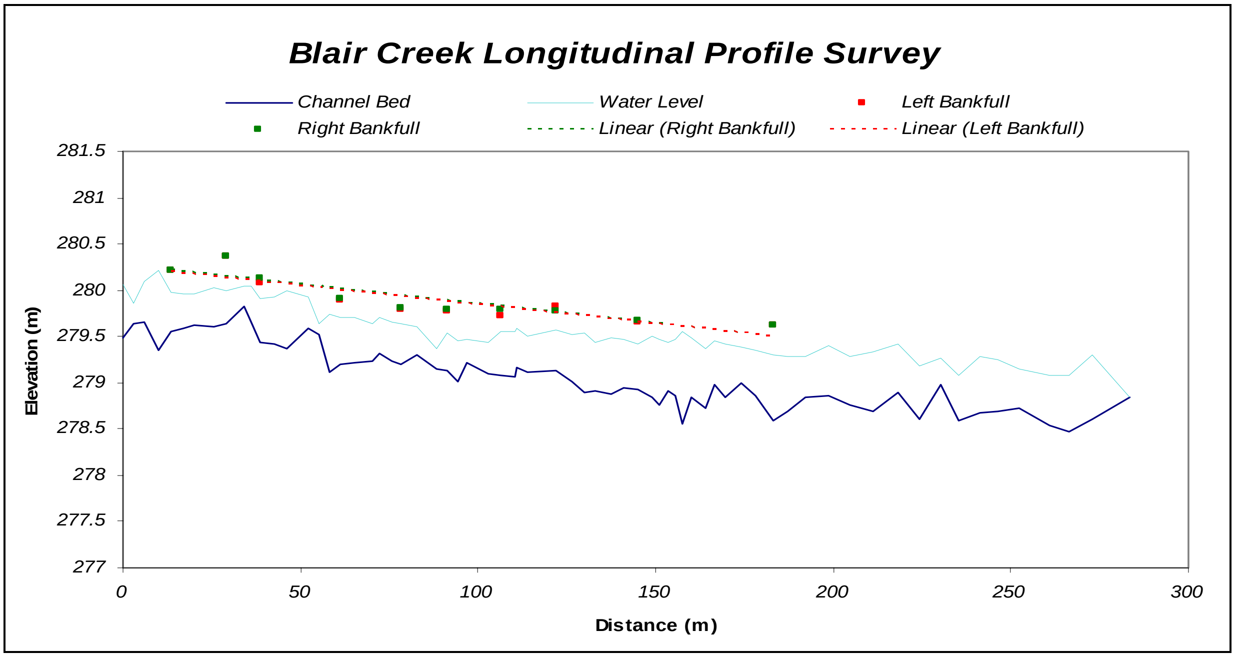

Eramosa Above Watson Road Froude Number Versus Flow
Frouse Number
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
106444
106432
106383
106327
106284
106204
106171
106147
106124
106117
106084
106064
106059
106025
106024

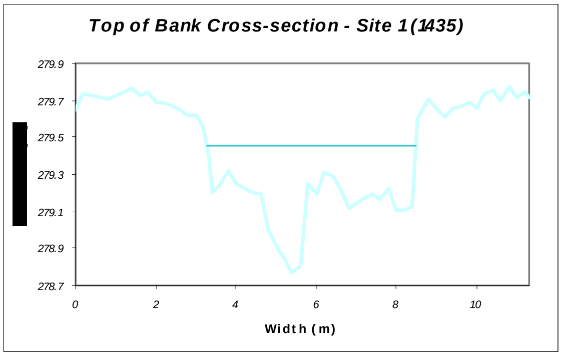

Eramosa River Above Watson Road Mean Channel Velocity Versus Flow
Mean Channel Velocity (m/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
106444
106432
106383
106327
106284
106204
106171
106147
106124
106117
106084
106064
106059
106025
106024

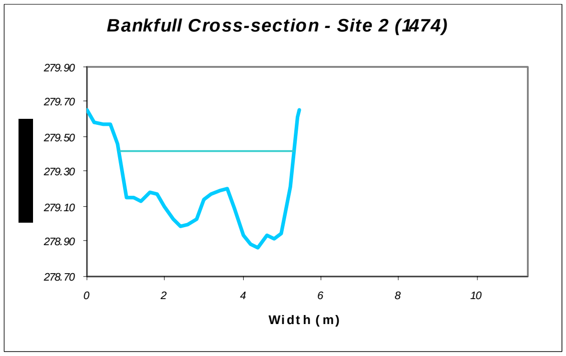

Eramosa River Above Watson Road Width/Depth Ratio Versus Flow
Width/Depth Ratio
0
10
20
30
40
50
60
70
80
90
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
106444
106432
106383
106327
106284
106204
106171
106147
106124
106117
106084
106064
106059
106025
106024

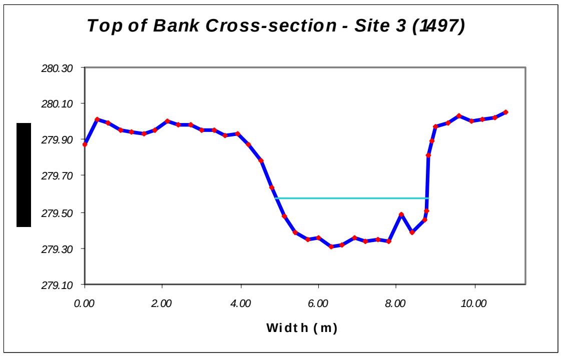
D-3: BLAIR CREEK REACH

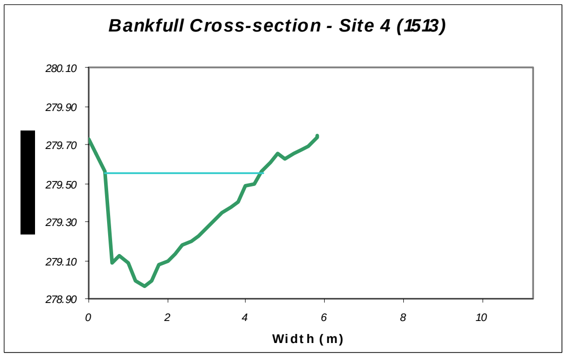


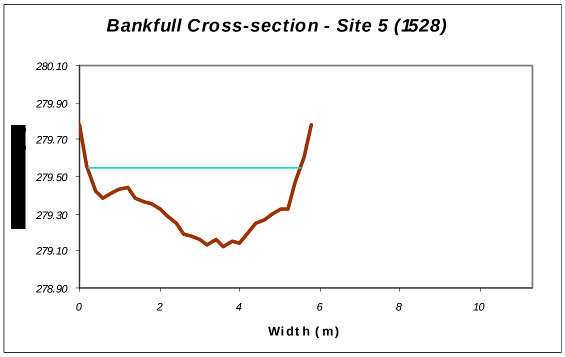


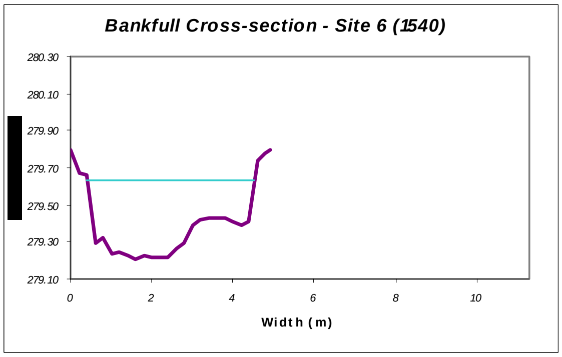

Top of Bank Cross-section - Site 1 (1435)

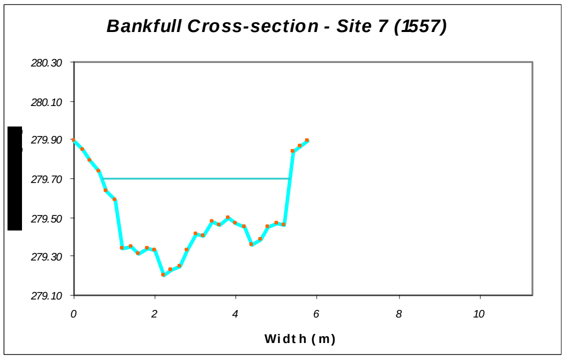

Bankfull Cross-section - Site 2 (1474)

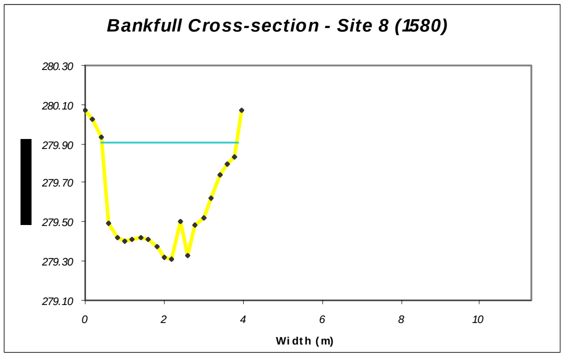

Top of Bank Cross-section - Site 3 (1497)

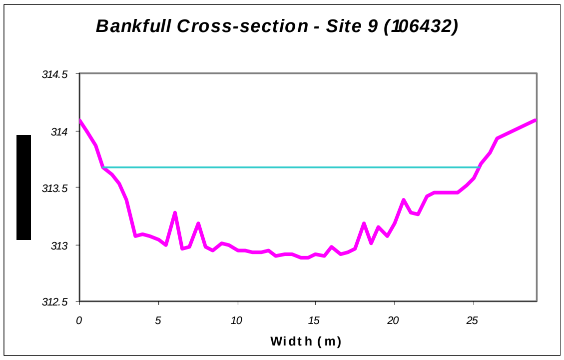

Bankfull Cross-section - Site 4 (1513)

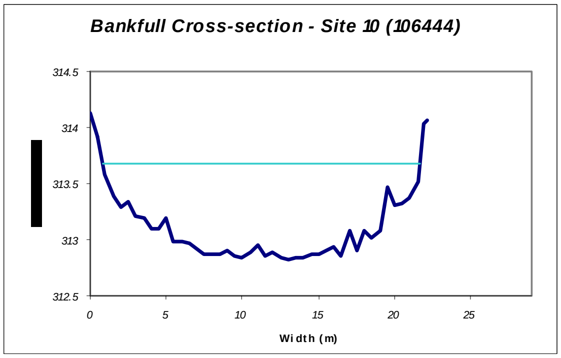

Bankfull Cross-section - Site 5 (1528)

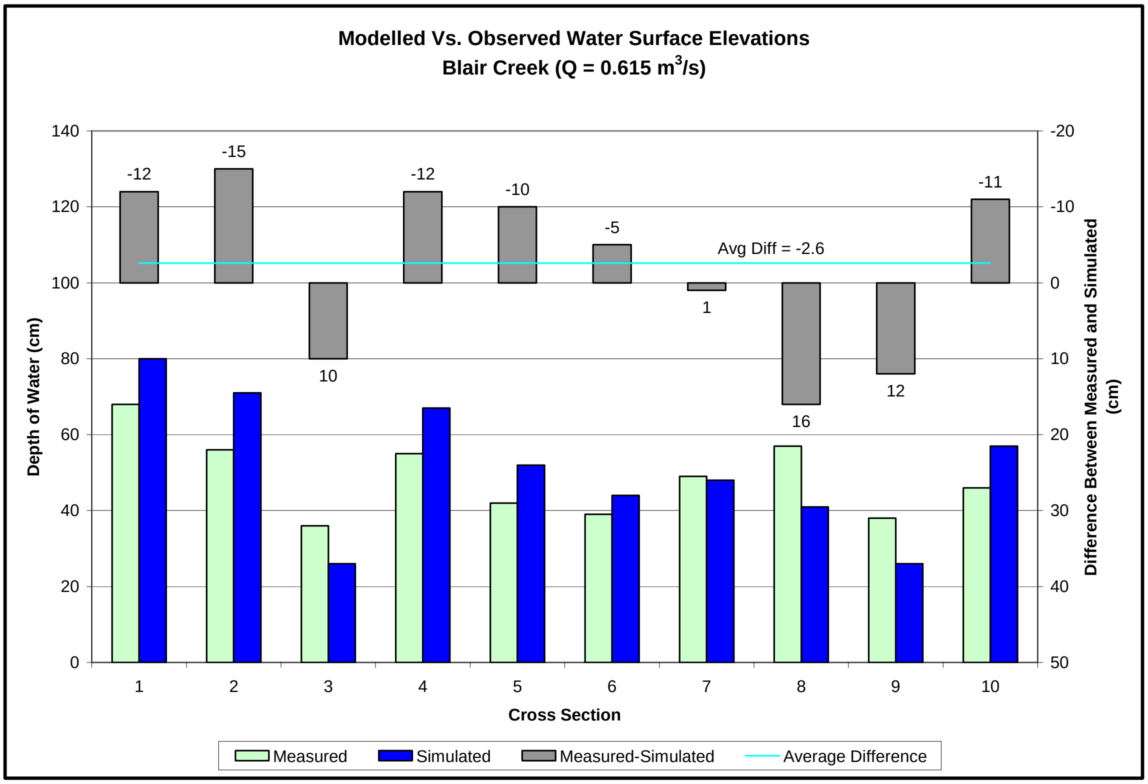

Bankfull Cross-section - Site 6 (1540)

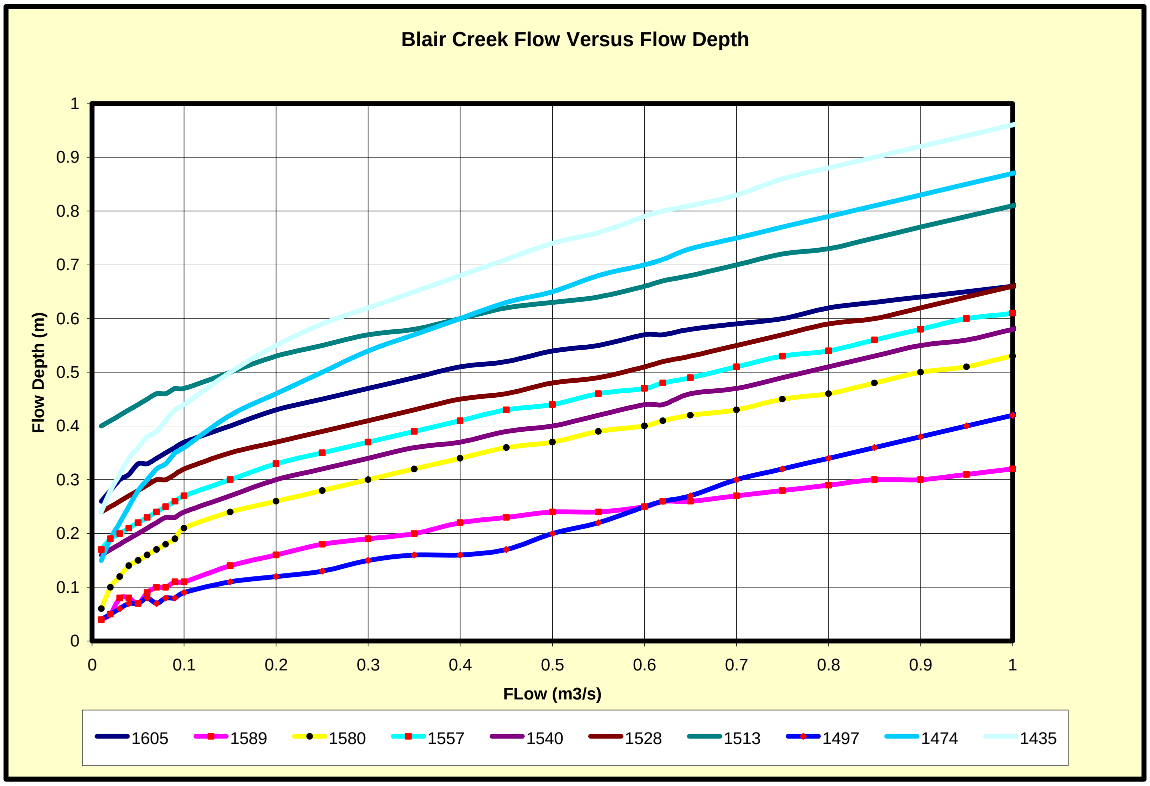

Bankfull Cross-section - Site 7 (1557)

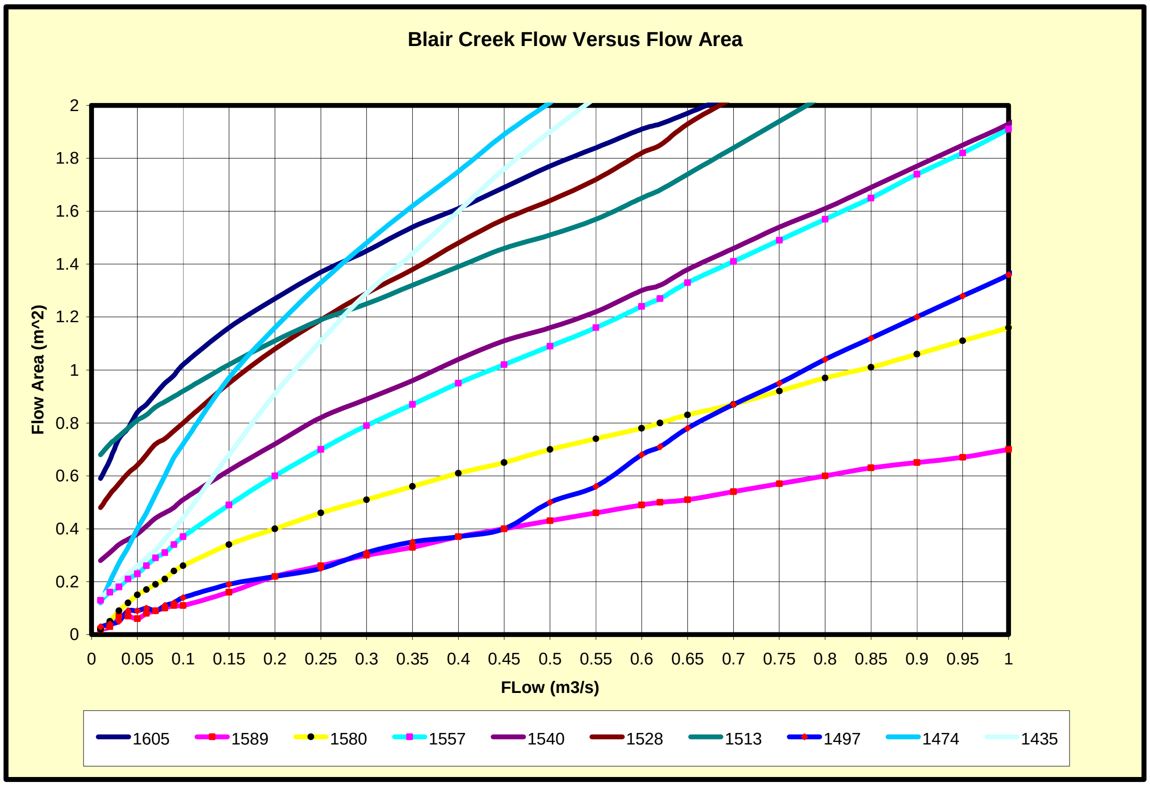

Bankfull Cross-section - Site 8 (1580)

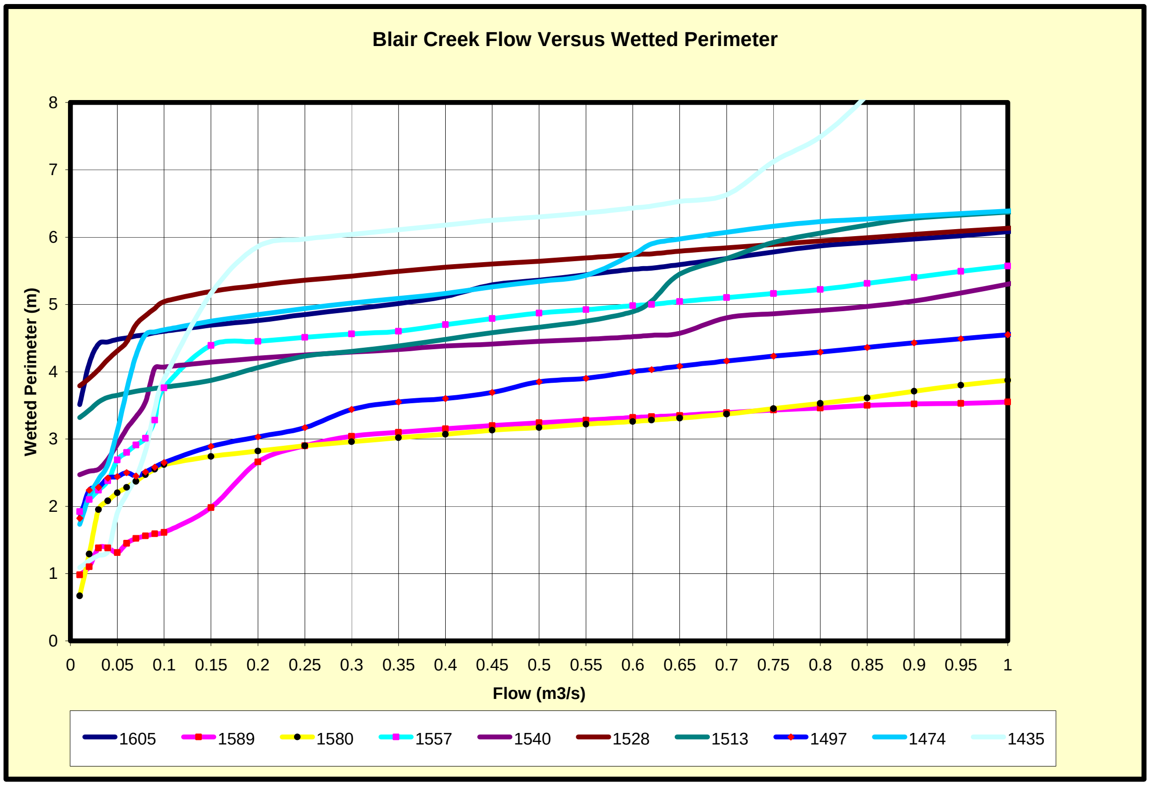

Bankfull Cross-section - Site 9 (106432)
314.5
314
313.5
313
312.5
0
5
10
15
20
25
Width (m)

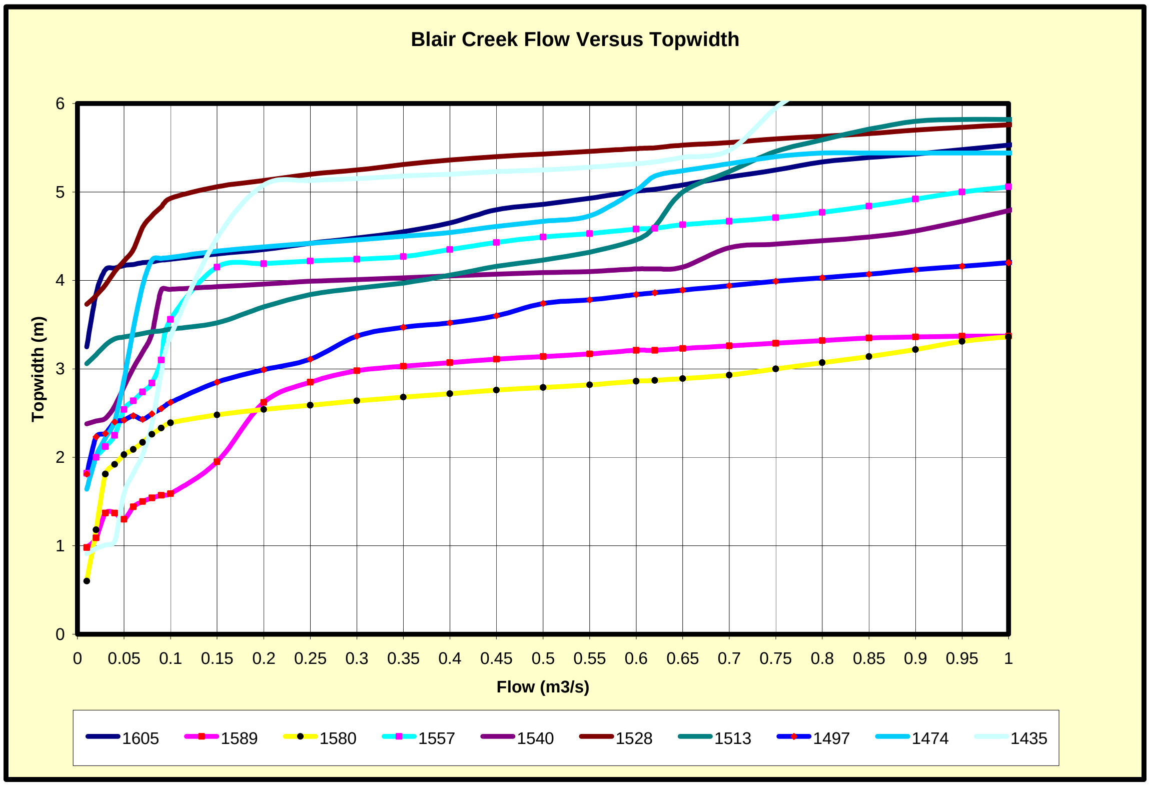

Bankfull Cross-section - Site 10 (106444)
314.5
314
313.5
313
312.5
0
5
10
15
20
25
Width (m)

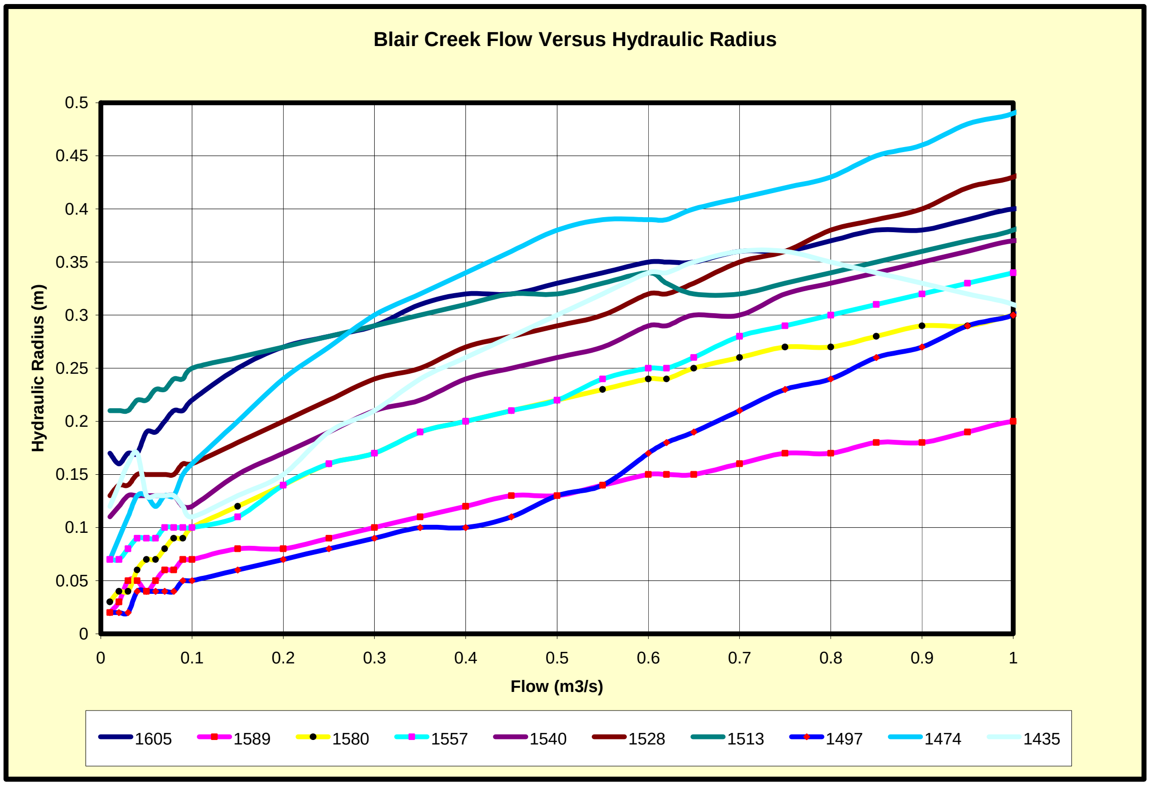

Modelled Vs. Observed Water Surface Elevations
Blair Creek (Q = 0.615 m³/s)
Depth of Water (cm)
140
120
100
80
60
40
20
0
Difference Between Measured and Simulated (cm)
-20
-10
0
10
20
30
40
50
-12
-15
10
-12
-10
-5
1
16
12
-11
Avg Diff = -2.6
1
2
3
4
5
6
7
8
9
10
Cross Section
Measured
Simulated
Measured-Simulated
Average Difference

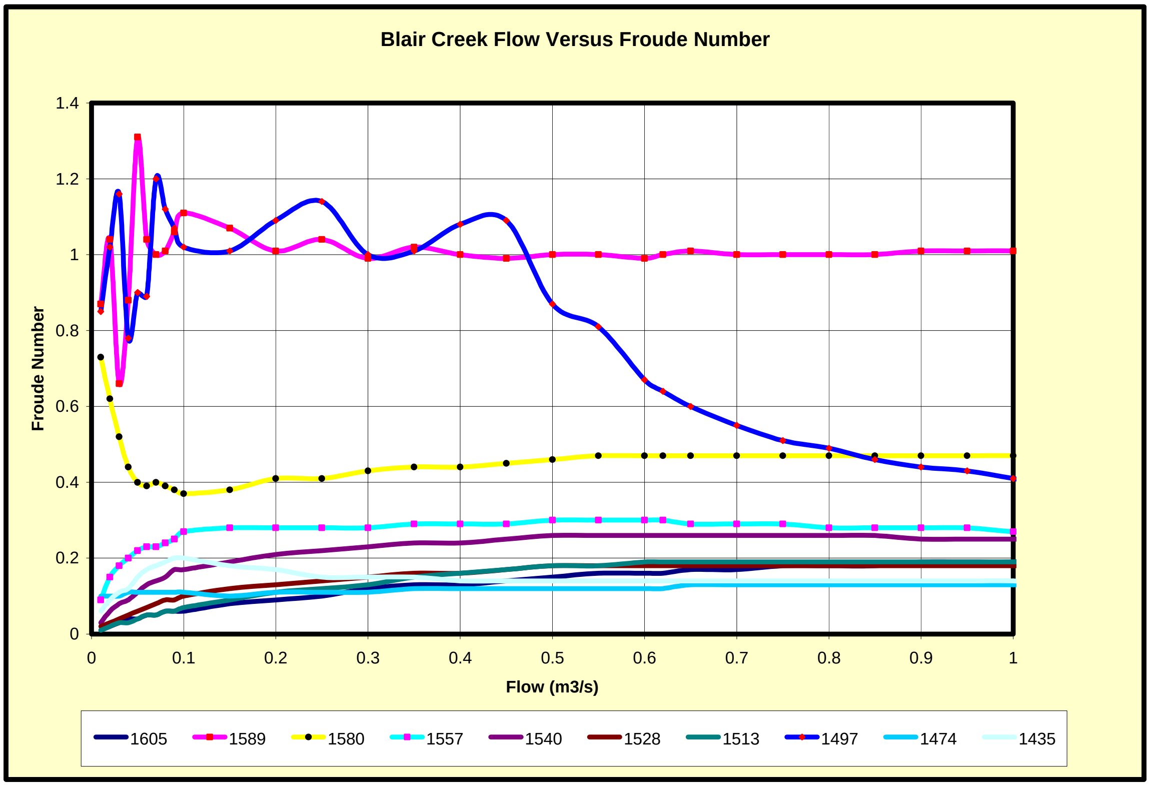

Blair Creek Flow Versus Flow Depth
Flow Depth (m)
FLow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1605
1589
1580
1557
1540
1528
1513
1497
1474
1435

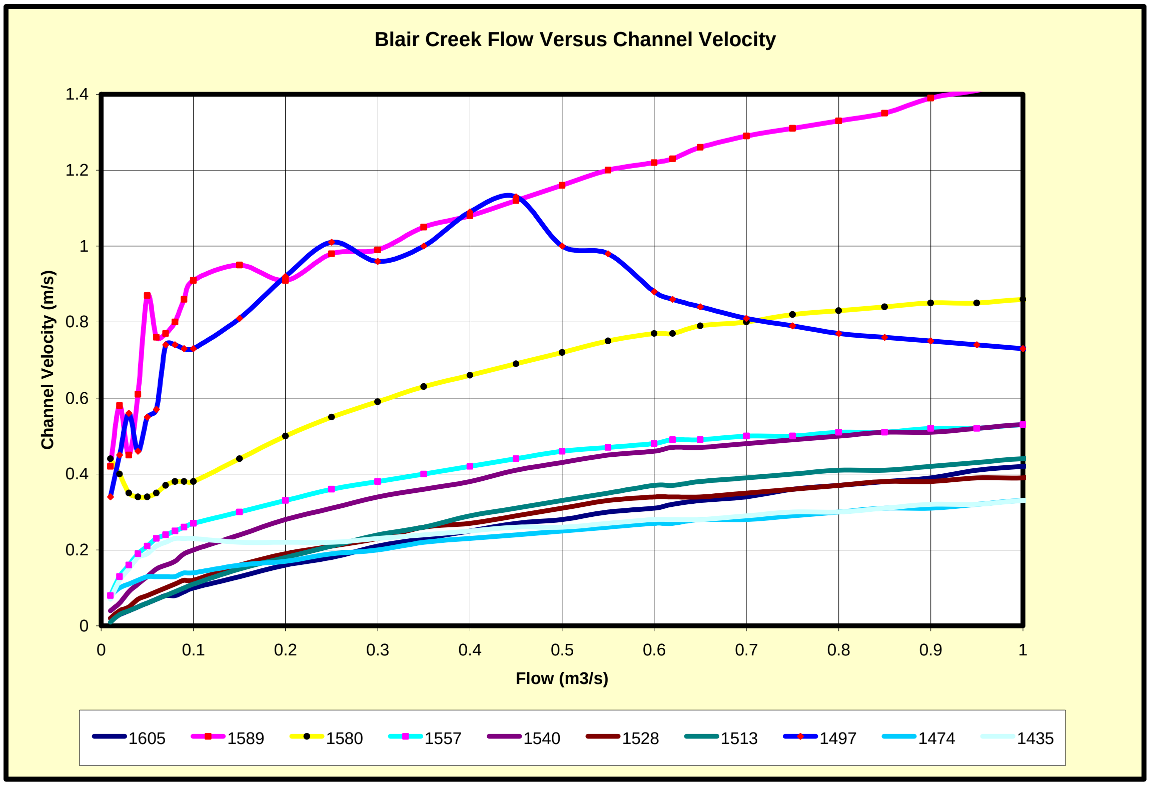

Blair Creek Flow Versus Flow Area
Flow Area (m^2)
FLow (m3/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1605
1589
1580
1557
1540
1528
1513
1497
1474
1435

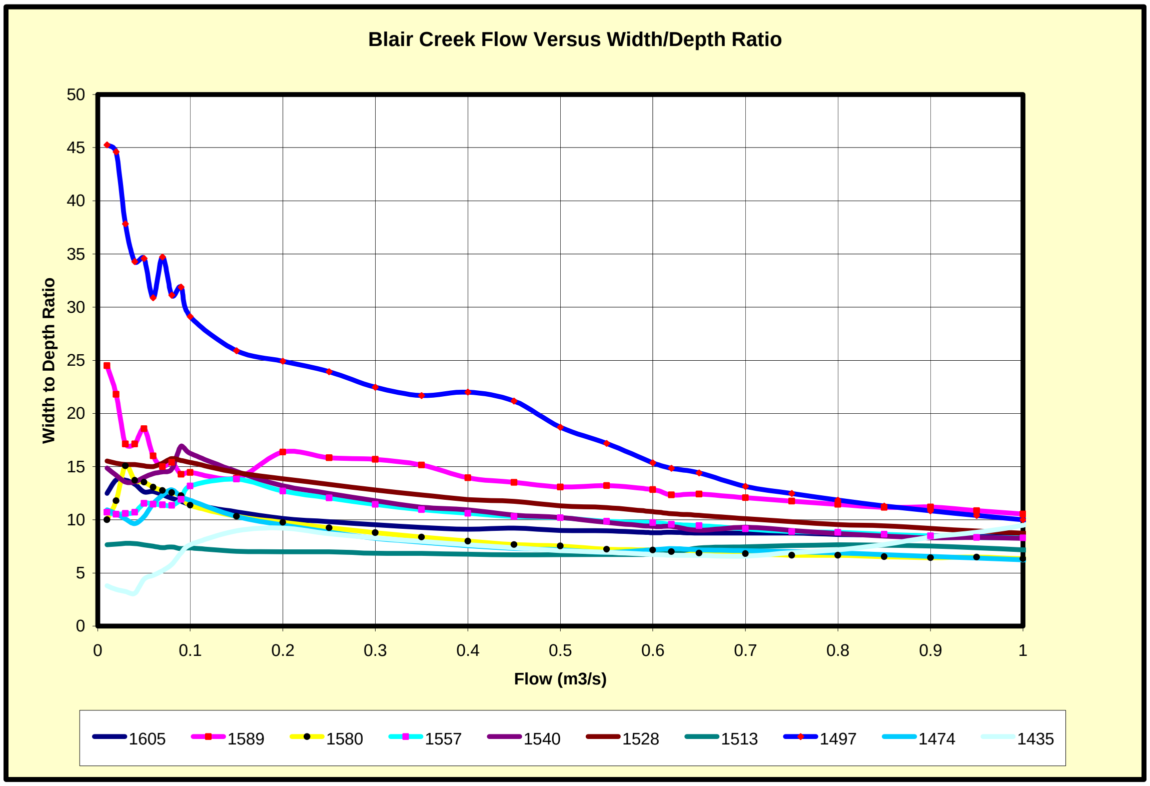

Blair Creek Flow Versus Wetted Perimeter
Wetted Perimeter (m)
0
1
2
3
4
5
6
7
8
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
Flow (m3/s)
1605
1589
1580
1557
1540
1528
1513
1497
1474
1435


Blair Creek Flow Versus Topwidth
Topwidth (m)
0
1
2
3
4
5
6
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
Flow (m3/s)
1605
1589
1580
1557
1540
1528
1513
1497
1474
1435

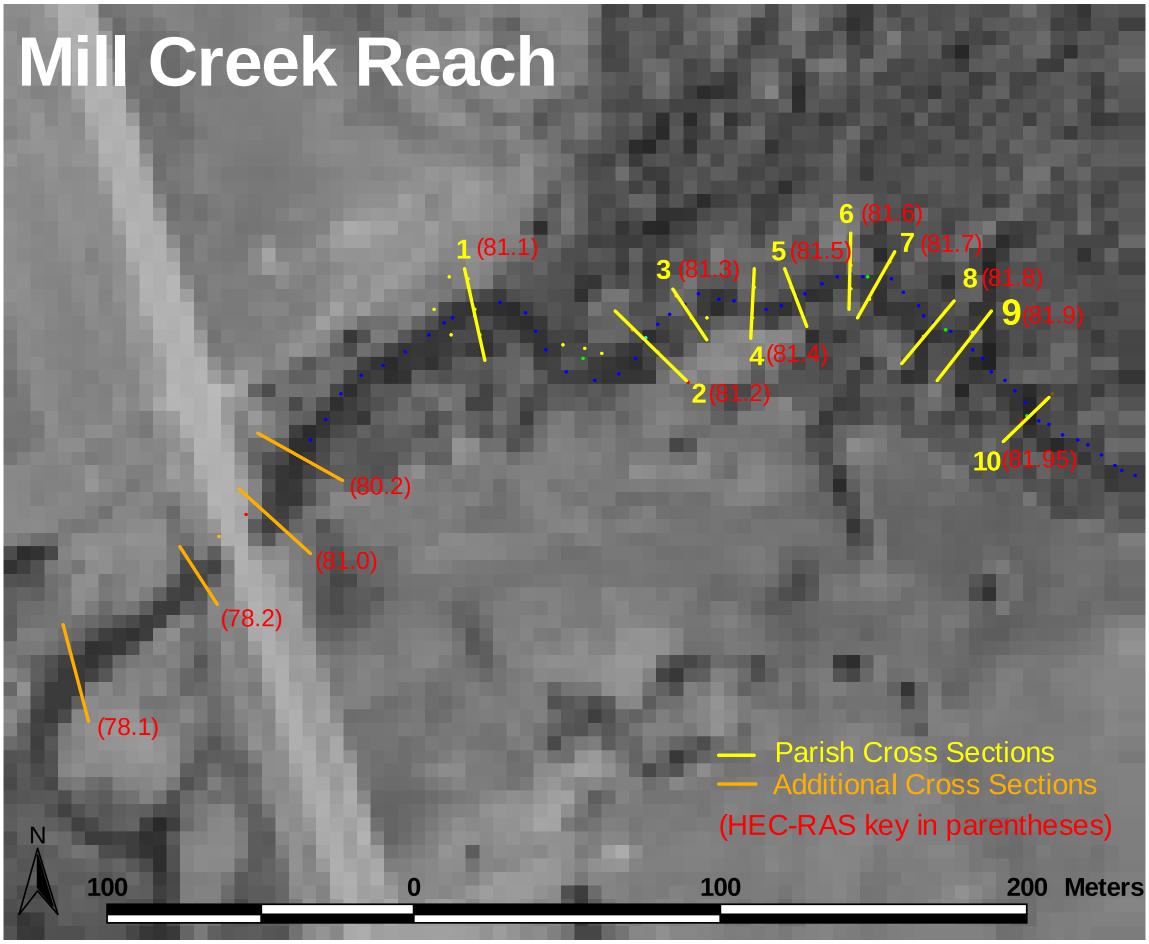

Blair Creek Flow Versus Hydraulic Radius
Hydraulic Radius (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1605
1589
1580
1557
1540
1528
1513
1497
1474
1435

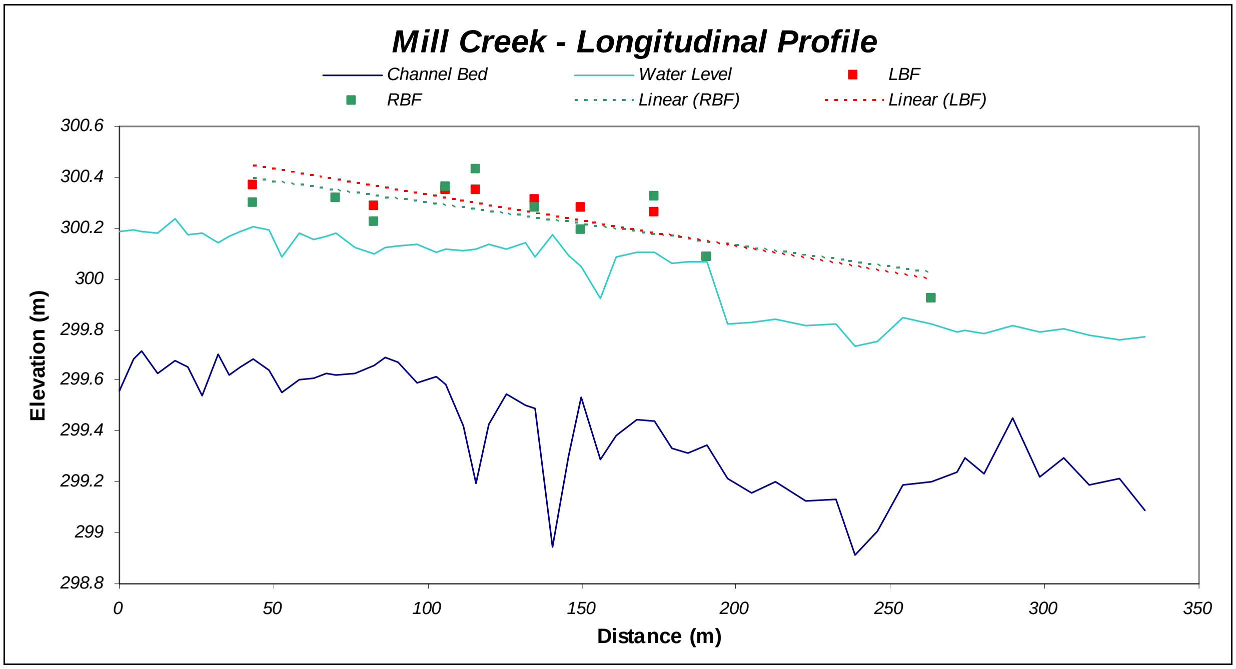

Blair Creek Flow Versus Froude Number
Froude Number
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1605
1589
1580
1557
1540
1528
1513
1497
1474
1435

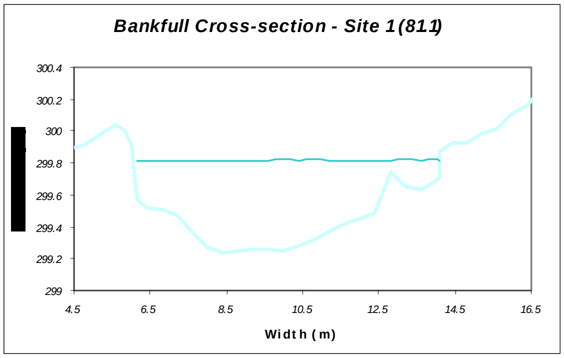

Blair Creek Flow Versus Channel Velocity
Channel Velocity (m/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1605
1589
1580
1557
1540
1528
1513
1497
1474
1435

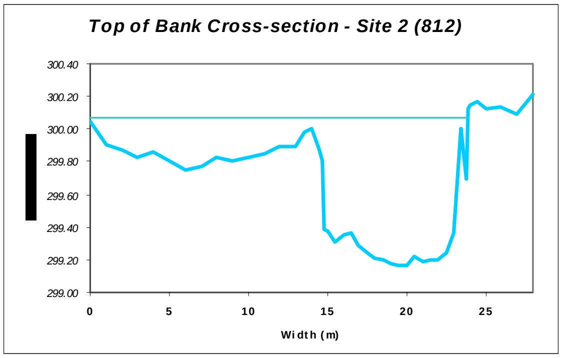

Blair Creek Flow Versus Width/Depth Ratio
Width to Depth Ratio
0
5
10
15
20
25
30
35
40
45
50
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1605
1589
1580
1557
1540
1528
1513
1497
1474
1435

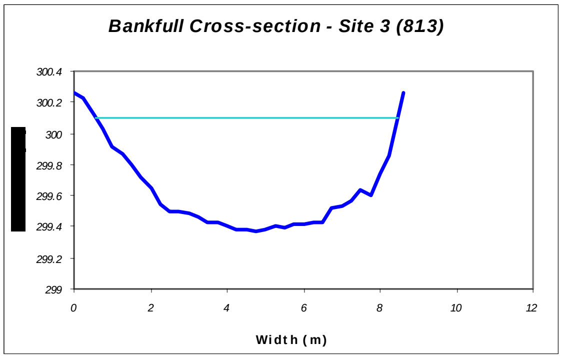
D-4: MILL CREEK

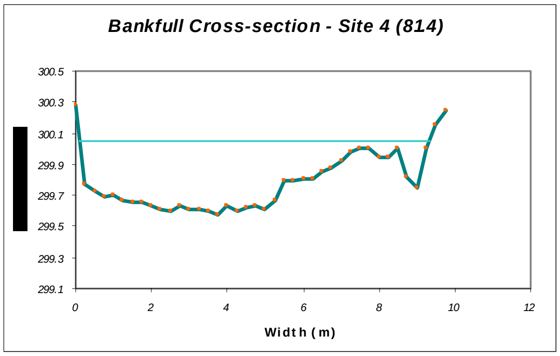


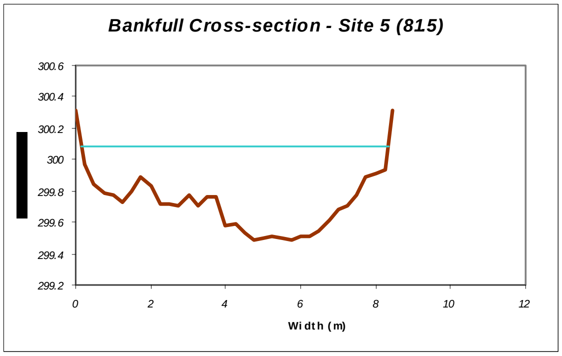


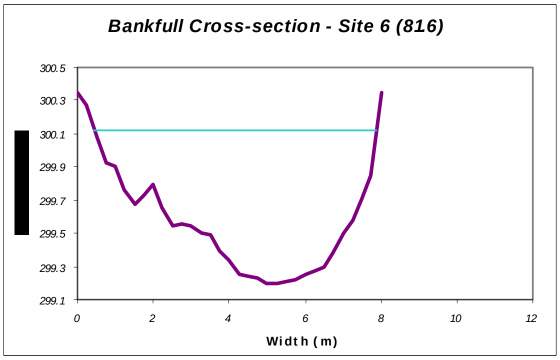

Bankfull Cross-section - Site 1 (811)
300.4
300.2
300
299.8
299.6
299.4
299.2
299
4.5
6.5
8.5
10.5
12.5
14.5
16.5
Width (m)

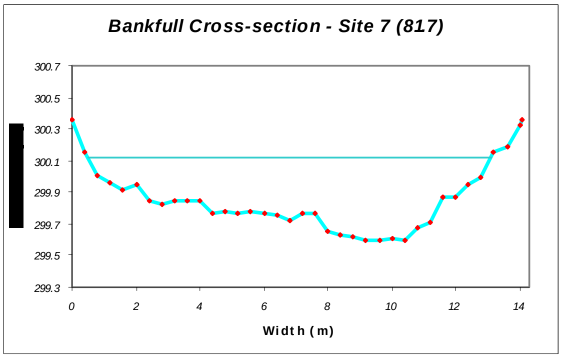

Top of Bank Cross-section - Site 2 (812)
300.40
300.20
300.00
299.80
299.60
299.40
299.20
299.00
0
5
10
15
20
25
Width (m)

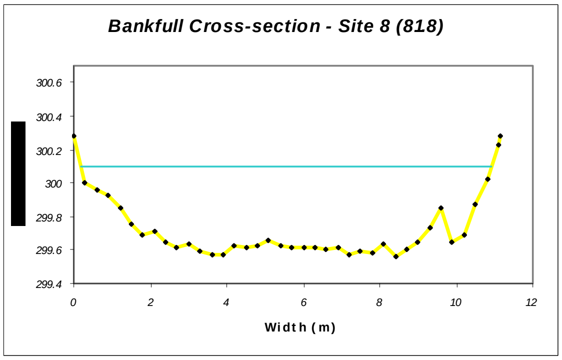

Bankfull Cross-section - Site 3 (813)
300.4
300.2
300
299.8
299.6
299.4
299.2
299
0
2
4
6
8
10
12
Width (m)

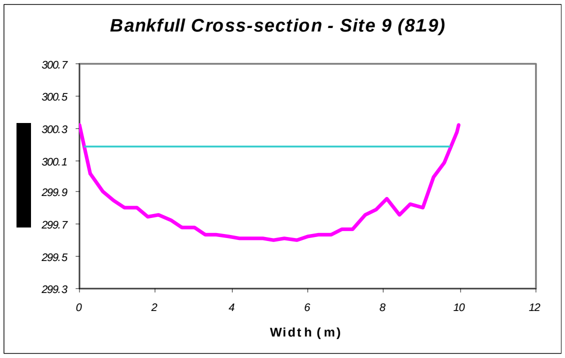

Bankfull Cross-section - Site 4 (814)
300.5
300.3
300.1
299.9
299.7
299.5
299.3
299.1
0
2
4
6
8
10
12
Width (m)

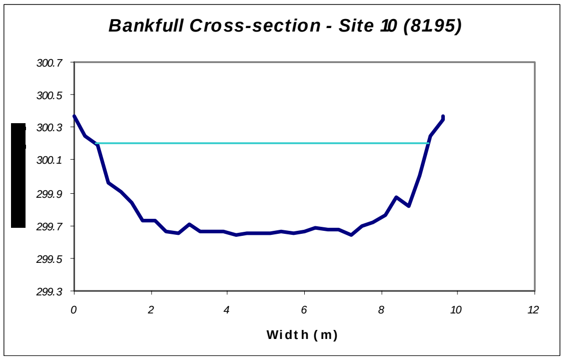

Bankfull Cross-section - Site 5 (815)
300.6
300.4
300.2
300
299.8
299.6
299.4
299.2
0
2
4
6
8
10
12
Width (m)

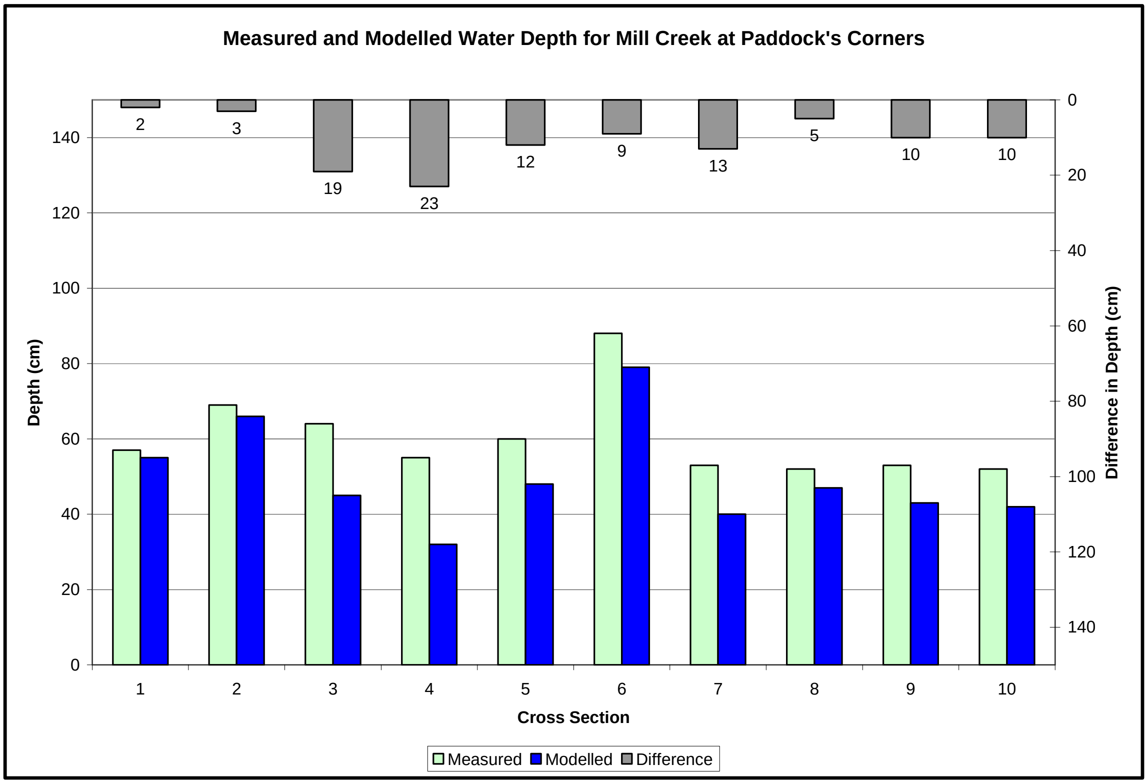

Bankfull Cross-section - Site 6 (816)
300.5
300.3
300.1
299.9
299.7
299.5
299.3
299.1
0
2
4
6
8
10
12
Width (m)

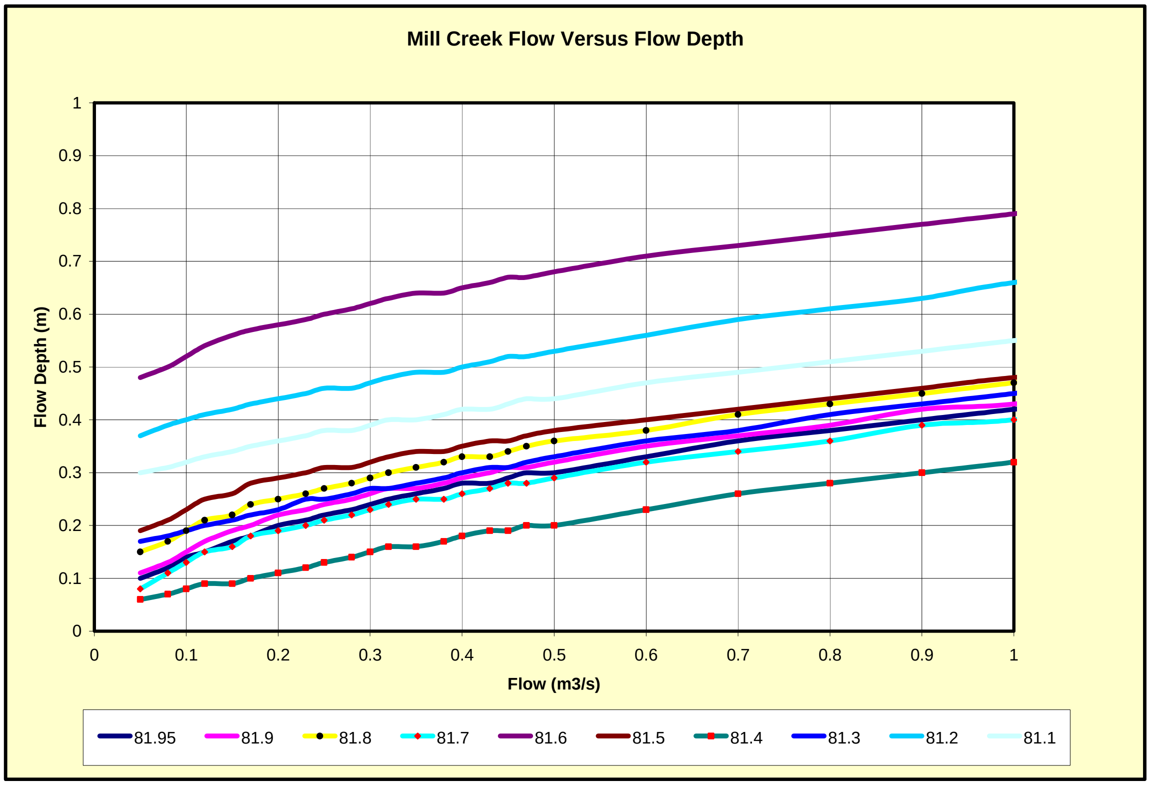

Bankfull Cross-section - Site 7 (817)
300.7
300.5
300.3
300.1
299.9
299.7
299.5
299.3
0
2
4
6
8
10
12
14
Width (m)

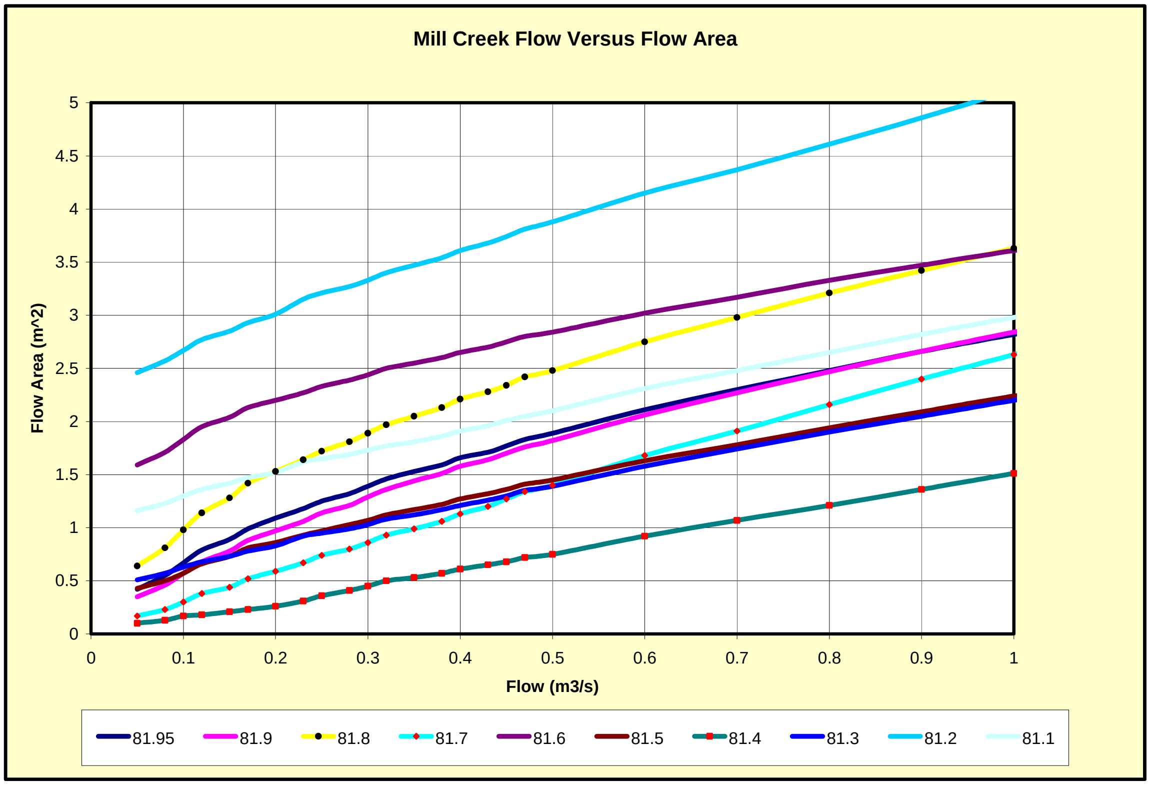

Bankfull Cross-section - Site 8 (818)
300.6
300.4
300.2
300
299.8
299.6
299.4
0
2
4
6
8
10
12
Width (m)

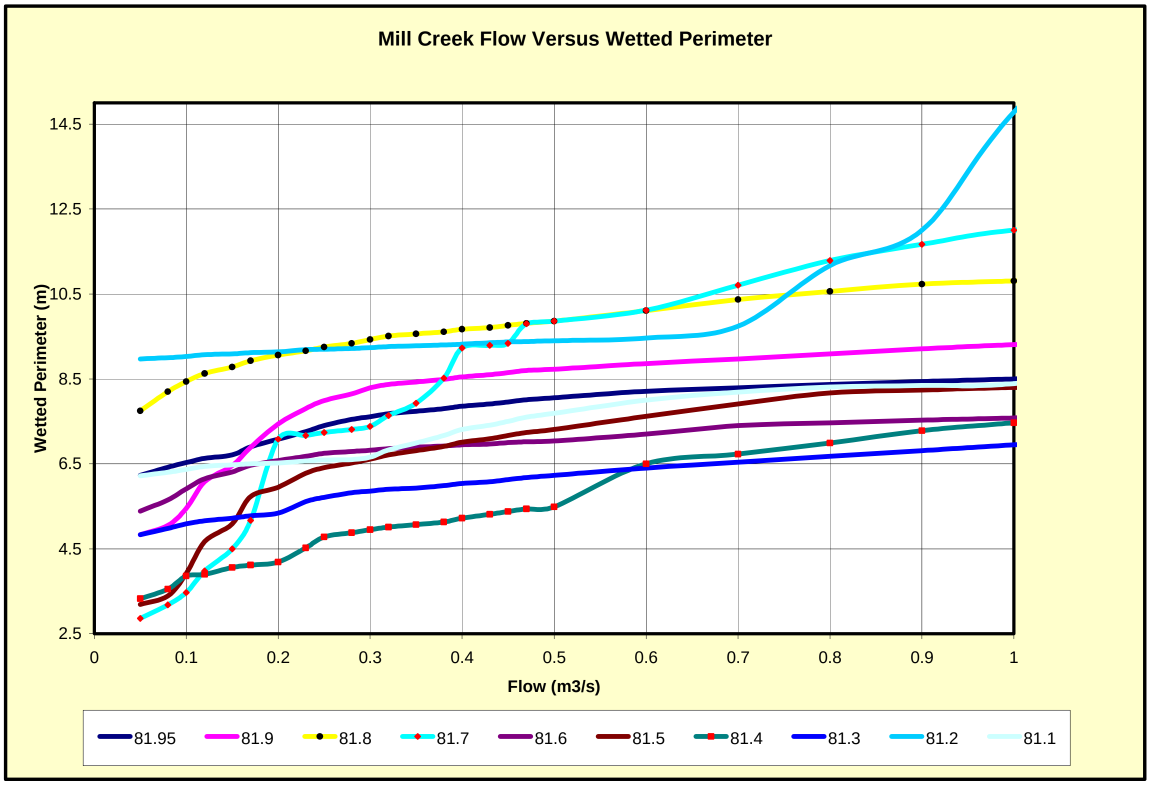

Bankfull Cross-section - Site 9 (819)
[redacted]
300.7
300.5
300.3
300.1
299.9
299.7
299.5
299.3
0
2
4
6
8
10
12
Width (m)

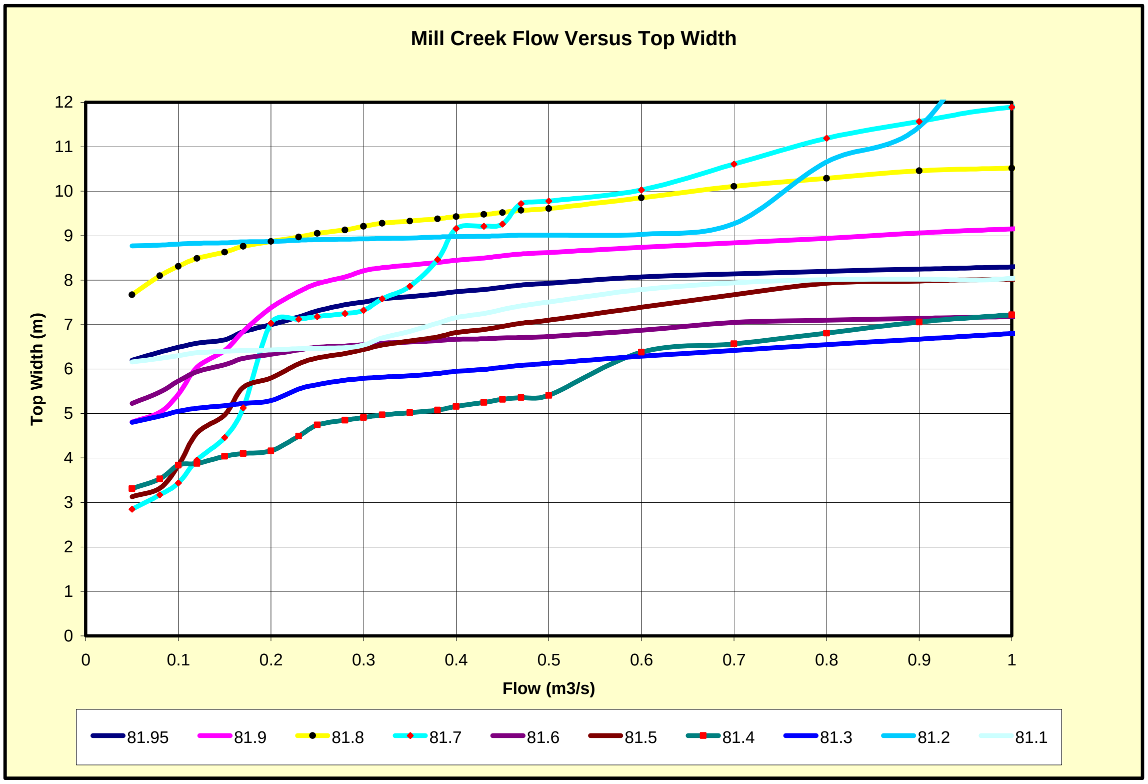

Bankfull Cross-section - Site 10 (8195)
[redacted]
300.7
300.5
300.3
300.1
299.9
299.7
299.5
299.3
0
2
4
6
8
10
12
Width (m)

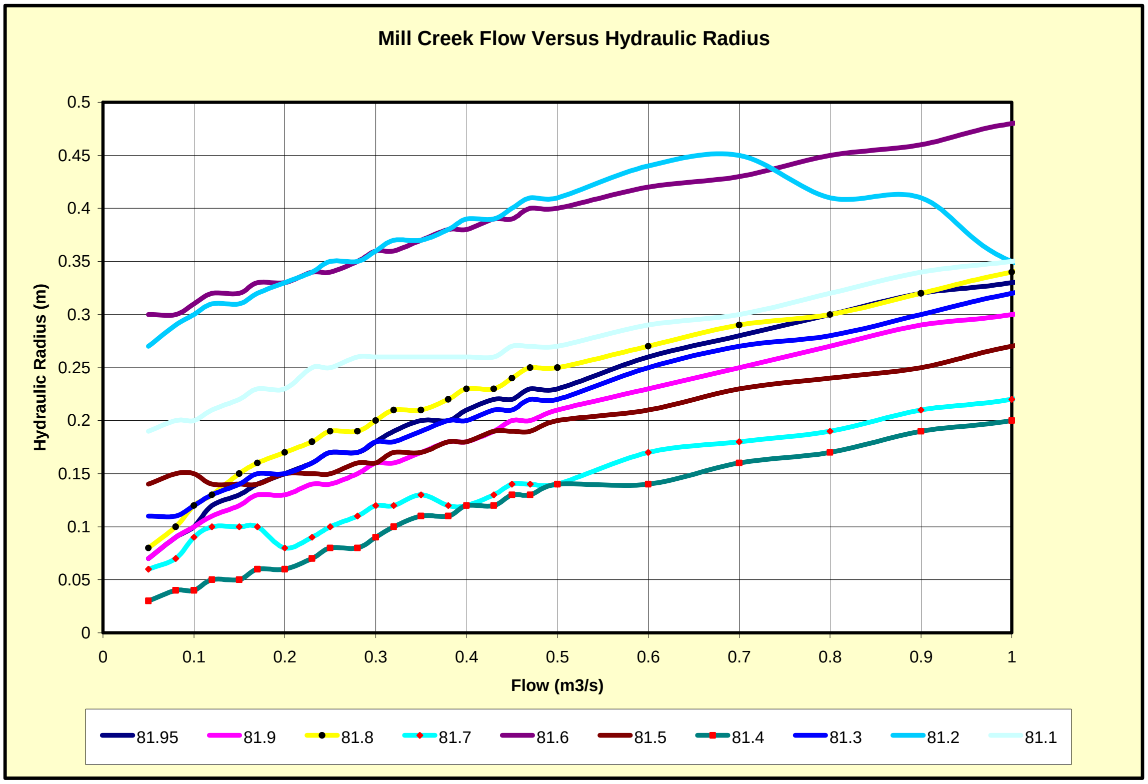

Measured and Modelled Water Depth for Mill Creek at Paddock's Corners
Depth (cm)
140
120
100
80
60
40
20
0
Difference in Depth (cm)
0
20
40
60
80
100
120
140
2
3
19
23
12
9
13
5
10
10
1
2
3
4
5
6
7
8
9
10
Cross Section
Measured
Modelled
Difference

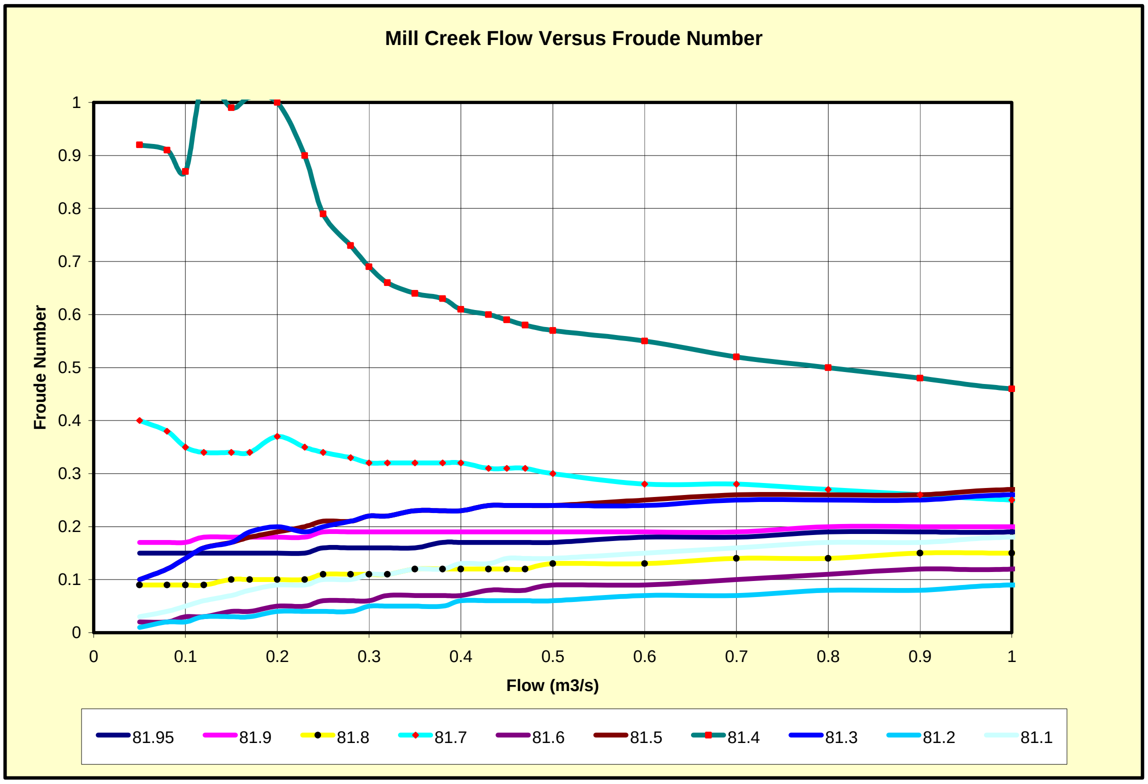

Mill Creek Flow Versus Flow Depth
Flow Depth (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
81.95
81.9
81.8
81.7
81.6
81.5
81.4
81.3
81.2
81.1

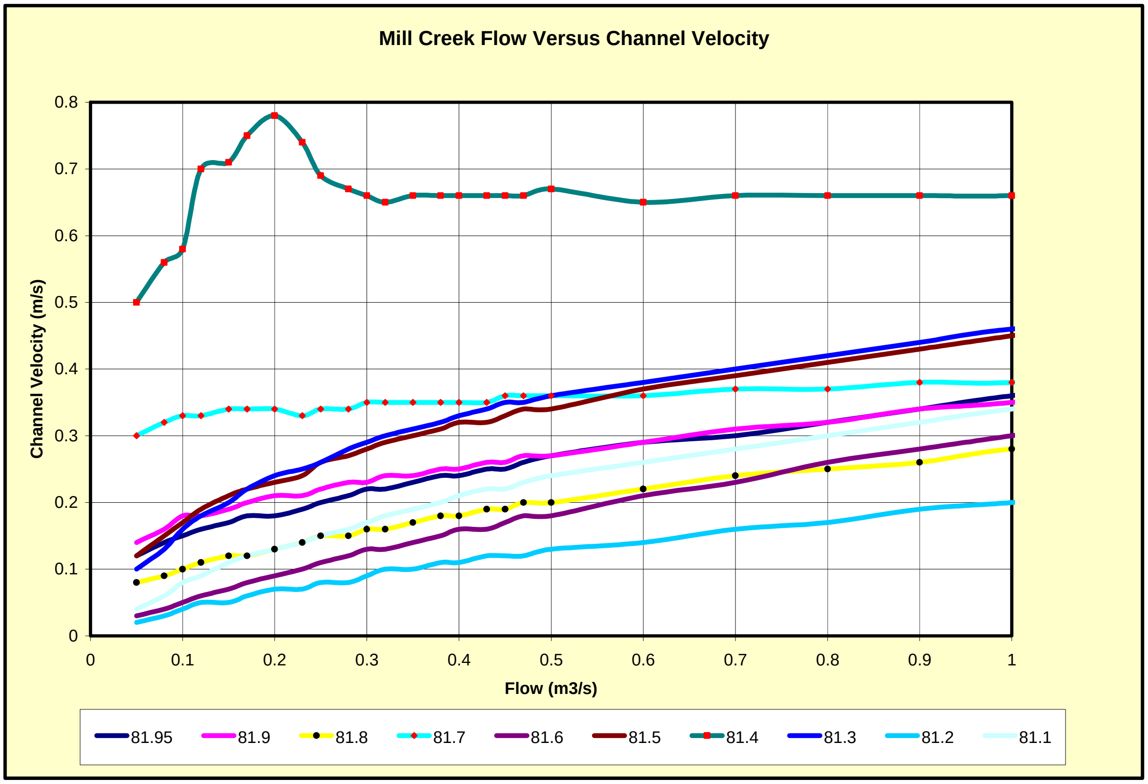

Mill Creek Flow Versus Flow Area
Flow Area (m^2)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
81.95
81.9
81.8
81.7
81.6
81.5
81.4
81.3
81.2
81.1

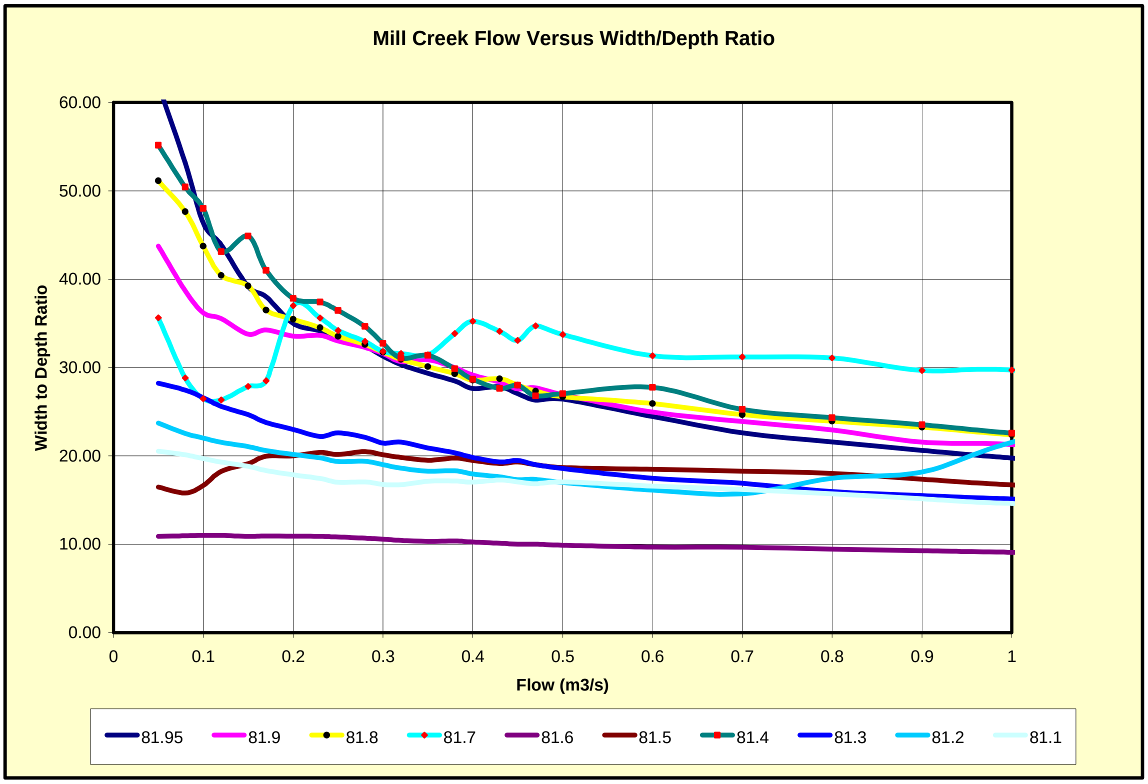

Mill Creek Flow Versus Wetted Perimeter
Wetted Perimeter (m)
14.5
12.5
10.5
8.5
6.5
4.5
2.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow (m3/s)
81.95
81.9
81.8
81.7
81.6
81.5
81.4
81.3
81.2
81.1


Mill Creek Flow Versus Top Width
Top Width (m)
12
11
10
9
8
7
6
5
4
3
2
1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow (m3/s)
81.95
81.9
81.8
81.7
81.6
81.5
81.4
81.3
81.2
81.1

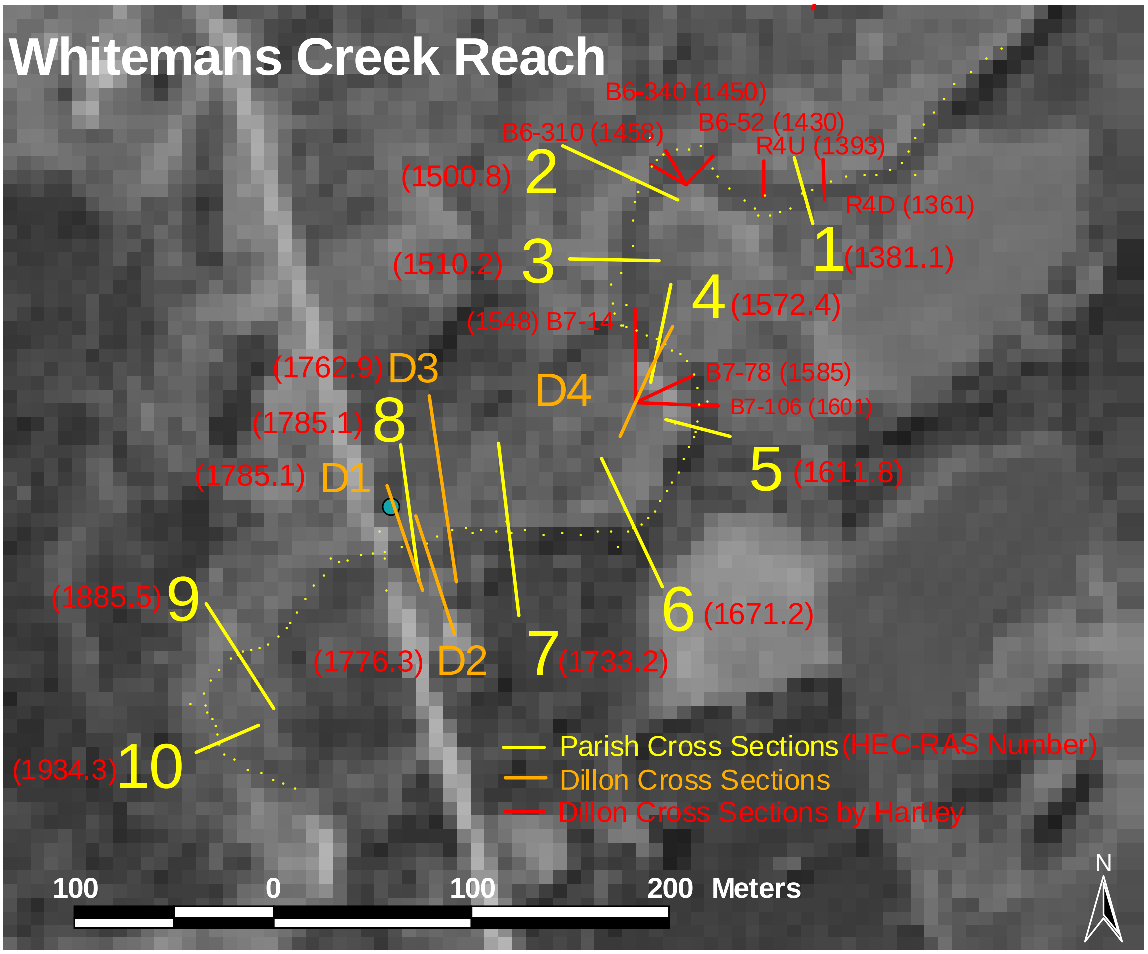

Mill Creek Flow Versus Hydraulic Radius
Hydraulic Radius (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
81.95
81.9
81.8
81.7
81.6
81.5
81.4
81.3
81.2
81.1

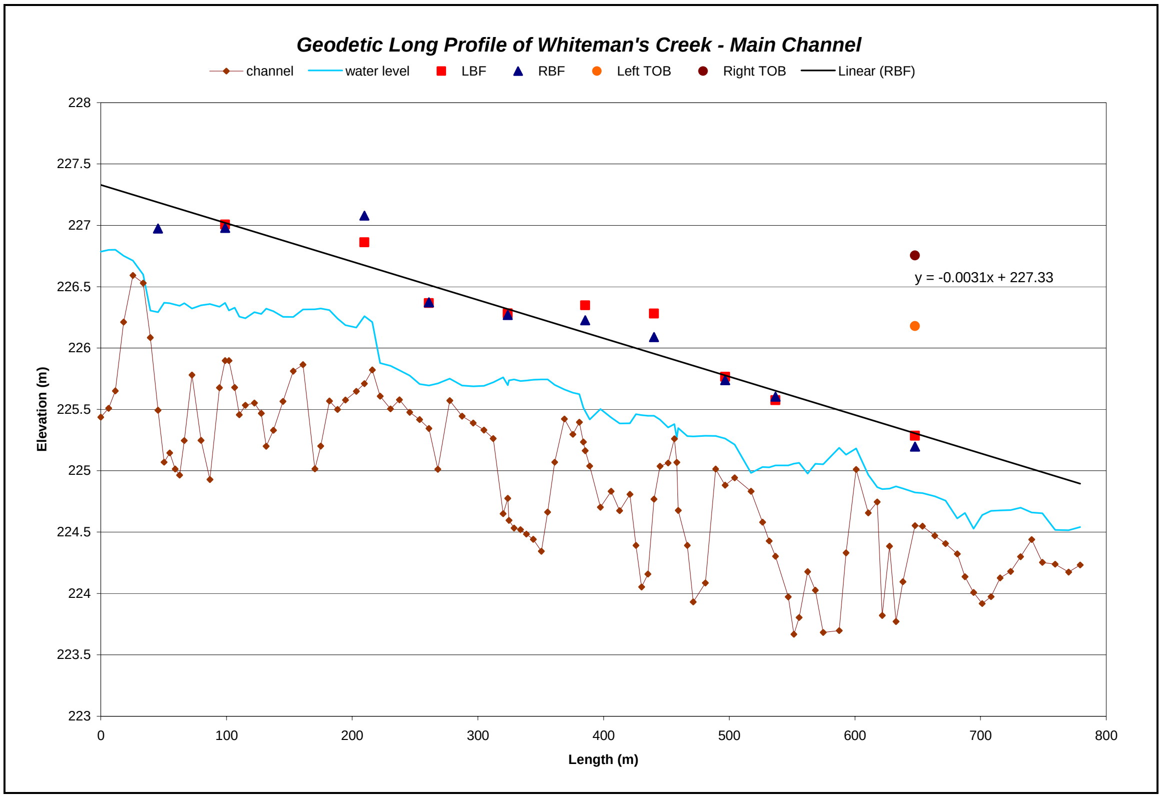

Mill Creek Flow Versus Froude Number
Froude Number
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
81.95
81.9
81.8
81.7
81.6
81.5
81.4
81.3
81.2
81.1

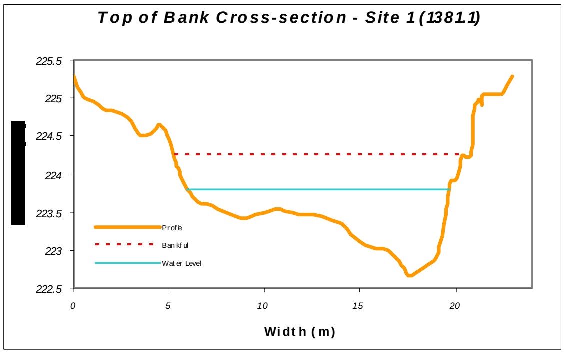

Mill Creek Flow Versus Channel Velocity
Channel Velocity (m/s)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow (m3/s)
81.95
81.9
81.8
81.7
81.6
81.5
81.4
81.3
81.2
81.1

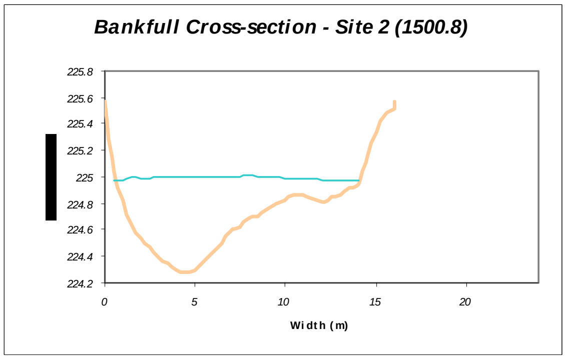

Mill Creek Flow Versus Width/Depth Ratio
Width to Depth Ratio
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Flow (m3/s)
81.95
81.9
81.8
81.7
81.6
81.5
81.4
81.3
81.2
81.1

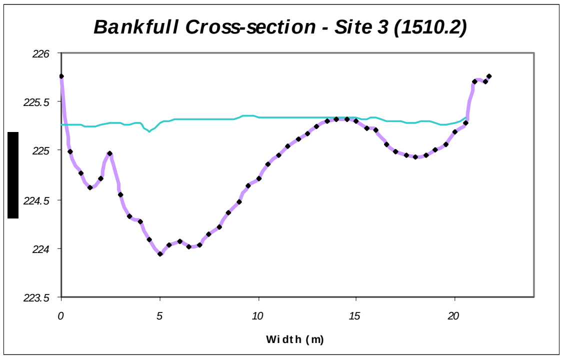
D-5: WHITEMANS CREEK

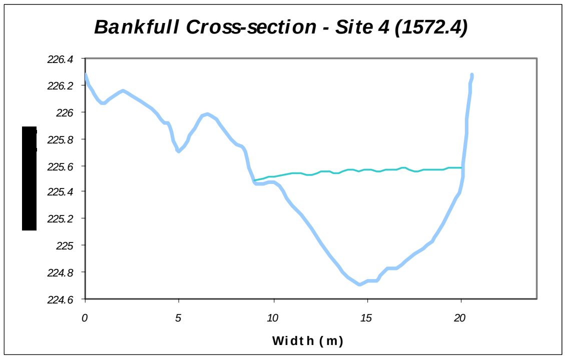


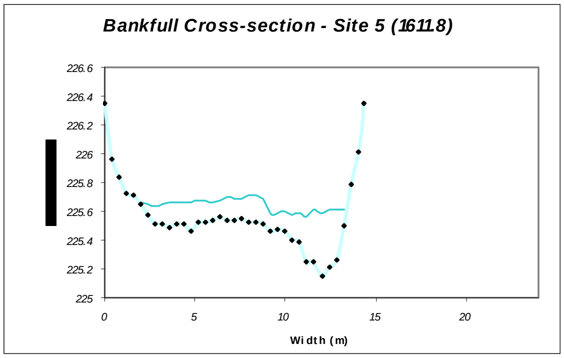

Geodetic Long Profile of Whiteman's Creek - Main Channel
channel
water level
LBF
RBF
Left TOB
Right TOB
Linear (RBF)
y = -0.0031x + 227.33
Elevation (m)
228
227.5
227
226.5
226
225.5
225
224.5
224
223.5
223
Length (m)
0
100
200
300
400
500
600
700
800

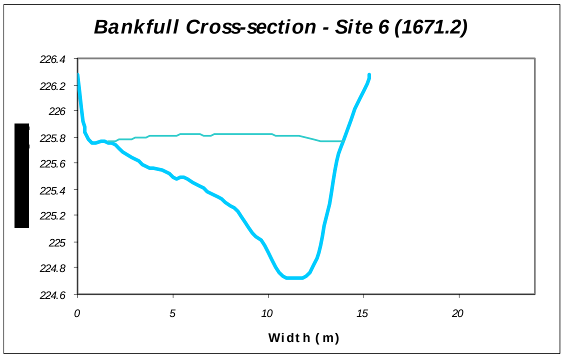

Top of Bank Cross-section - Site 1 (1381.1)
225.5
225
224.5
224
223.5
223
222.5
Profile
Bankfull
Water Level
0
5
10
15
20
Width (m)

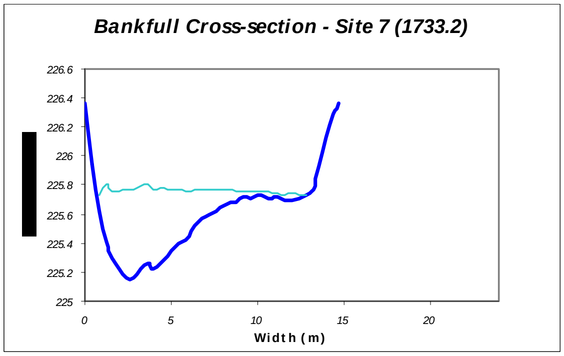

Bankfull Cross-section - Site 2 (1500.8)
225.8
225.6
225.4
225.2
225
224.8
224.6
224.4
224.2
0
5
10
15
20
Width (m)

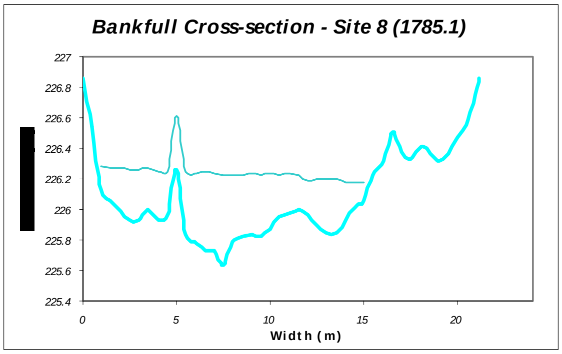

Bankfull Cross-section - Site 3 (1510.2)
226
225.5
225
224.5
224
223.5
0
5
10
15
20
Width (m)

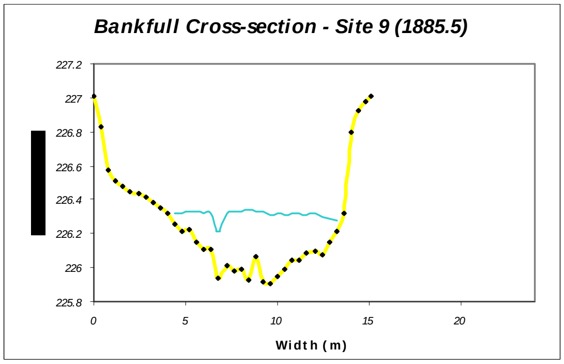

Bankfull Cross-section - Site 4 (1572.4)
226.4
226.2
226
225.8
225.6
225.4
225.2
225
224.8
224.6
0
5
10
15
20
Width (m)

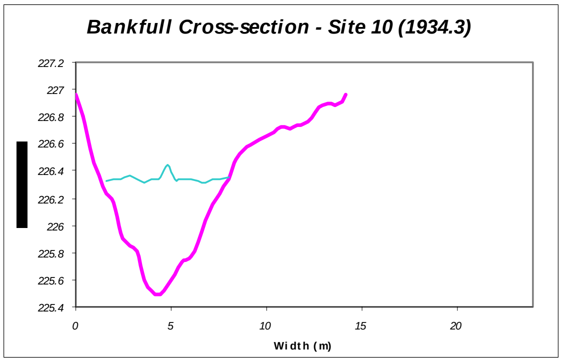

Bankfull Cross-section - Site 5 (1611.8)

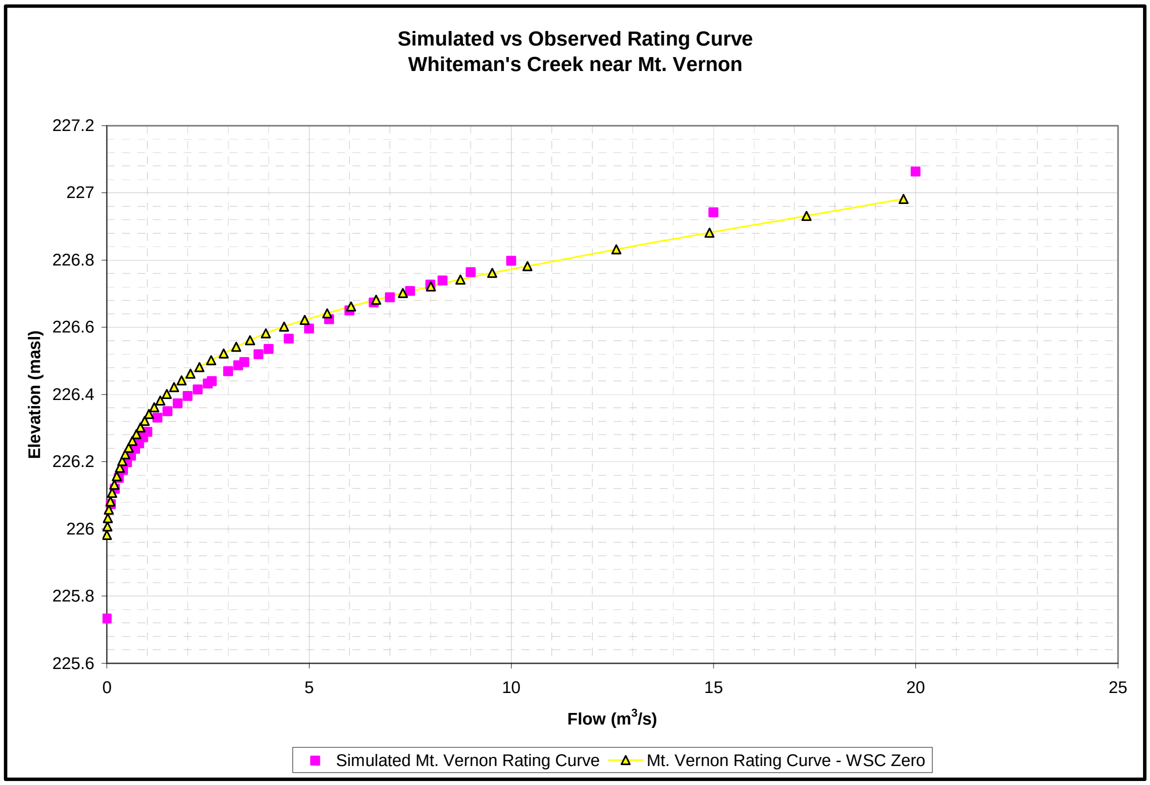

Bankfull Cross-section - Site 6 (1671.2)

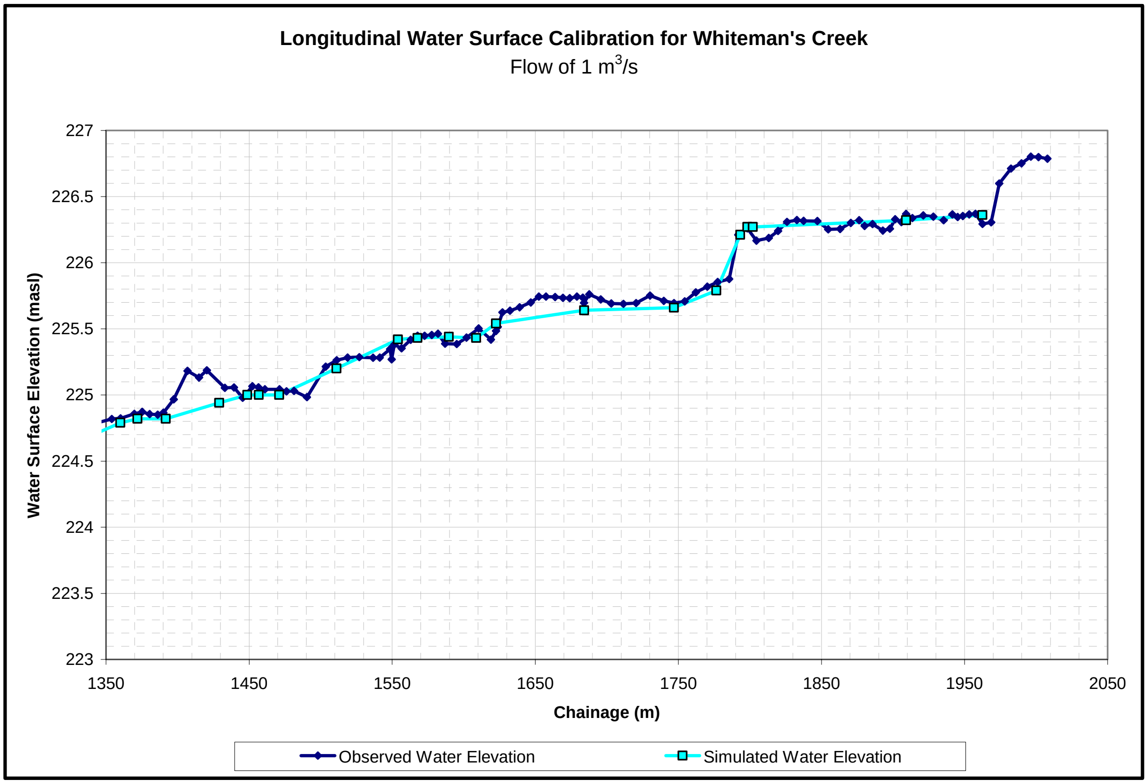

Bankfull Cross-section - Site 7 (1733.2)

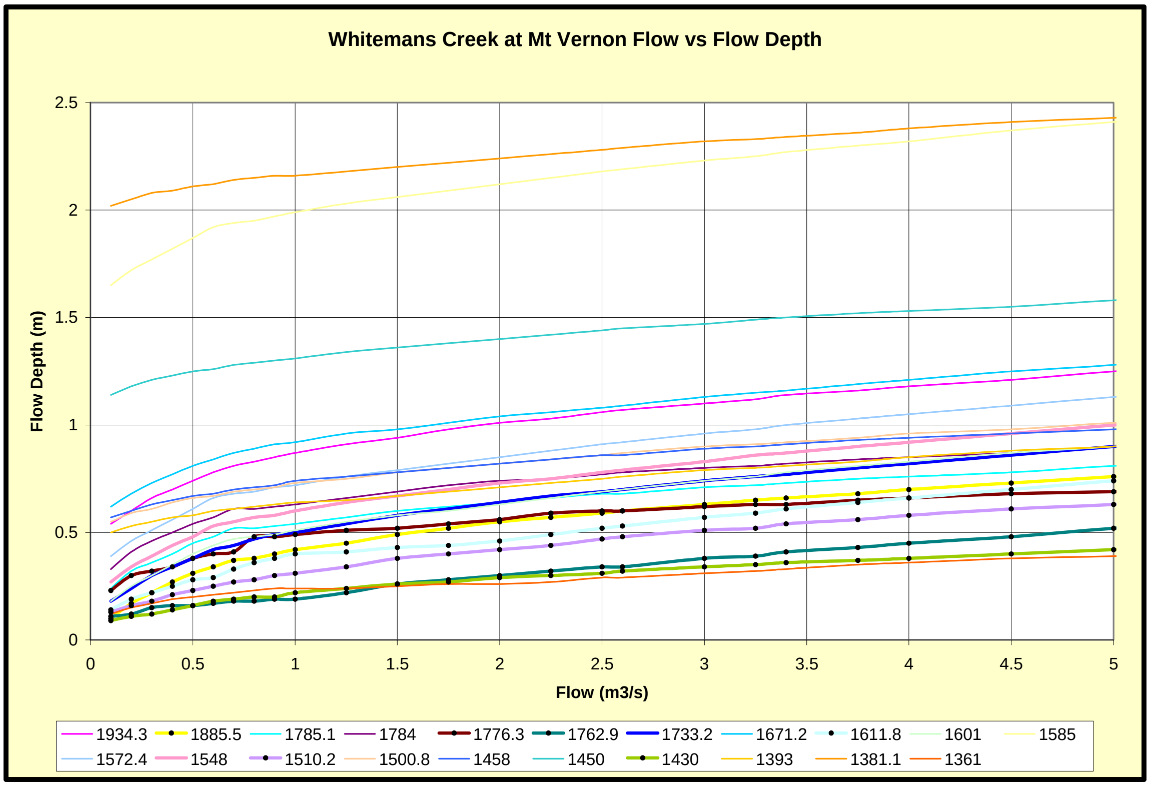

Bankfull Cross-section - Site 8 (1785.1)

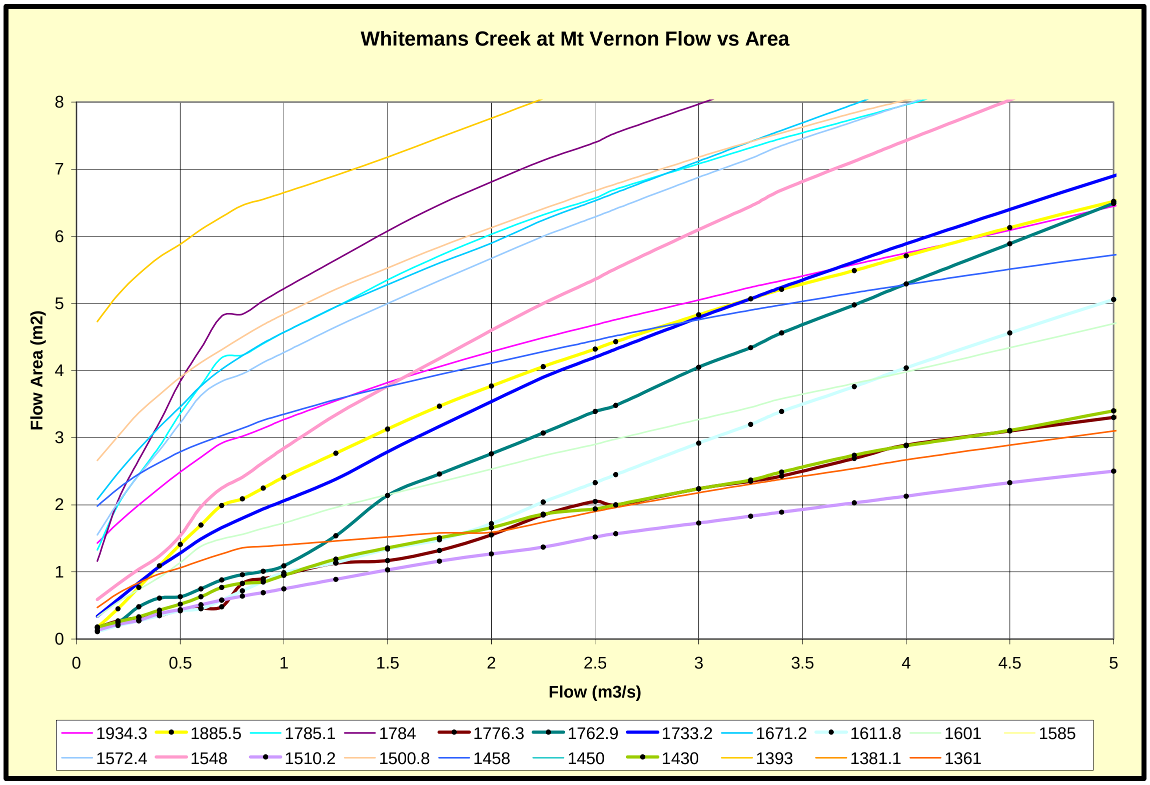

Bankfull Cross-section - Site 9 (1885.5)

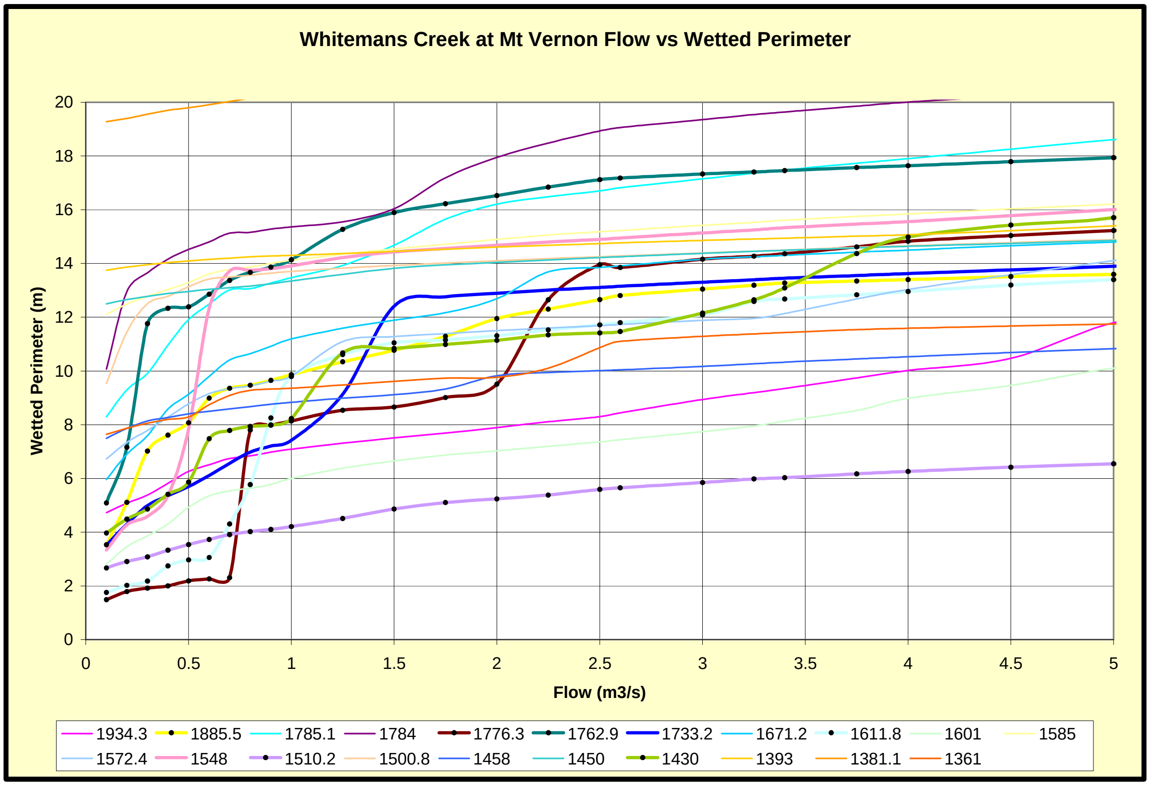

Bankfull Cross-section - Site 10 (1934.3)

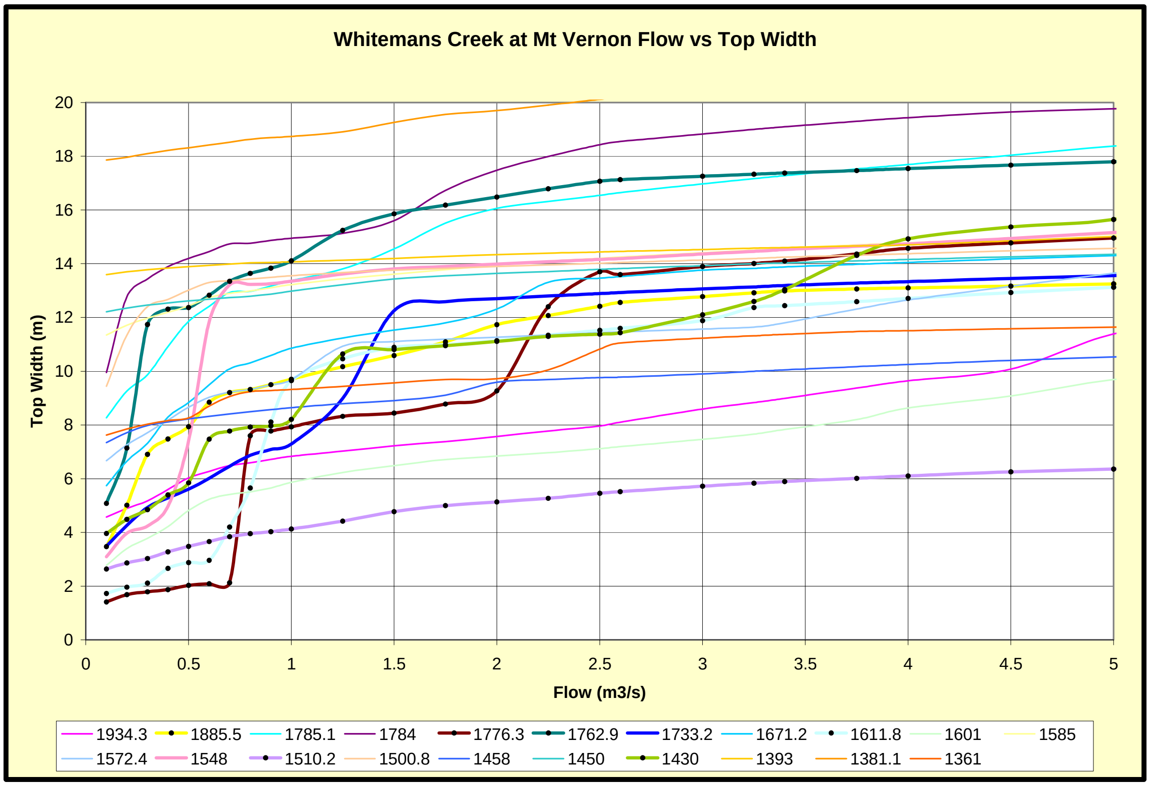

Simulated vs Observed Rating Curve
Whiteman's Creek near Mt. Vernon
Elevation (masl)
227.2
227
226.8
226.6
226.4
226.2
226
225.8
225.6
0
5
10
15
20
25
Flow (m3/s)
Simulated Mt. Vernon Rating Curve
Mt. Vernon Rating Curve - WSC Zero

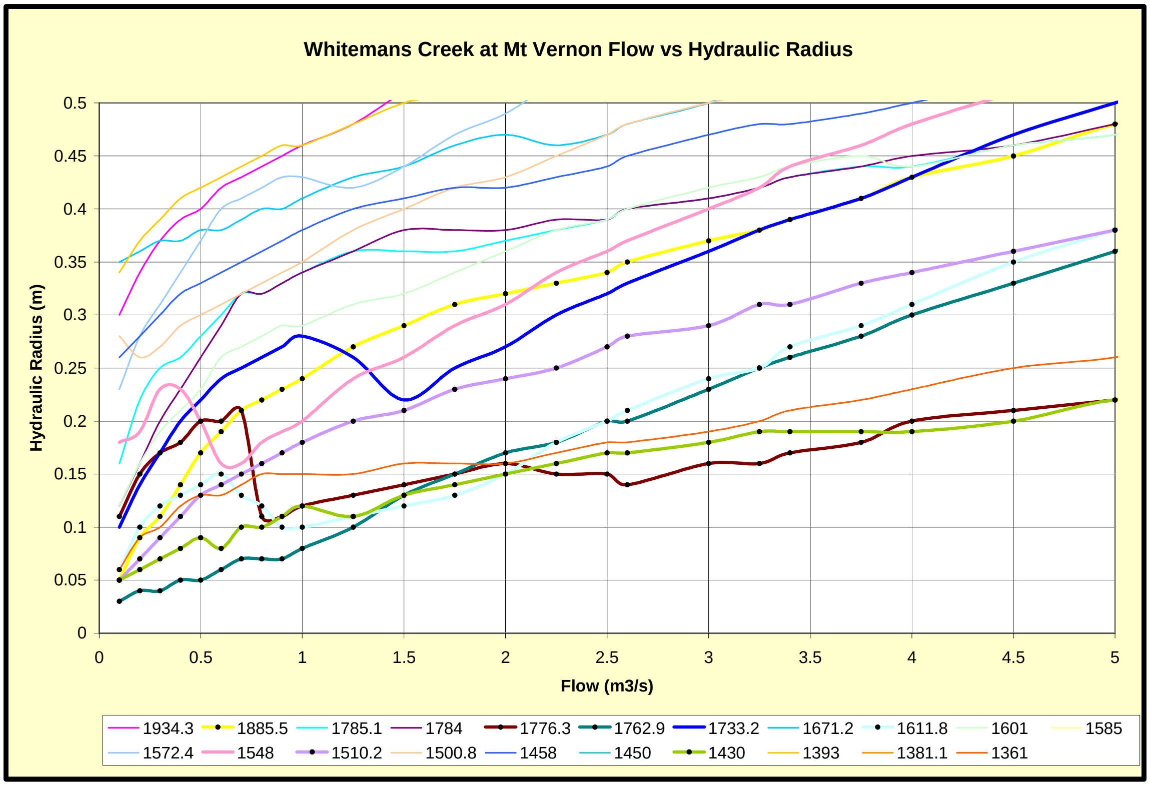

Longitudinal Water Surface Calibration for Whiteman's Creek
Flow of 1 m3/s
Water Surface Elevation (masl)
227
226.5
226
225.5
225
224.5
224
223.5
223
1350
1450
1550
1650
1750
1850
1950
2050
Chainage (m)
Observed Water Elevation
Simulated Water Elevation

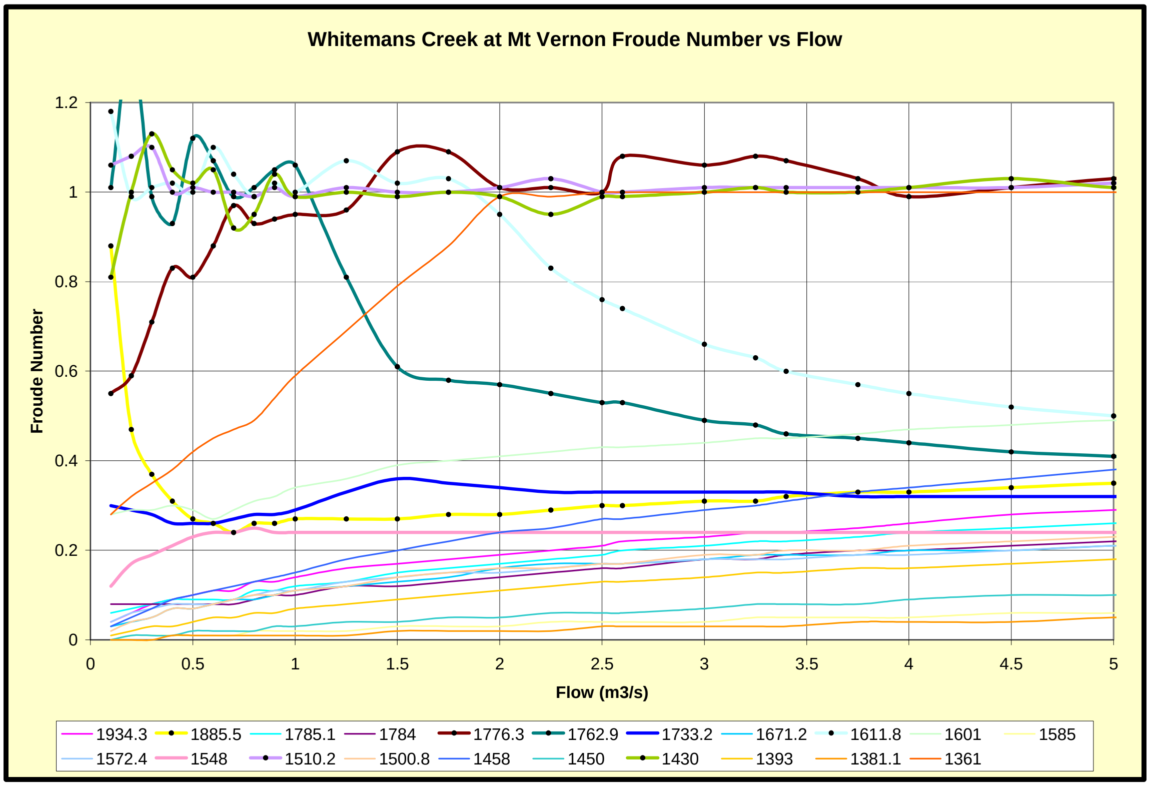

Whitemans Creek at Mt Vernon Flow vs Flow Depth
Flow Depth (m)
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
1934.3
1885.5
1785.1
1784
1776.3
1762.9
1733.2
1671.2
1611.8
1601
1585
1572.4
1548
1510.2
1500.8
1458
1450
1430
1393
1381.1
1361

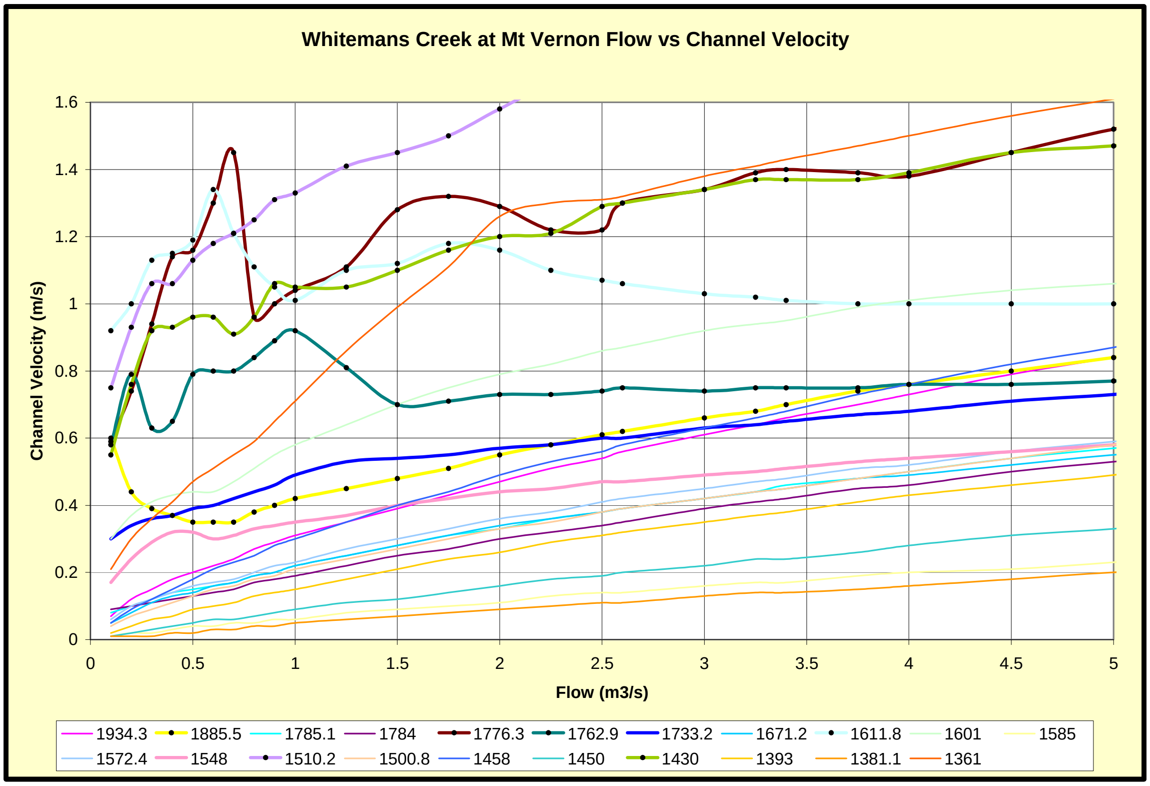

Whitemans Creek at Mt Vernon Flow vs Area
Flow Area (m2)
8
7
6
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
1934.3
1885.5
1785.1
1784
1776.3
1762.9
1733.2
1671.2
1611.8
1601
1585
1572.4
1548
1510.2
1500.8
1458
1450
1430
1393
1381.1
1361

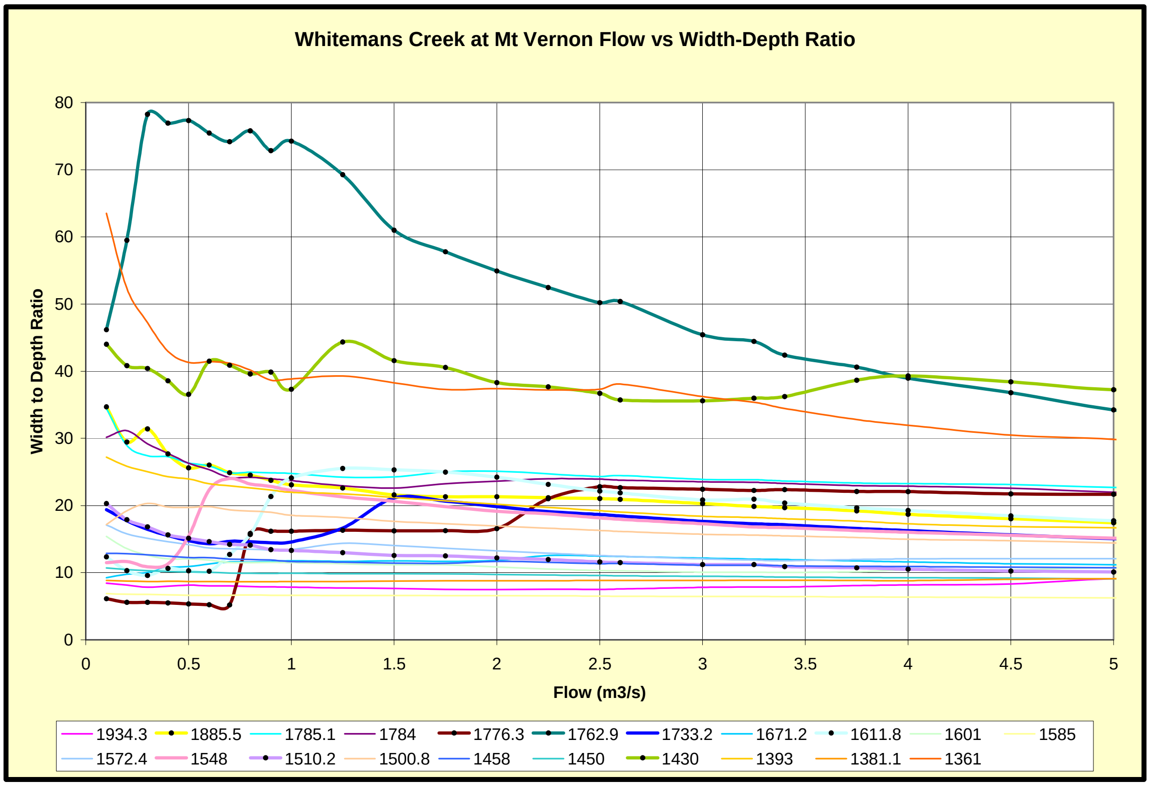

Whitemans Creek at Mt Vernon Flow vs Wetted Perimeter
Wetted Perimeter (m)
0
2
4
6
8
10
12
14
16
18
20
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1934.3
1885.5
1785.1
1784
1776.3
1762.9
1733.2
1671.2
1611.8
1601
1585
1572.4
1548
1510.2
1500.8
1458
1450
1430
1393
1381.1
1361


Whitemans Creek at Mt Vernon Flow vs Top Width
Top Width (m)
0
2
4
6
8
10
12
14
16
18
20
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1934.3
1885.5
1785.1
1784
1776.3
1762.9
1733.2
1671.2
1611.8
1601
1585
1572.4
1548
1510.2
1500.8
1458
1450
1430
1393
1381.1
1361


Whitemans Creek at Mt Vernon Flow vs Hydraulic Radius
Hydraulic Radius (m)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
1934.3
1885.5
1785.1
1784
1776.3
1762.9
1733.2
1671.2
1611.8
1601
1585
1572.4
1548
1510.2
1500.8
1458
1450
1430
1393
1381.1
1361

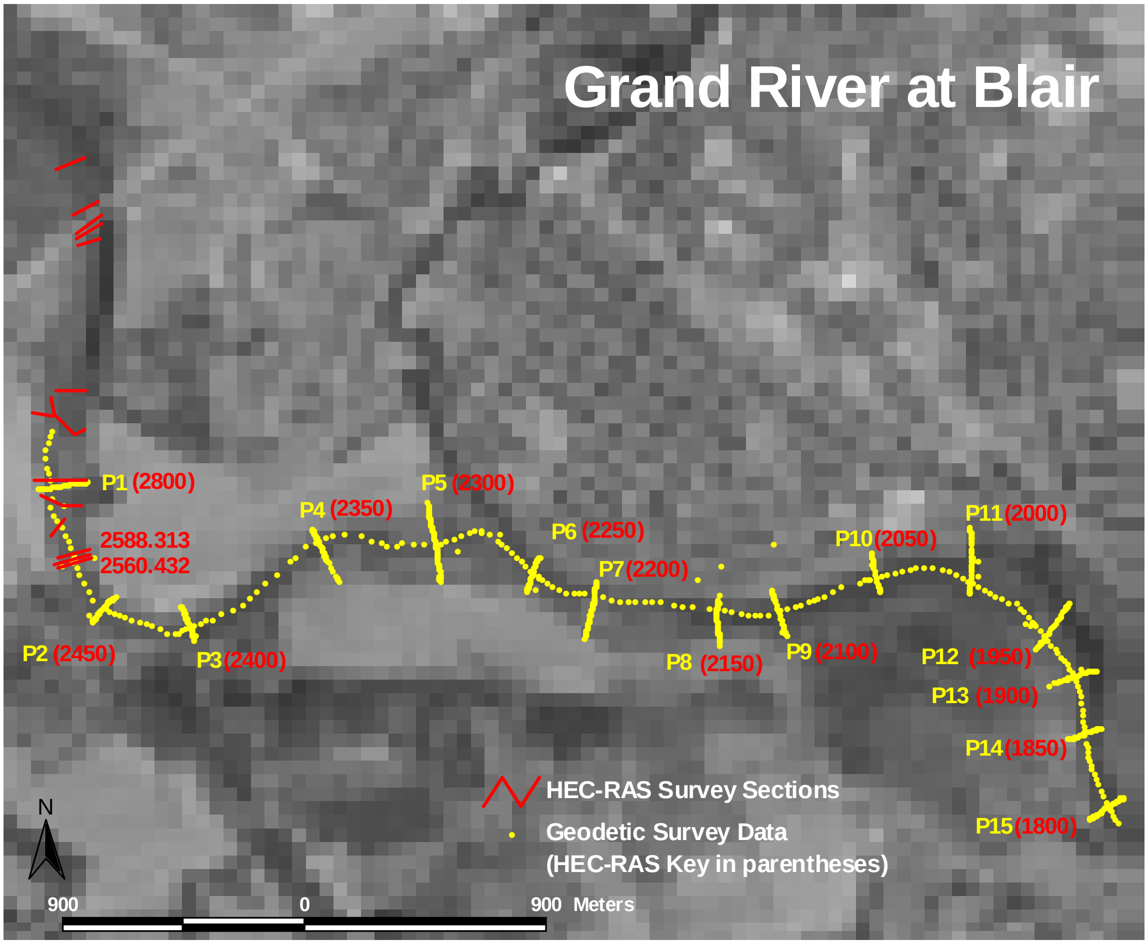

Whitemans Creek at Mt Vernon Froude Number vs Flow
Froude Number
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
1934.3
1885.5
1785.1
1784
1776.3
1762.9
1733.2
1671.2
1611.8
1601
1585
1572.4
1548
1510.2
1500.8
1458
1450
1430
1393
1381.1
1361

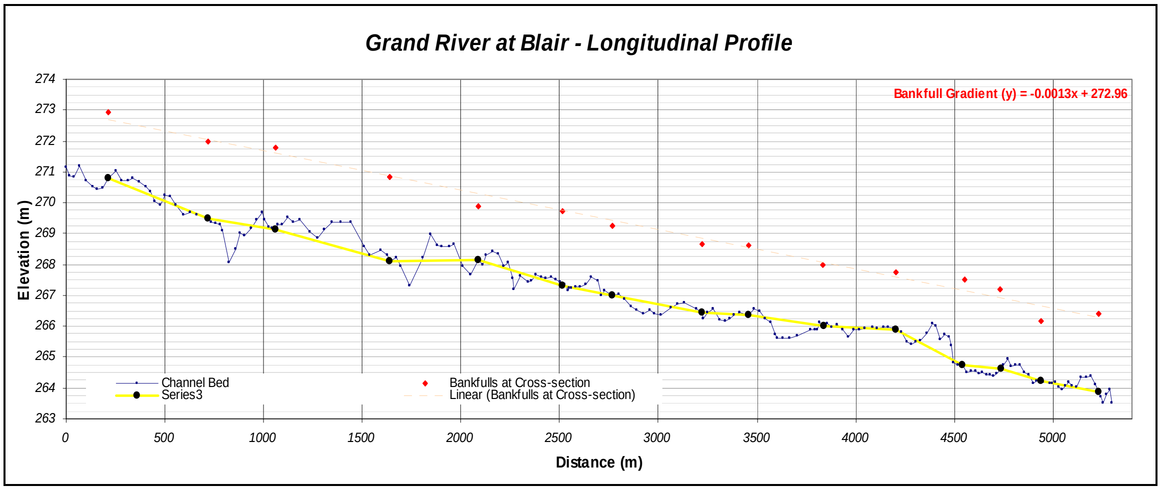

Whitemans Creek at Mt Vernon Flow vs Channel Velocity
Channel Velocity (m/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1934.3
1885.5
1785.1
1784
1776.3
1762.9
1733.2
1671.2
1611.8
1601
1585
1572.4
1548
1510.2
1500.8
1458
1450
1430
1393
1381.1
1361

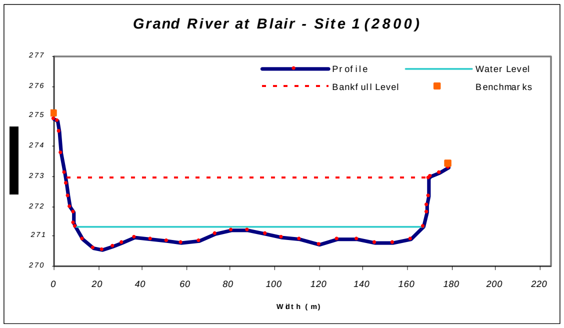

Whitemans Creek at Mt Vernon Flow vs Width-Depth Ratio
Width to Depth Ratio
0
10
20
30
40
50
60
70
80
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1934.3
1885.5
1785.1
1784
1776.3
1762.9
1733.2
1671.2
1611.8
1601
1585
1572.4
1548
1510.2
1500.8
1458
1450
1430
1393
1381.1
1361

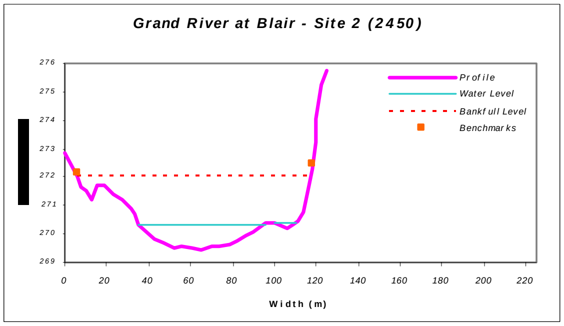
D-6: GRAND RIVER AT BLAIR REACH – Aquatic Vegetation

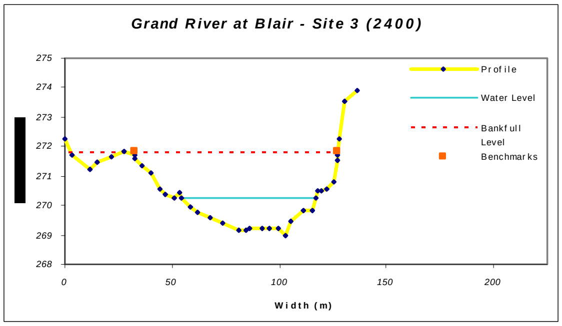
Note: Condition 1 has some presence and influence of aquatic vegetation in the reach

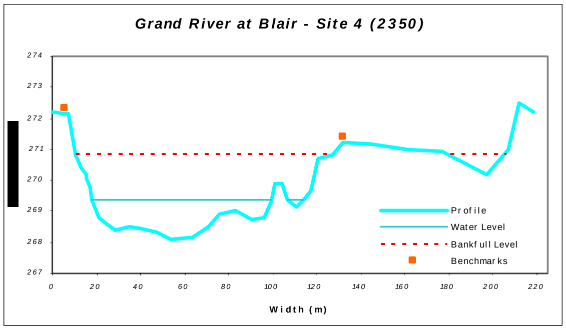


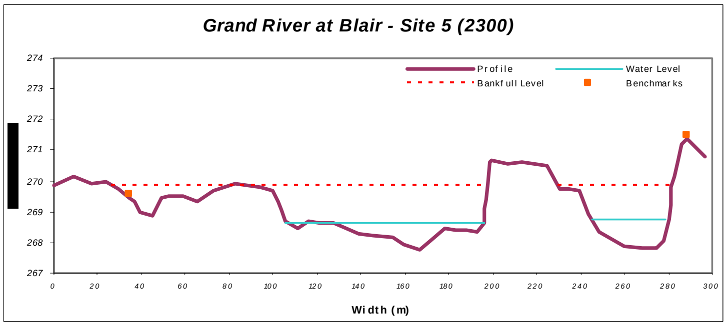


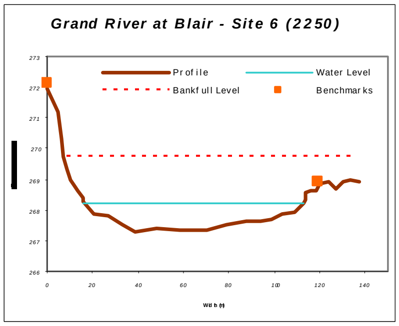

Grand River at Blair - Site 1 (2800)

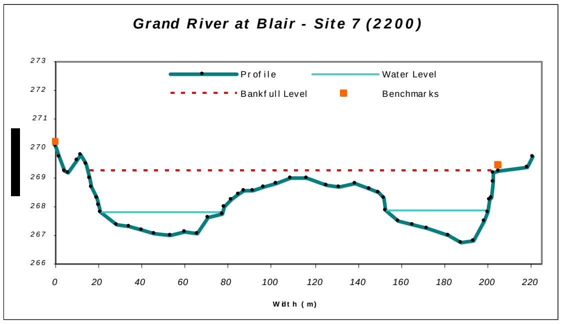

Grand River at Blair - Site 2 (2450)

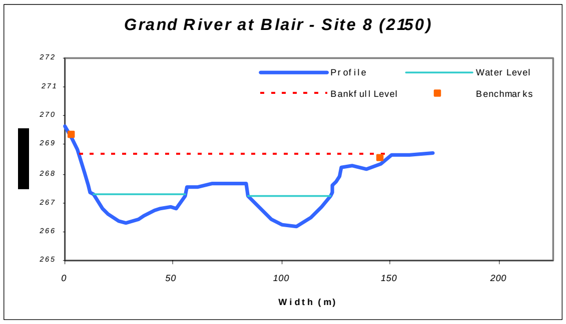

Grand River at Blair - Site 3 (2400)

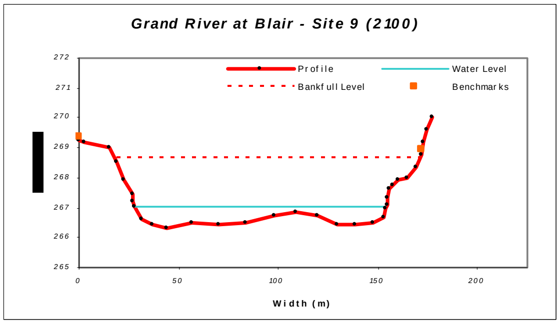

Grand River at Blair - Site 4 (2350)

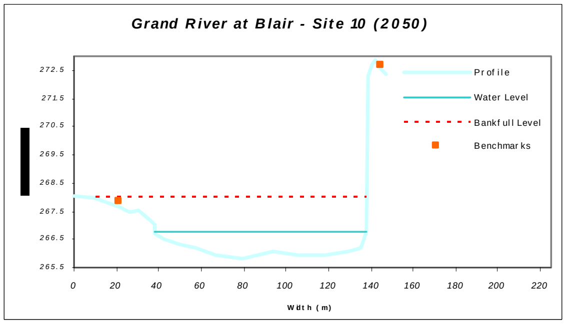

Grand River at Blair - Site 5 (2300)

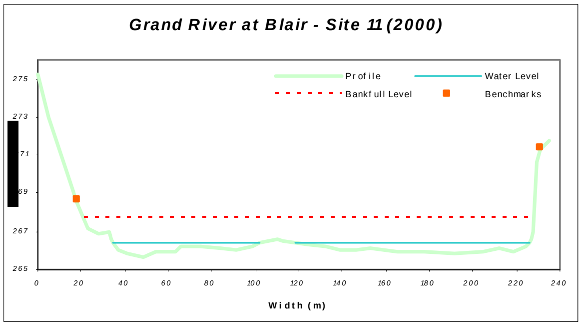

Grand River at Blair - Site 6 (2250)

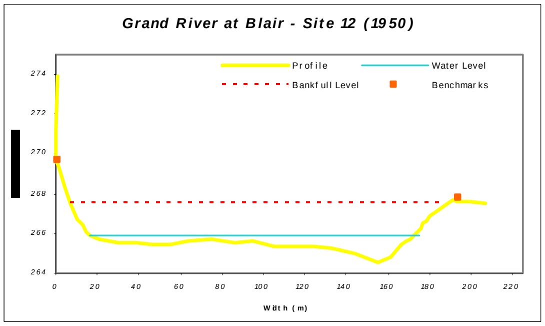

Grand River at Blair - Site 7 (2200)

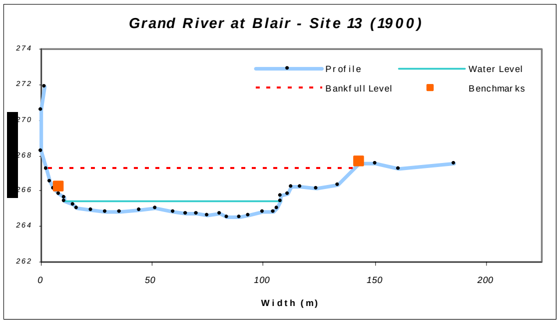

Grand River at Blair - Site 8 (2150)

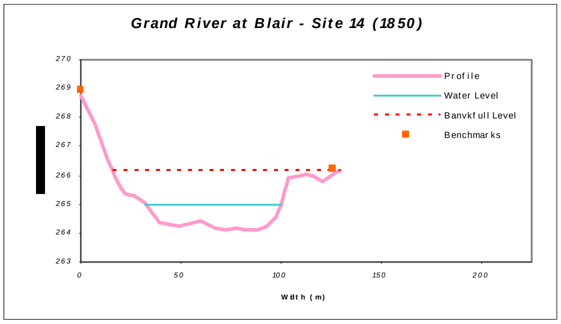

Grand River at Blair - Site 9 (2100)

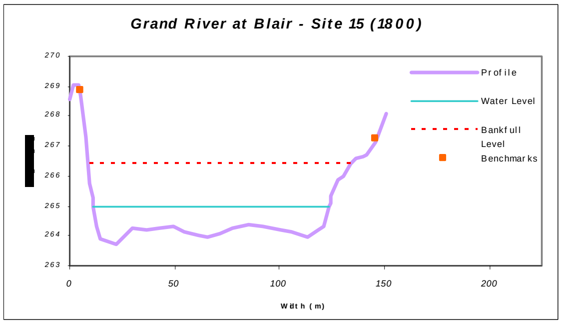

Grand River at Blair - Site 10 (2050)

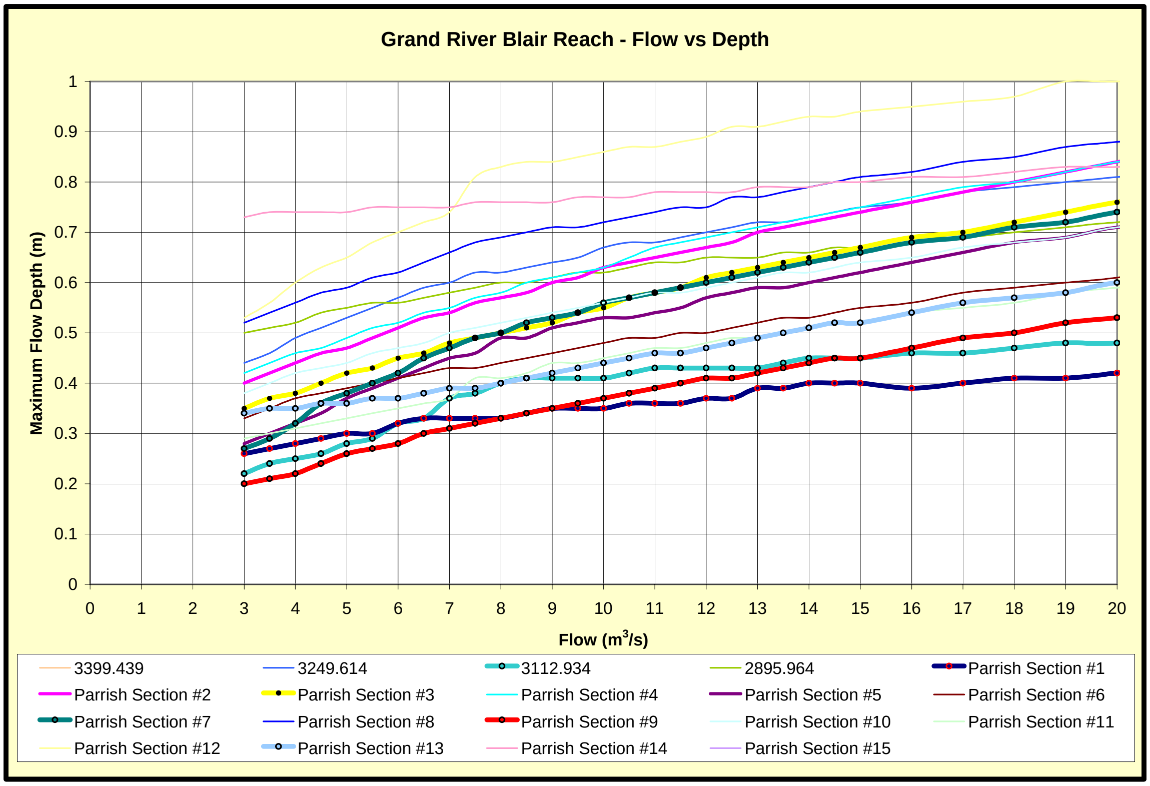

Grand River at Blair - Site 11 (2000)
Profile
Water Level
Bankfull Level
Benchmarks
275
273
271
269
267
265
[redacted]
0
20
40
60
80
100
120
140
160
180
200
220
240
Width (m)

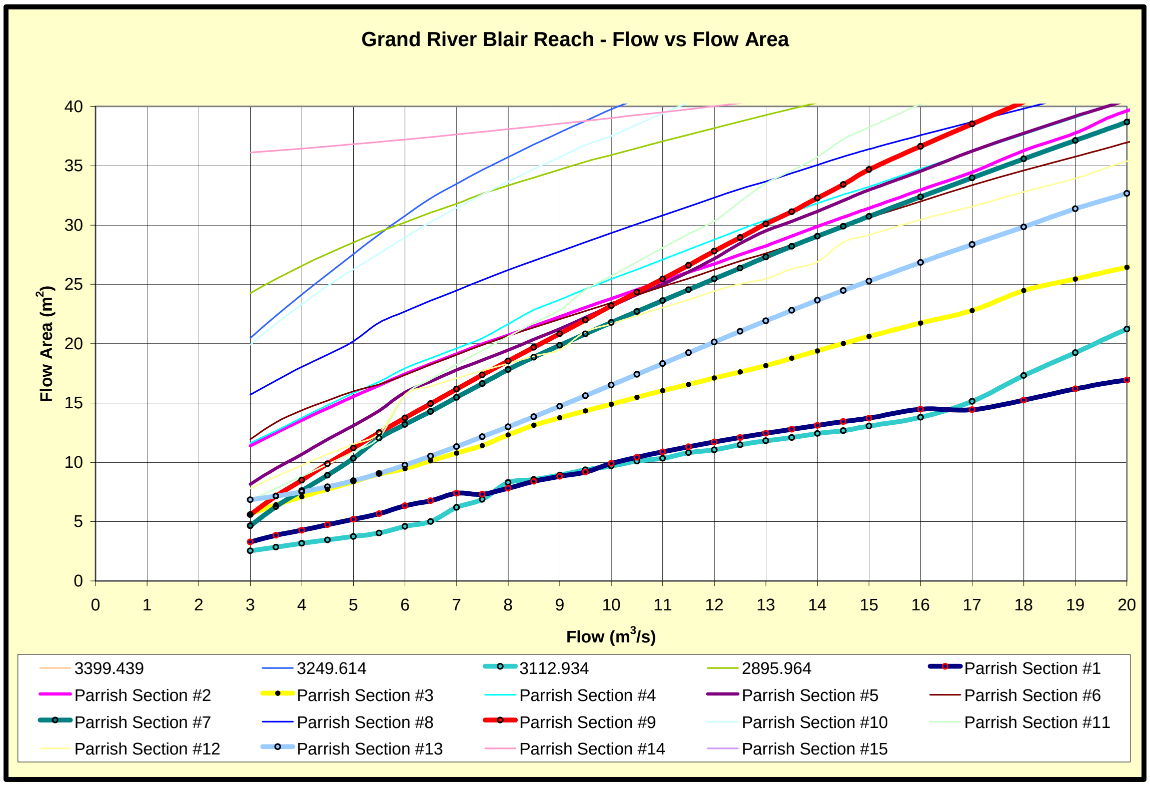

Grand River at Blair - Site 12 (1950)
Profile
Water Level
Bankfull Level
Benchmarks
274
272
270
268
266
264
[redacted]
0
20
40
60
80
100
120
140
160
180
200
220
Width (m)

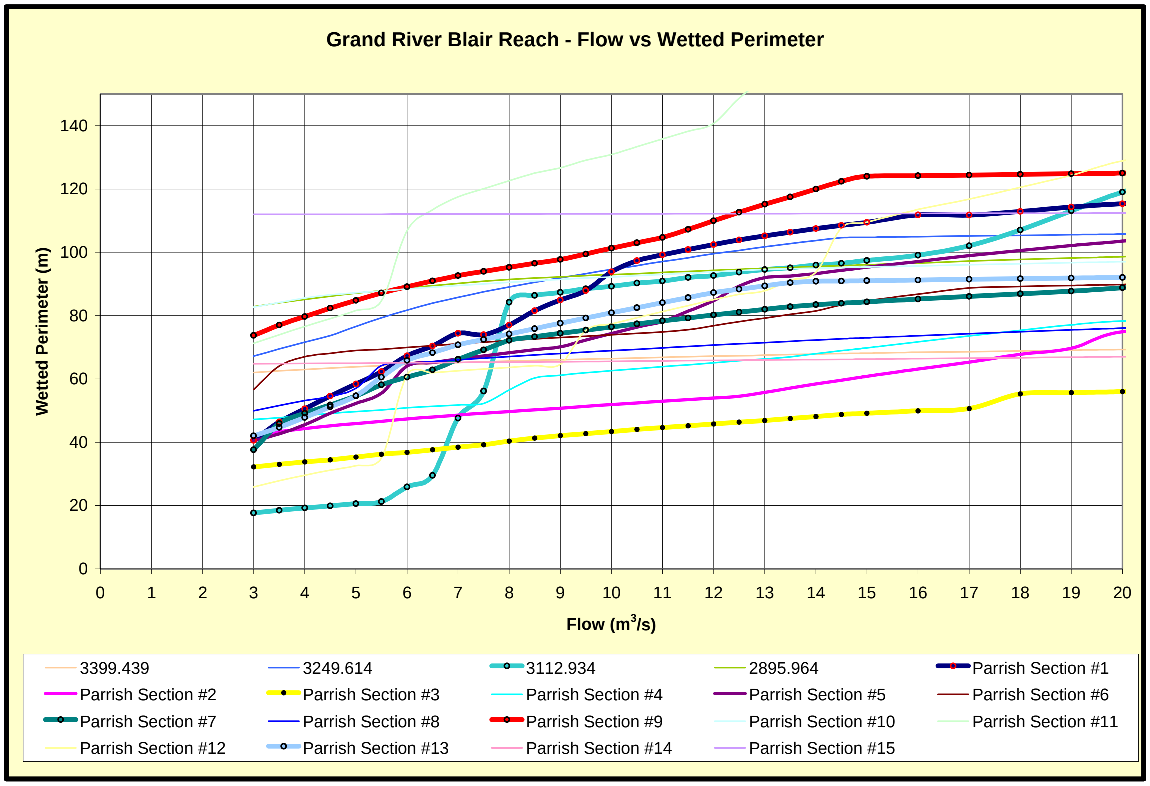

Grand River at Blair - Site 13 (1900)
Profile
Water Level
Bankfull Level
Benchmarks
274
272
270
268
266
264
262
[redacted]
0
50
100
150
200
Width (m)

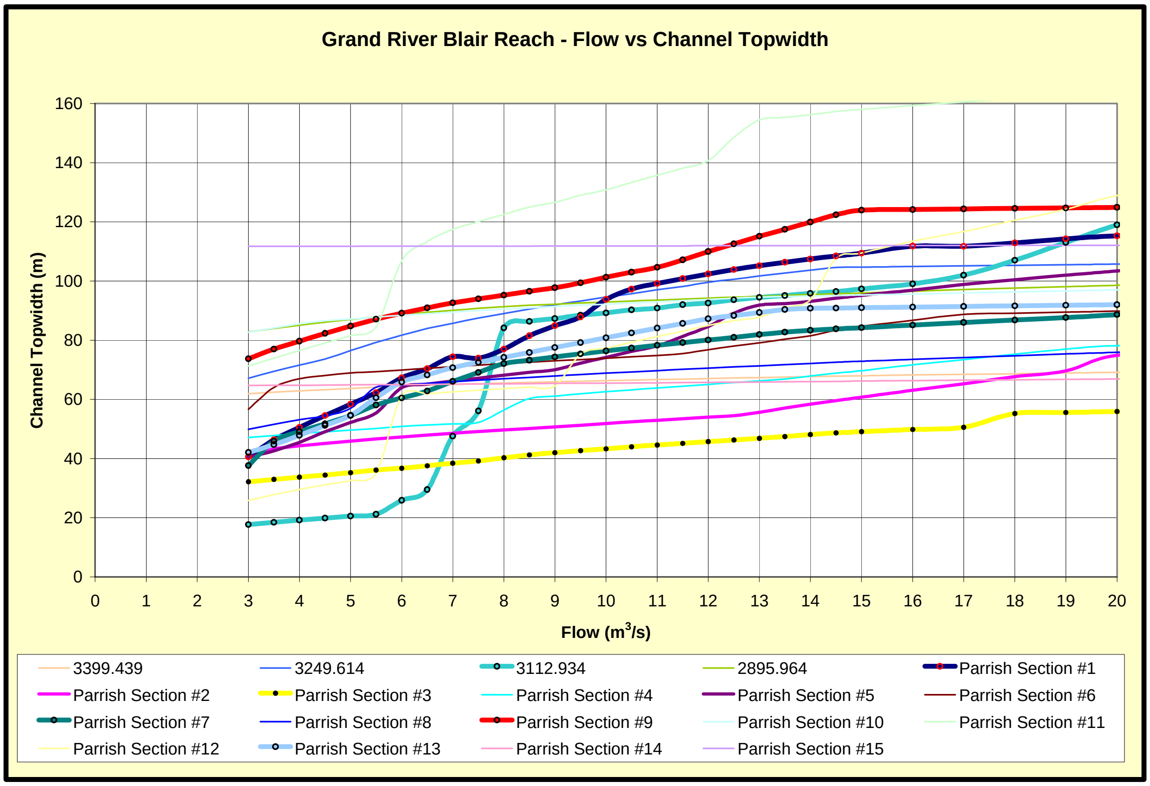

Grand River at Blair - Site 14 (1850)
Profile
Water Level
Banvkfull Level
Benchmarks
270
269
268
267
266
265
264
263
[redacted]
0
50
100
150
200
Width (m)

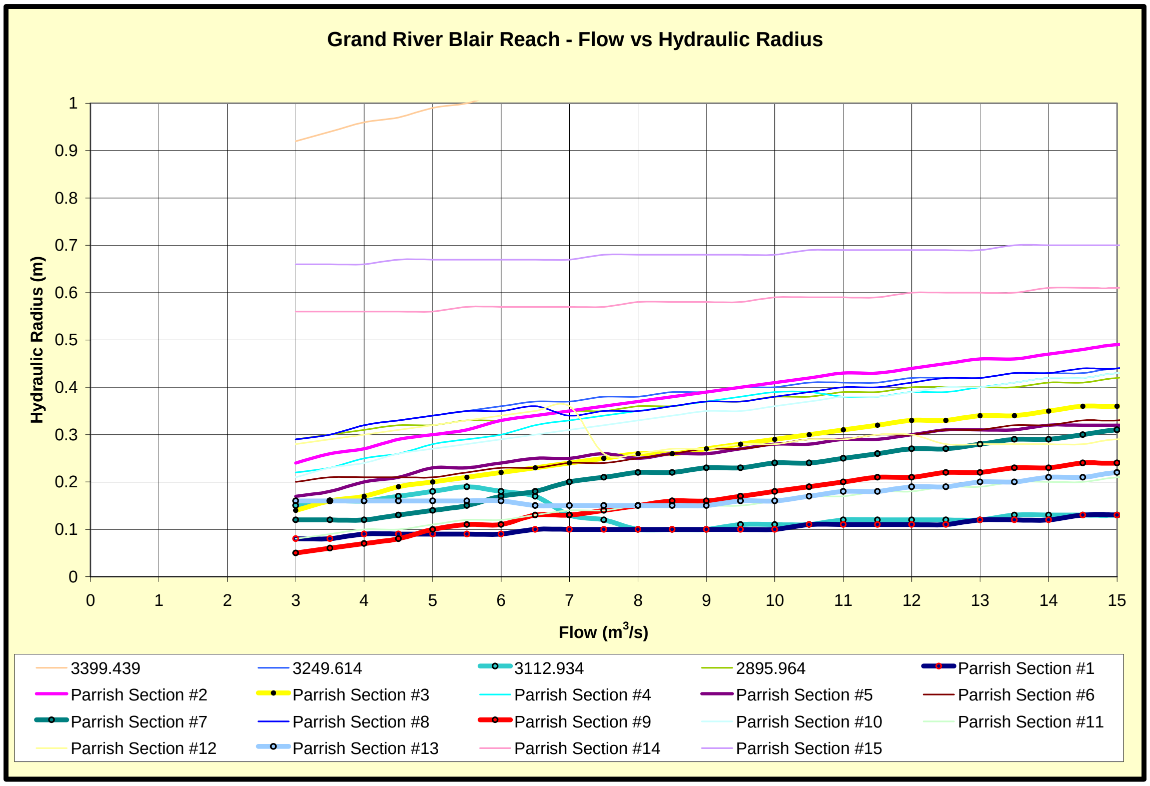

Grand River at Blair - Site 15 (1800)
Profile
Water Level
Bankfull Level
Benchmarks
270
269
268
267
266
265
264
263
[redacted]
0
50
100
150
200
Width (m)

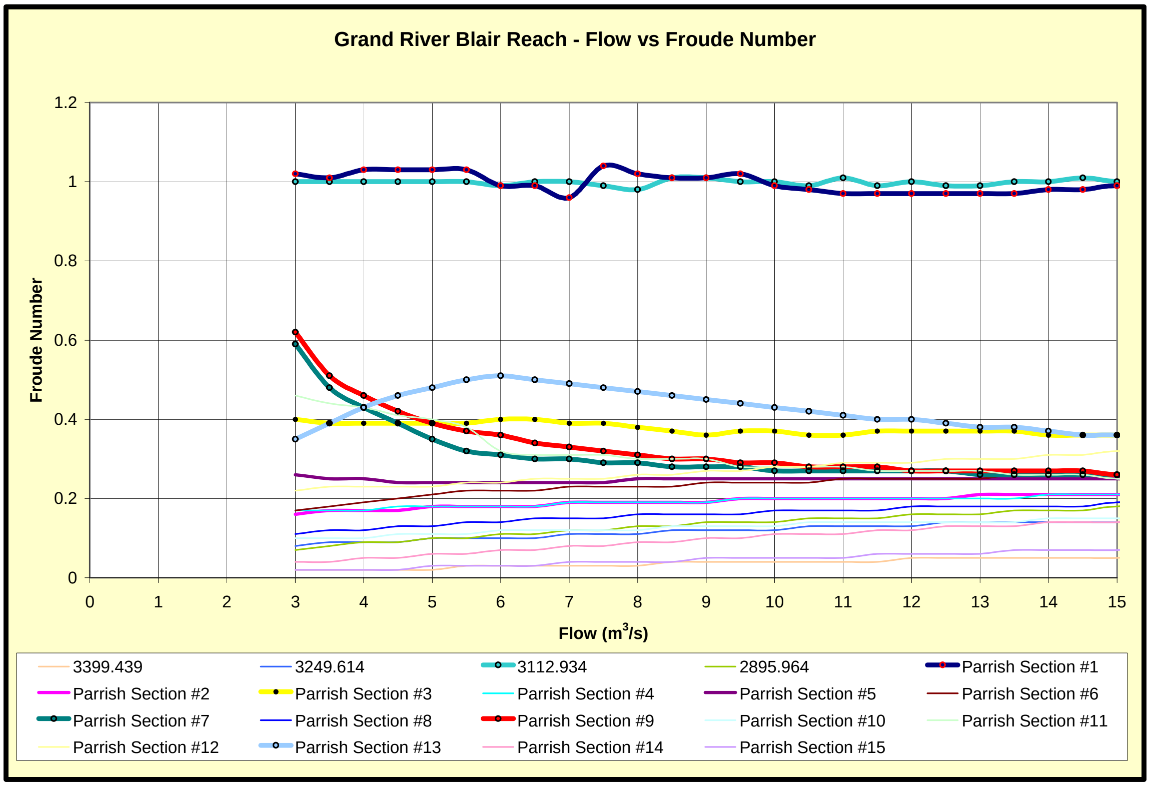

Grand River Blair Reach - Flow vs Depth
Maximum Flow Depth (m)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Flow (m³/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

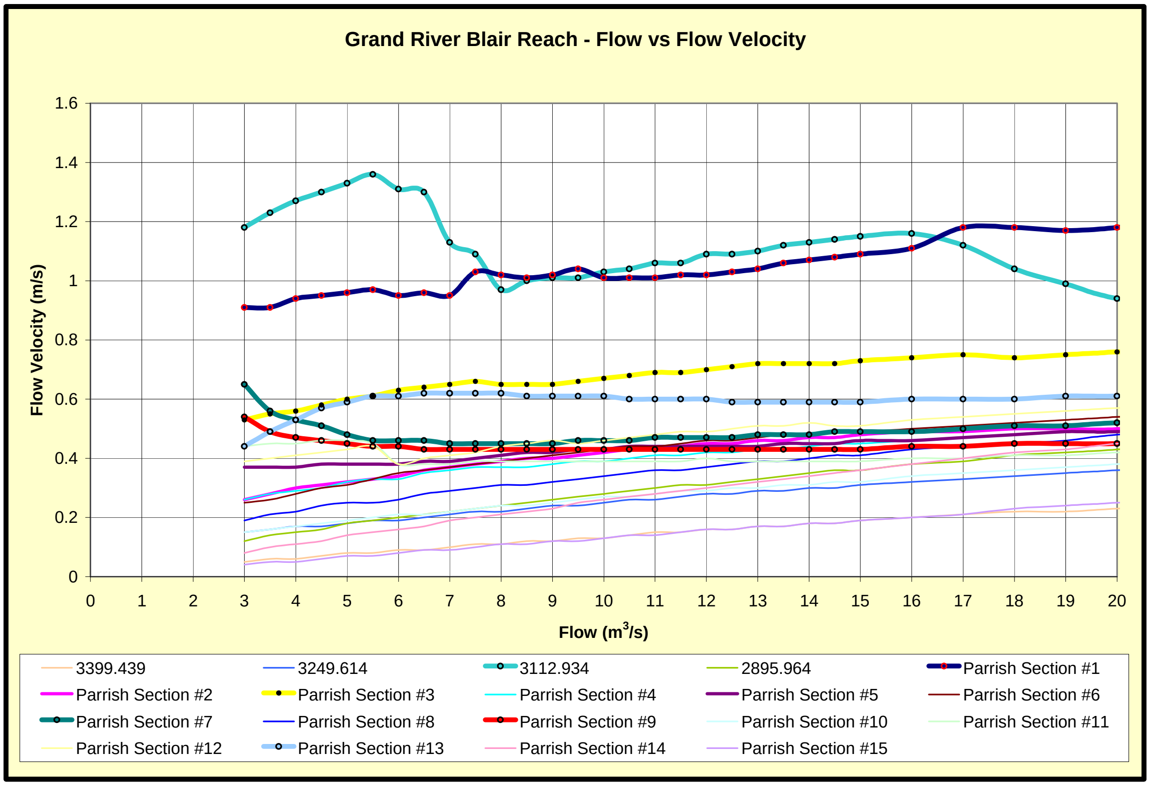

Grand River Blair Reach - Flow vs Flow Area
Flow Area (m²)
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Flow (m³/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

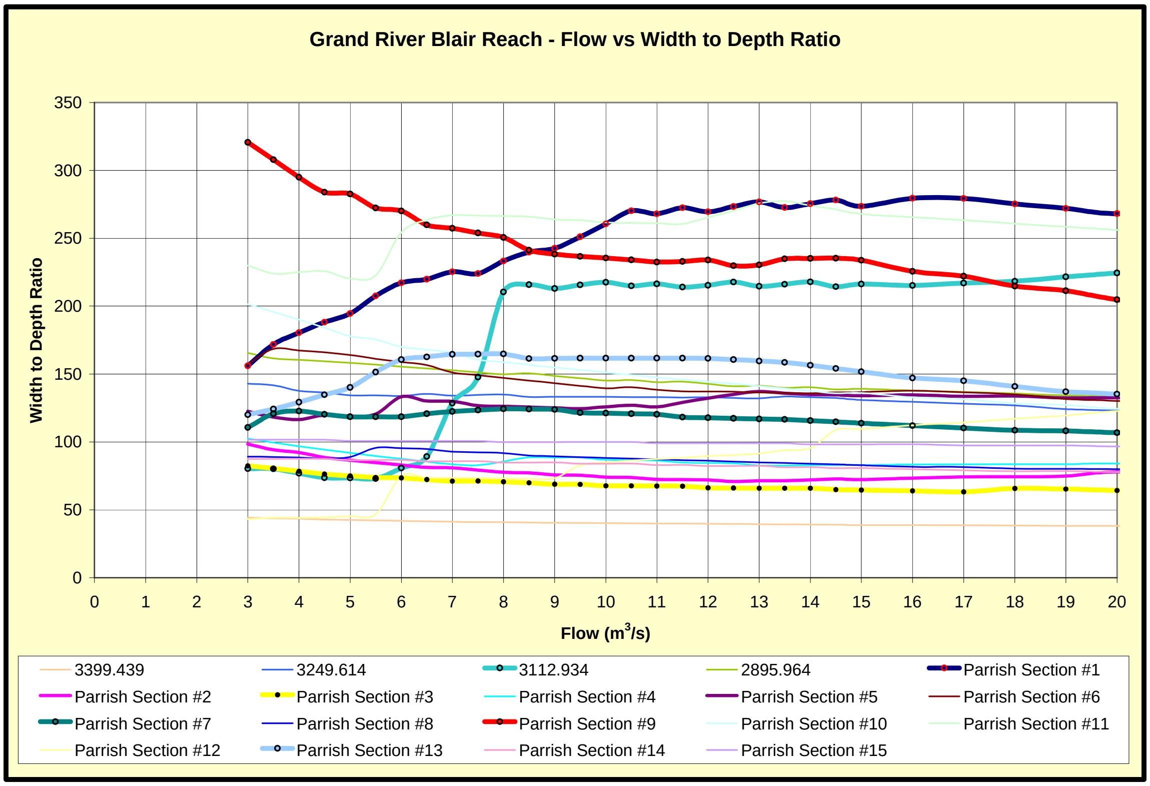

Grand River Blair Reach - Flow vs Wetted Perimeter
Wetted Perimeter (m)
0
20
40
60
80
100
120
140
Flow (m³/s)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15


Grand River Blair Reach - Flow vs Channel Topwidth
Channel Topwidth (m)
0
20
40
60
80
100
120
140
160
Flow (m³/s)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15


Grand River Blair Reach - Flow vs Hydraulic Radius
Hydraulic Radius (m)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Flow (m³/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

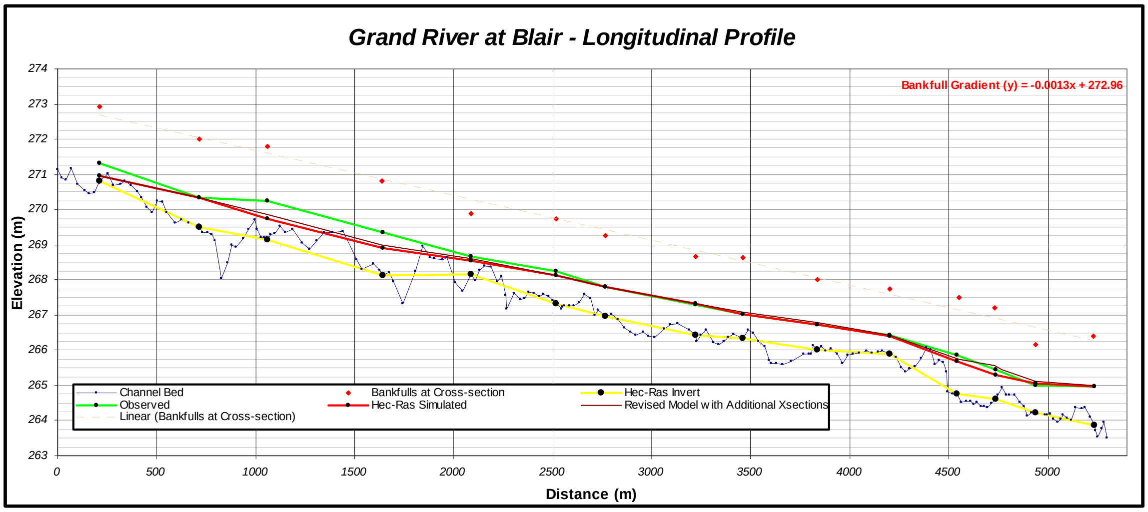

Grand River Blair Reach - Flow vs Froude Number
Froude Number
1.2
1
0.8
0.6
0.4
0.2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Flow (m³/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

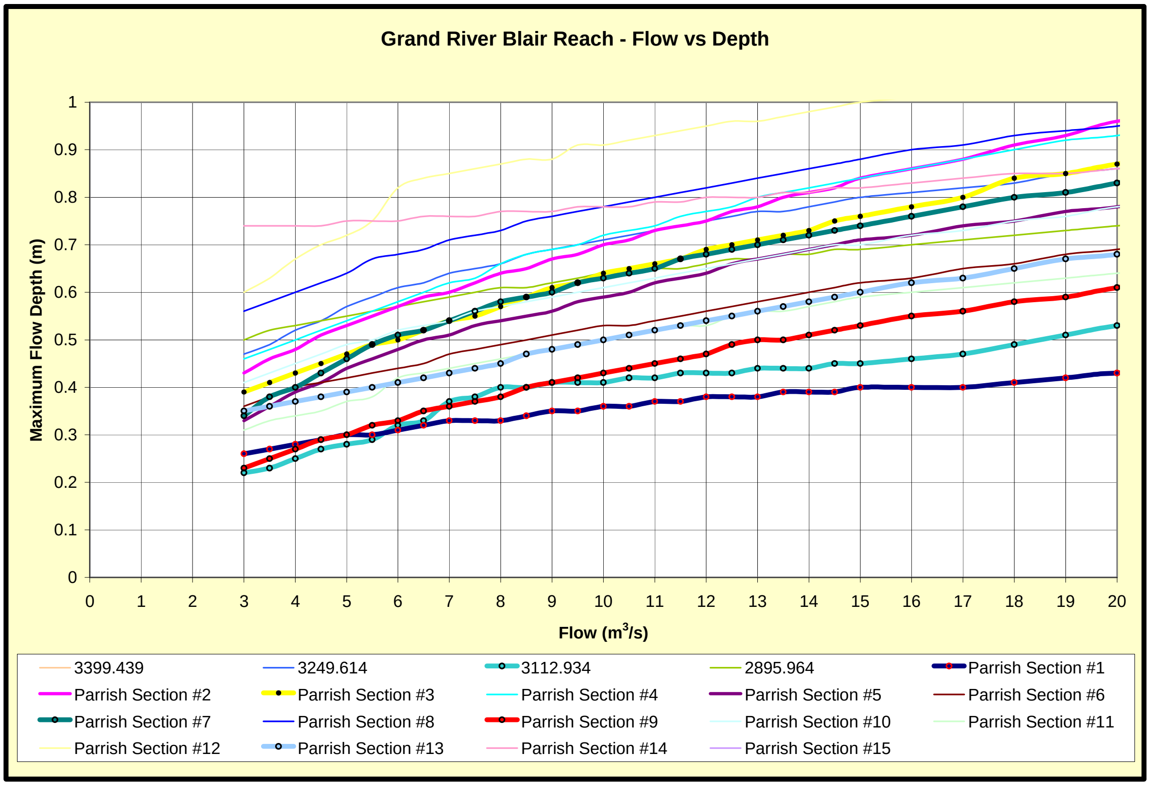

Grand River Blair Reach - Flow vs Flow Velocity
Flow Velocity (m/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Flow (m³/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

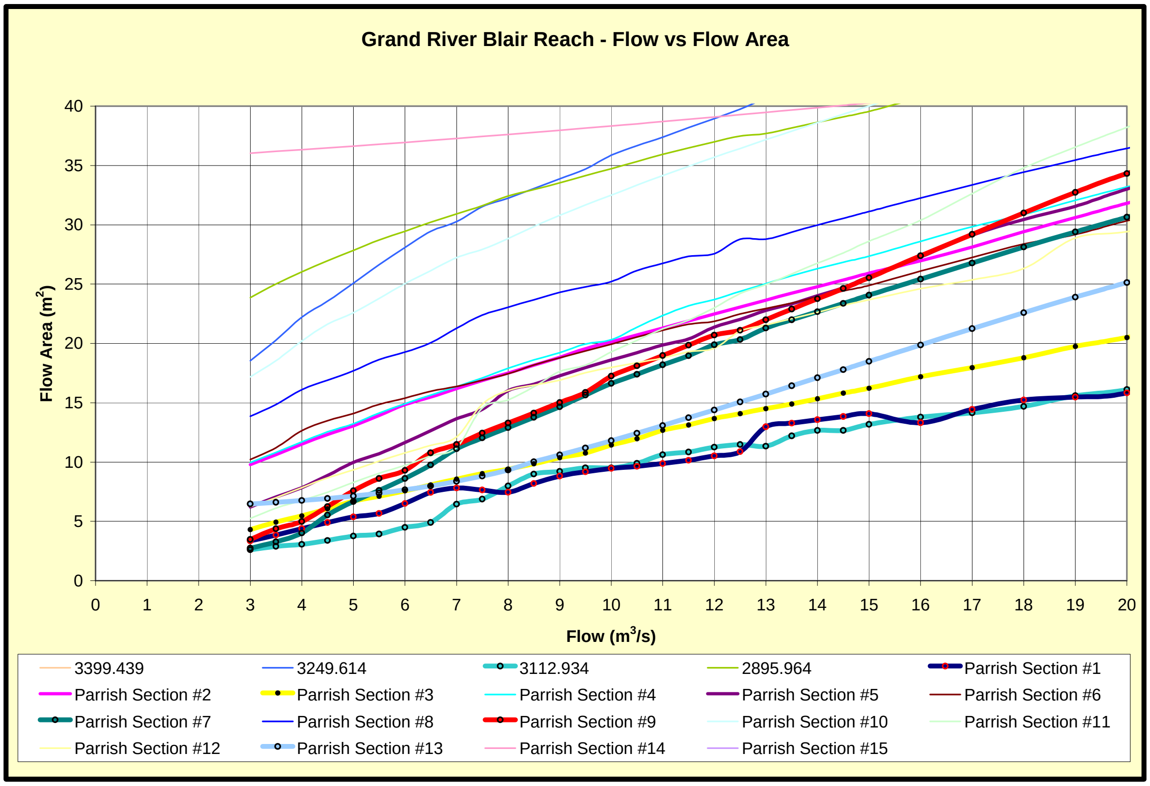

Grand River Blair Reach - Flow vs Width to Depth Ratio
Width to Depth Ratio
0
50
100
150
200
250
300
350
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Flow (m³/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

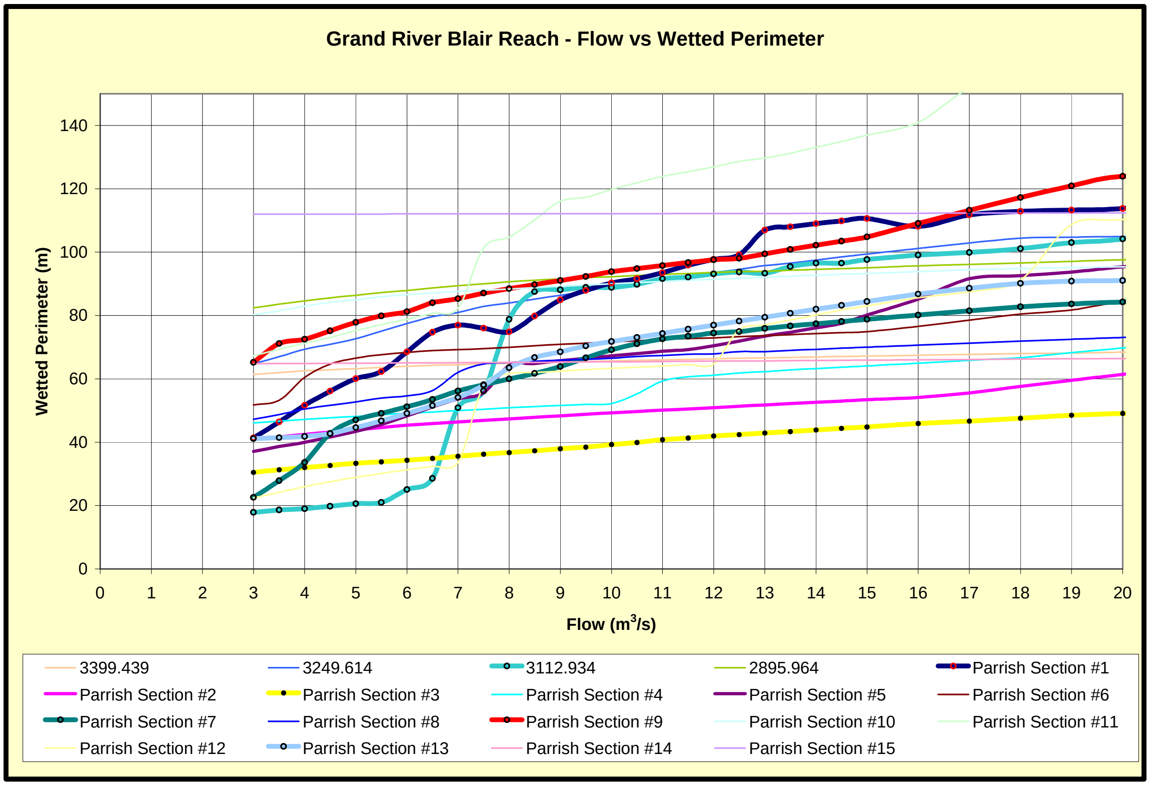
D-7: GRAND RIVER AT BLAIR REACH – Non-Vegetated

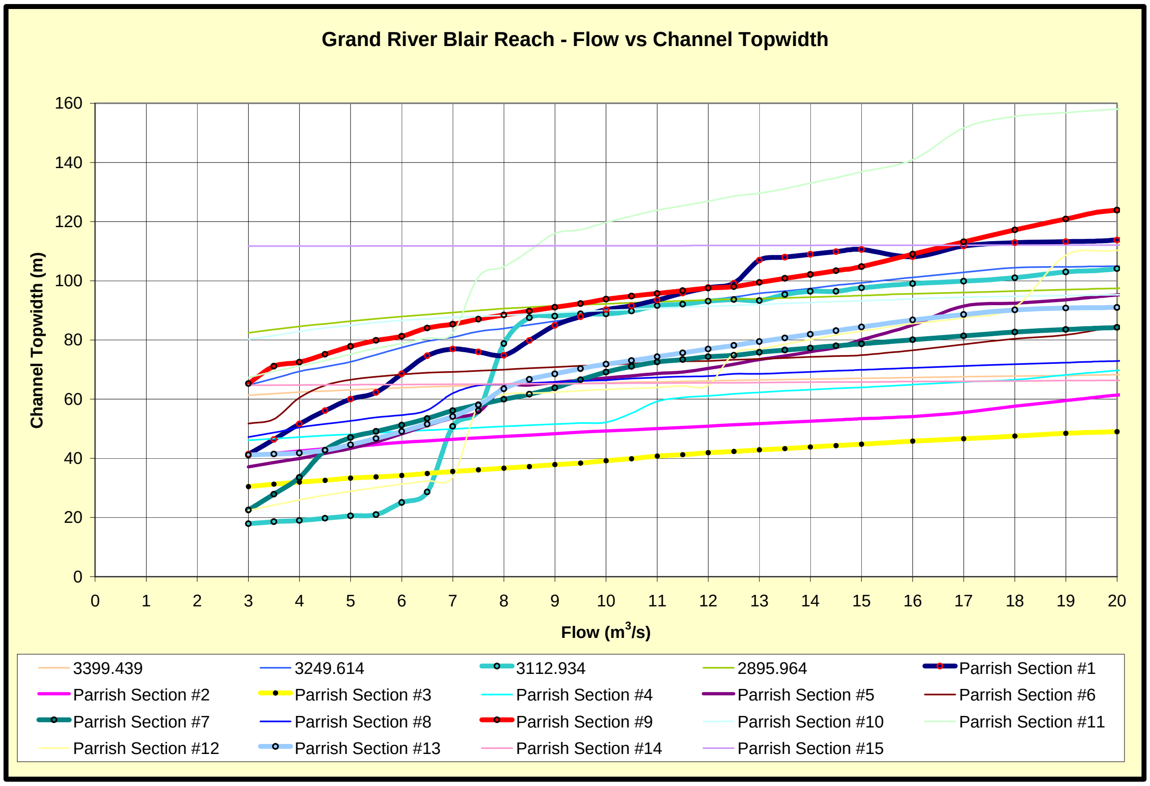
Note: Condition 2 attempts to removes the effects of the aquatic vegetation. The reach ortho photo, long profile and cross sections are the same as in Appendix D6, but hydraulic plots are slightly altered.

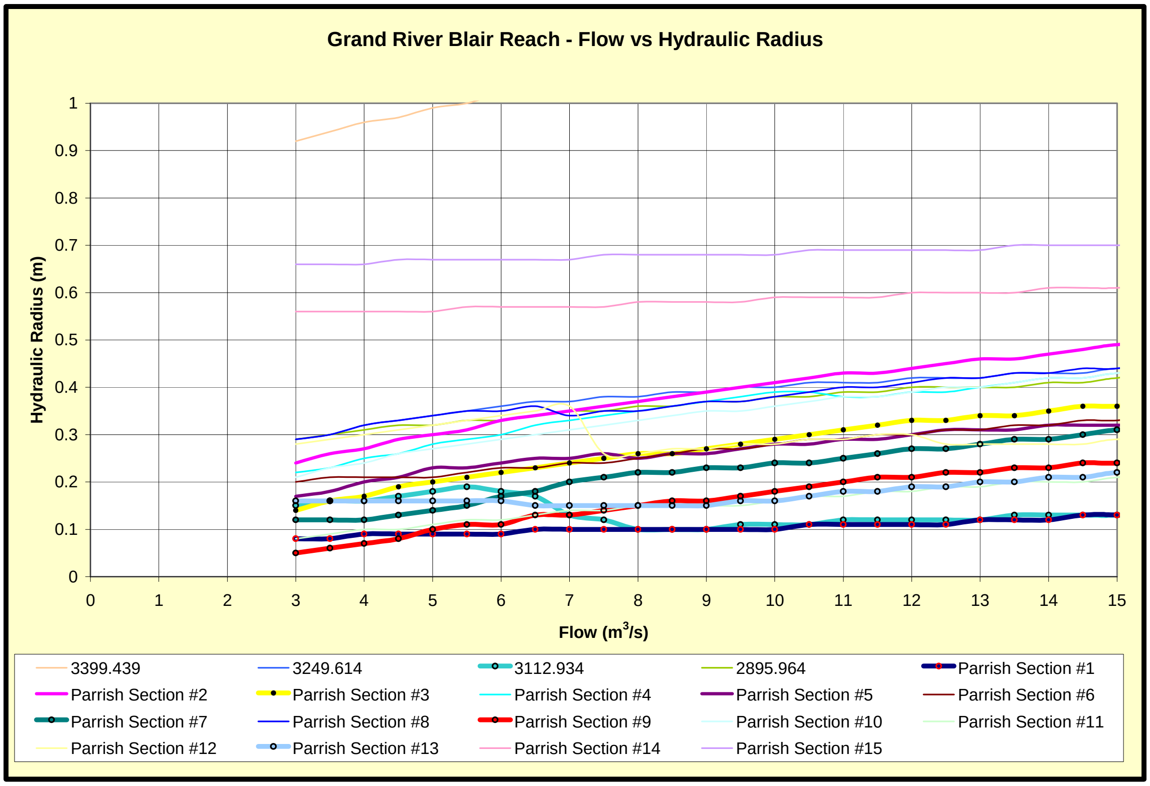


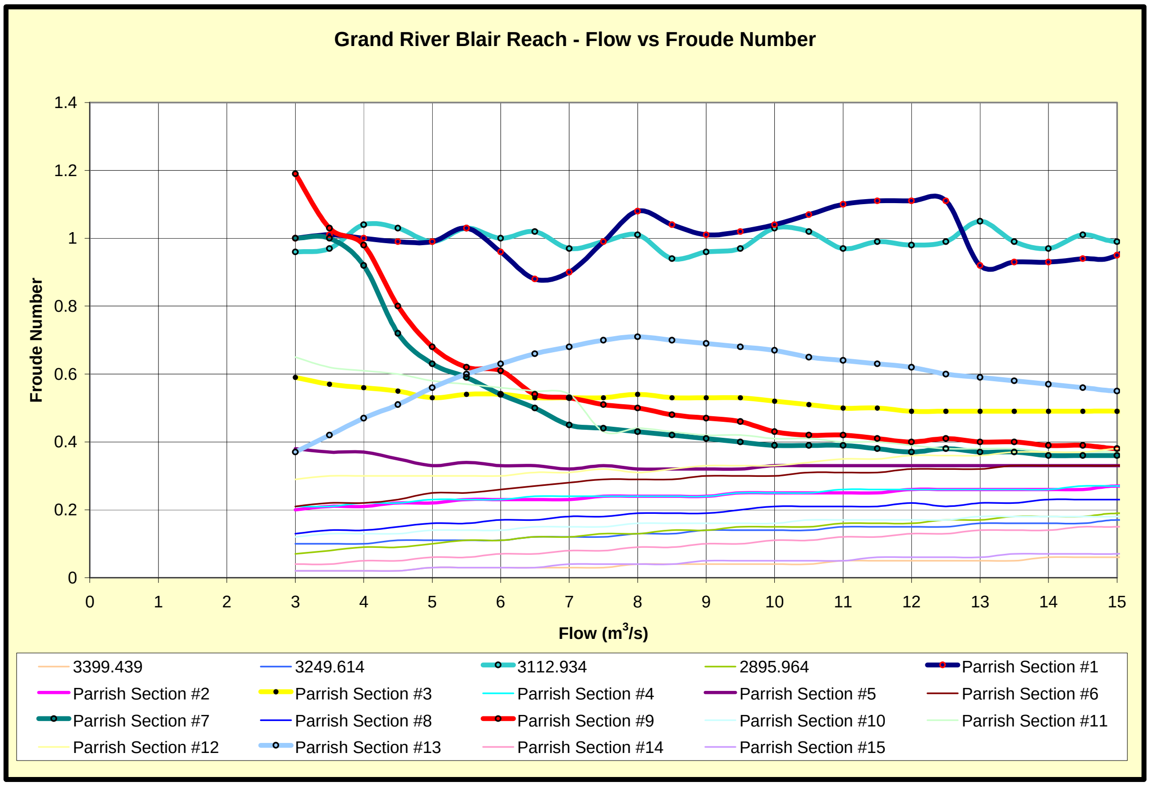


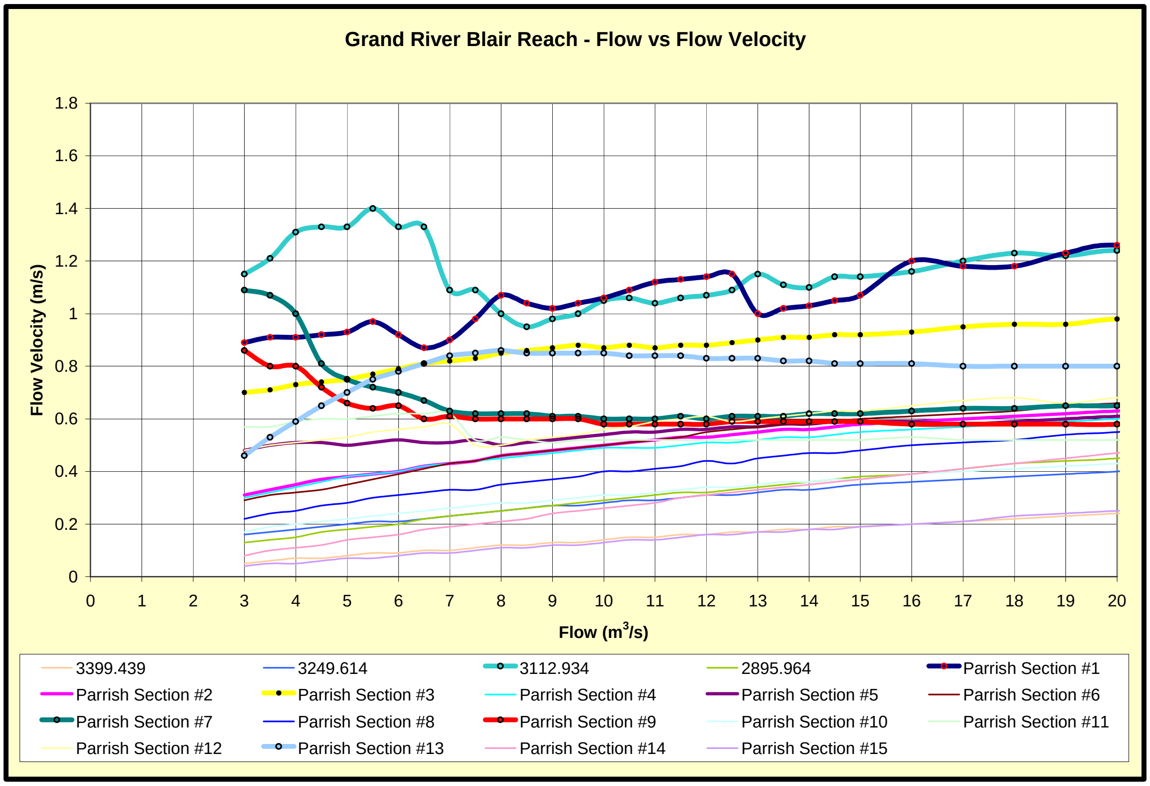

Grand River Blair Reach - Flow vs Flow Area
Flow Area (m²)
Flow (m³/s)
0
5
10
15
20
25
30
35
40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

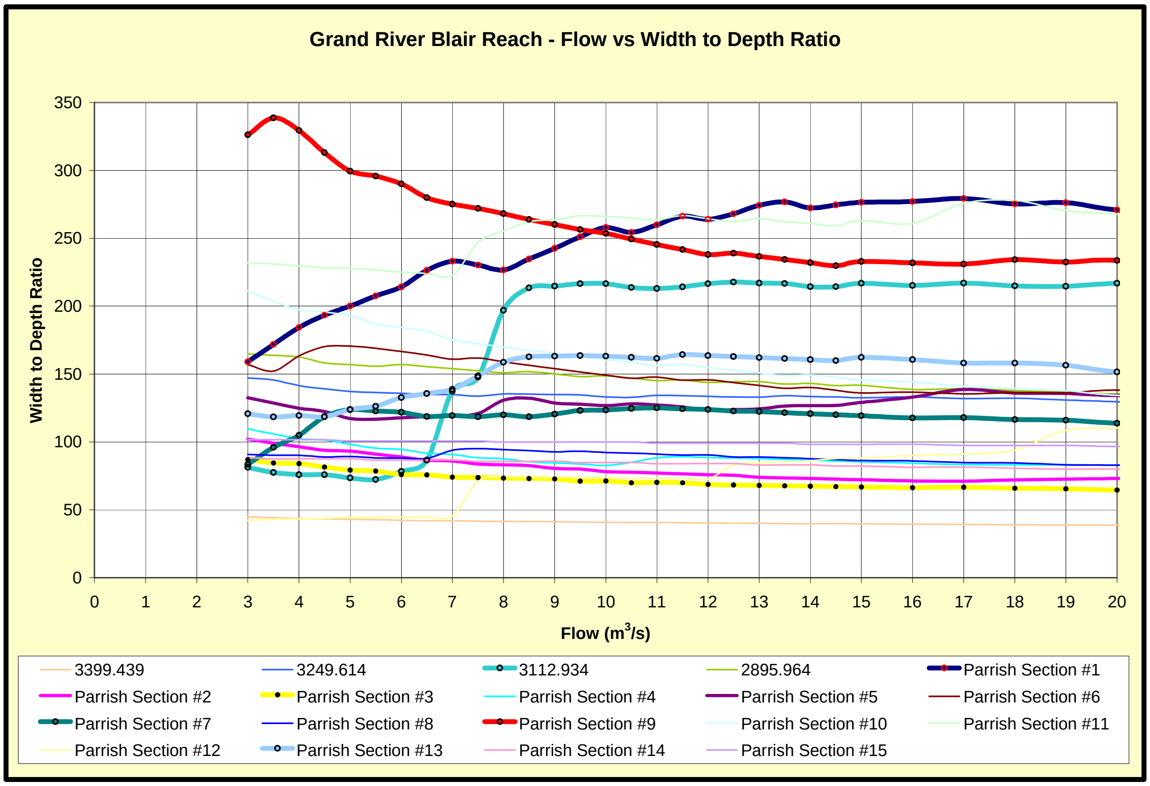

Grand River Blair Reach - Flow vs Wetted Perimeter
Wetted Perimeter (m)
Flow (m³/s)
0
20
40
60
80
100
120
140
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15


Grand River Blair Reach - Flow vs Channel Topwidth
Channel Topwidth (m)
0
20
40
60
80
100
120
140
160
Flow (m^3/s)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15


Grand River Blair Reach - Flow vs Hydraulic Radius
Hydraulic Radius (m)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Flow (m3/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

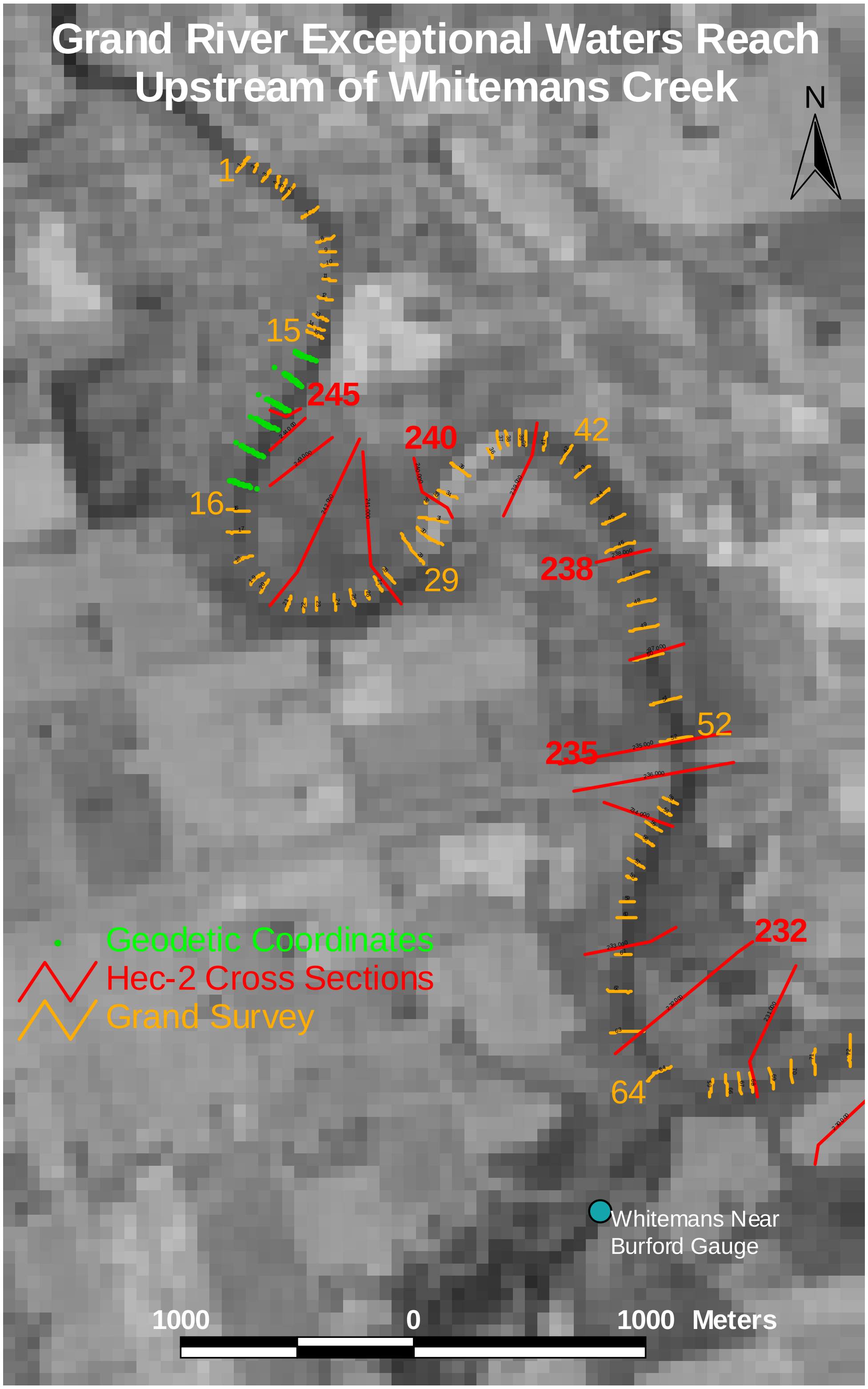

Grand River Blair Reach - Flow vs Froude Number
Froude Number
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Flow (m3/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

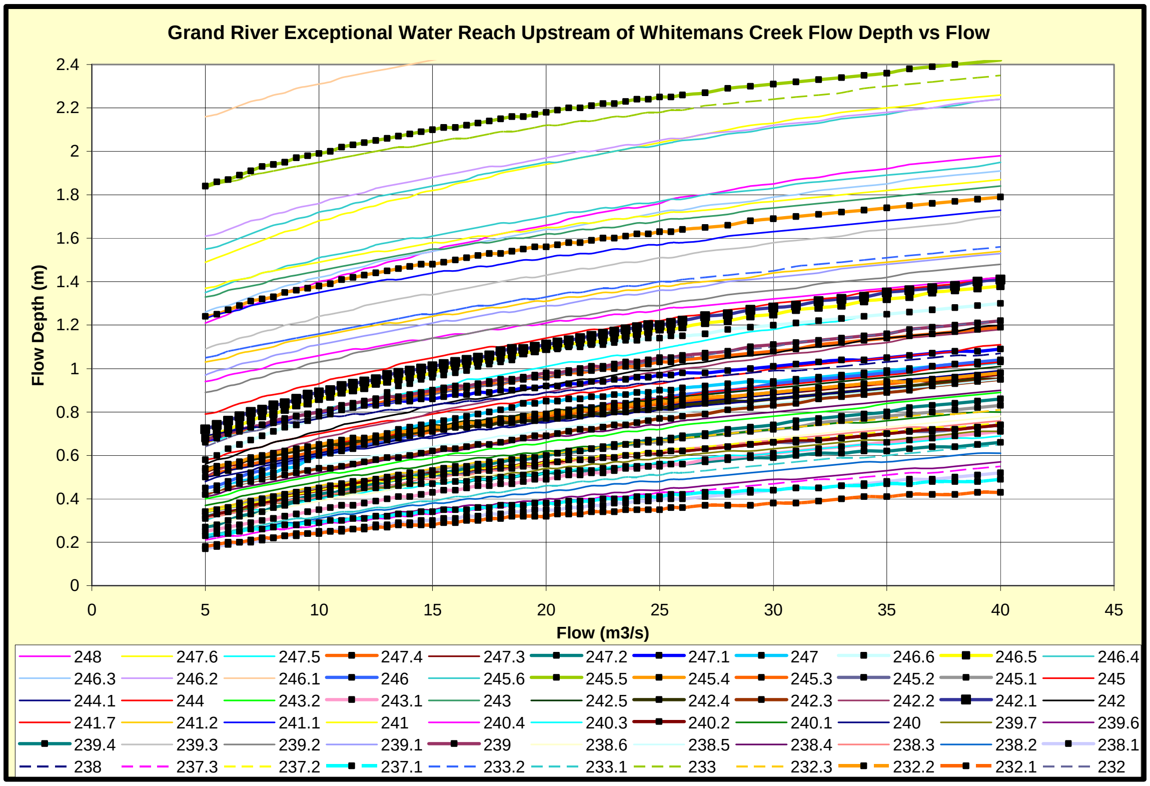

Grand River Blair Reach - Flow vs Flow Velocity
Flow Velocity (m/s)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Flow (m3/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

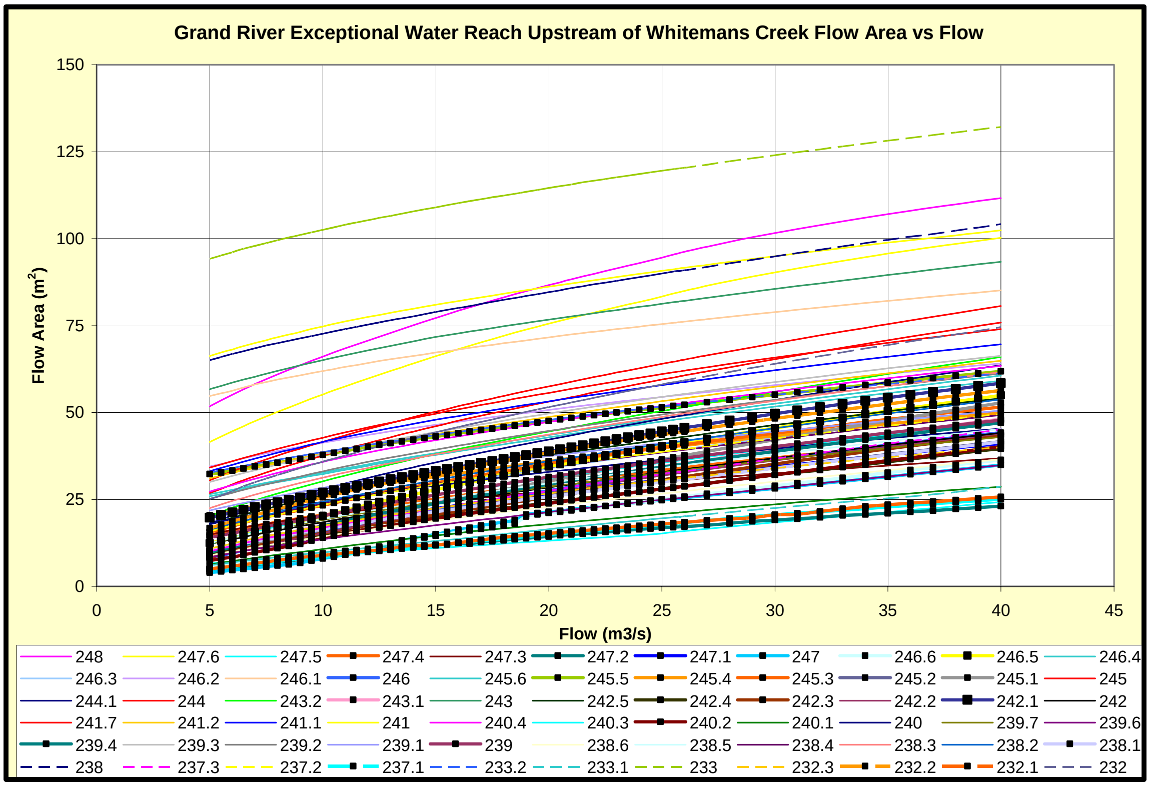

Grand River Blair Reach - Flow vs Width to Depth Ratio
Width to Depth Ratio
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Flow (m3/s)
3399.439
3249.614
3112.934
2895.964
Parrish Section #1
Parrish Section #2
Parrish Section #3
Parrish Section #4
Parrish Section #5
Parrish Section #6
Parrish Section #7
Parrish Section #8
Parrish Section #9
Parrish Section #10
Parrish Section #11
Parrish Section #12
Parrish Section #13
Parrish Section #14
Parrish Section #15

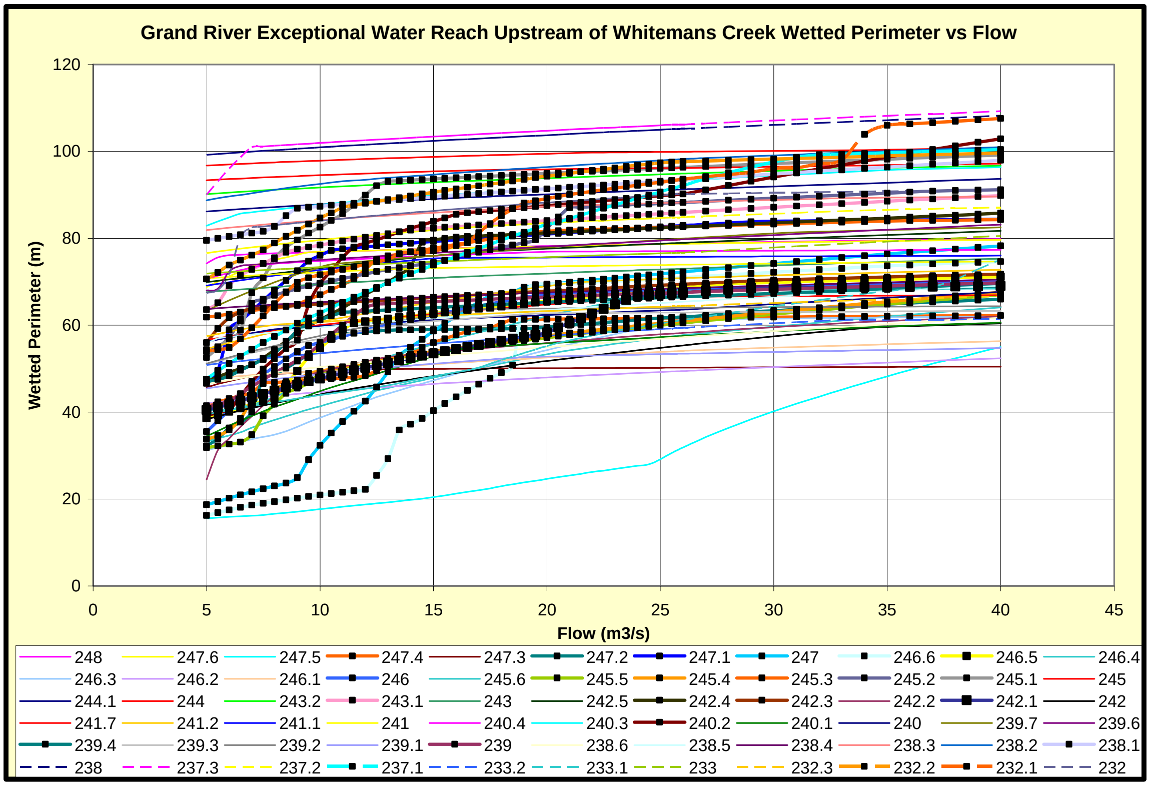
D-8: GRAND RIVER EXCEPTIONAL WATERS REACH – Upstream

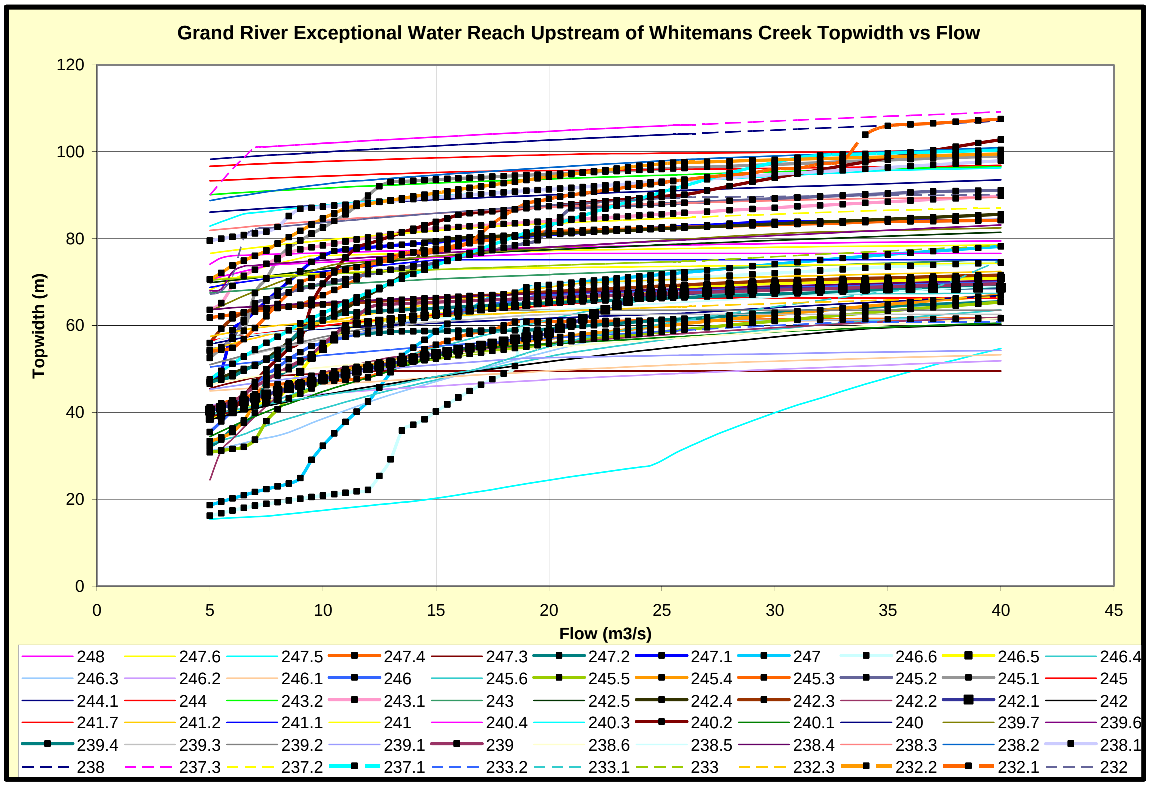
Upstream of Whiteman's Creek

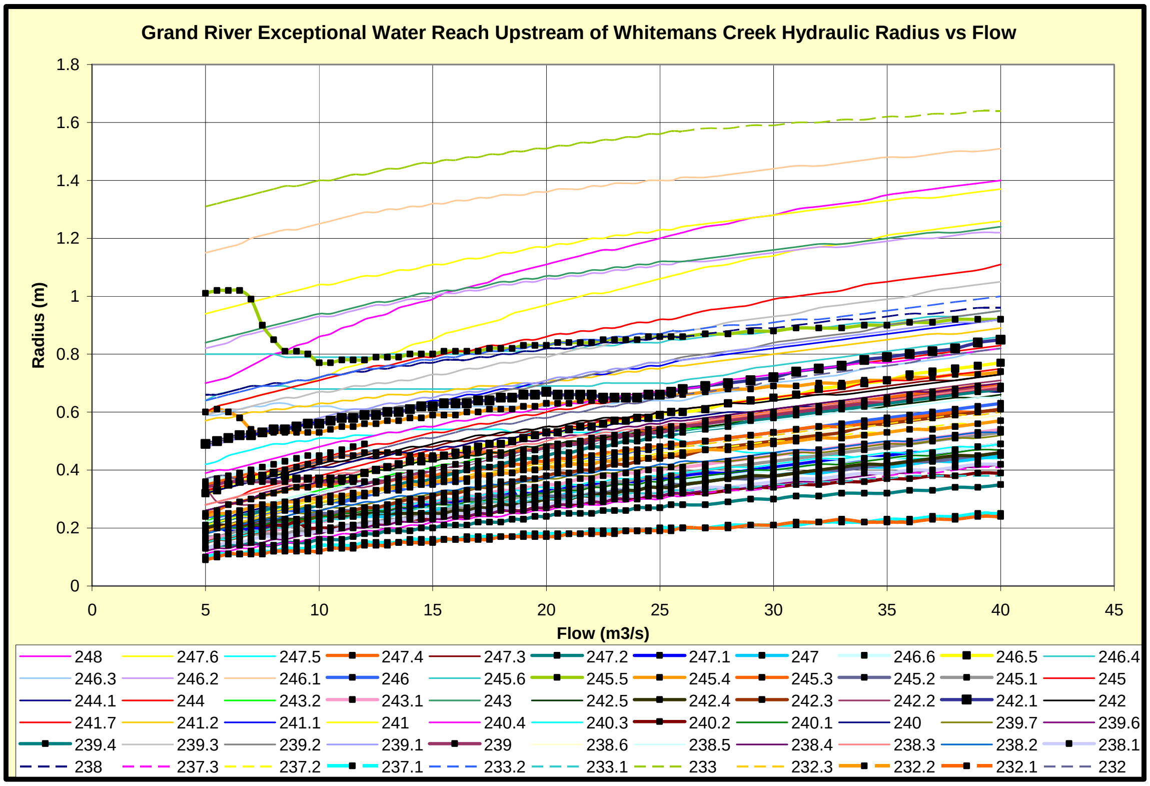


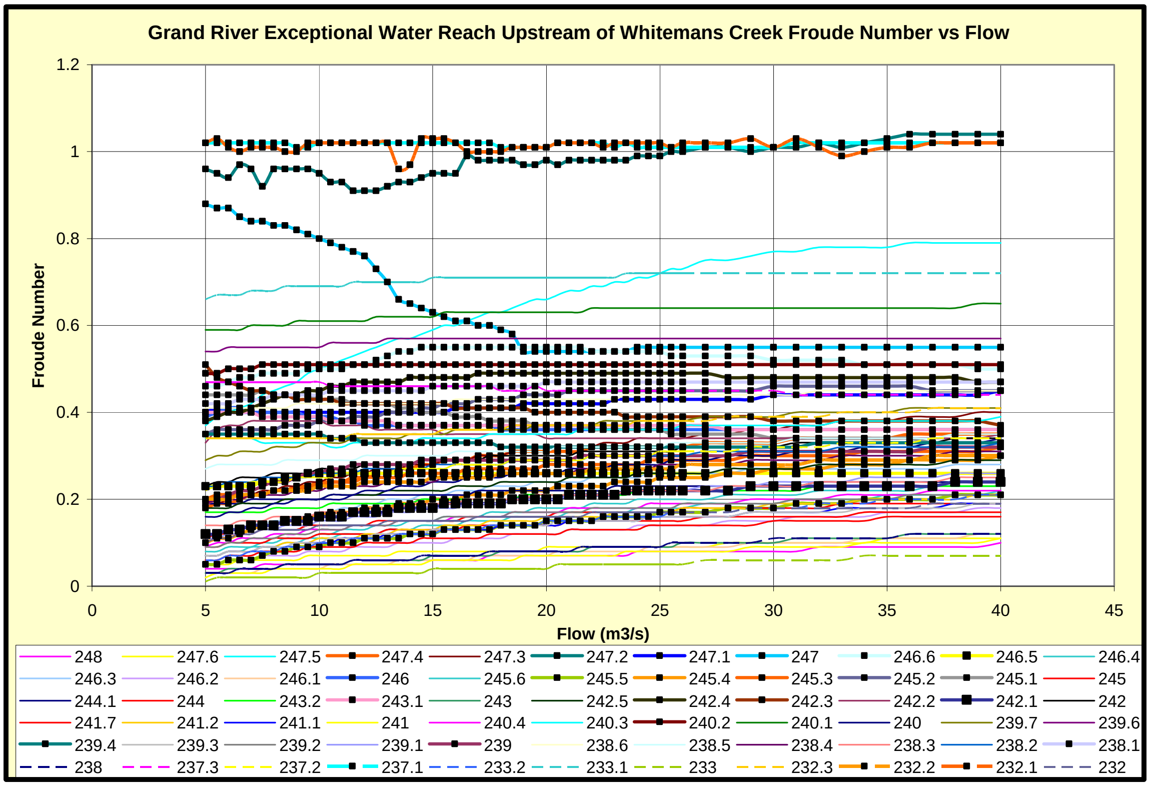

Grand River Exceptional Water Reach Upstream of Whitemans Creek Flow Depth vs Flow
Flow Depth (m)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
248
247.6
247.5
247.4
247.3
247.2
247.1
247
246.6
246.5
246.4
246.3
246.2
246.1
246
245.6
245.5
245.4
245.3
245.2
245.1
245
244.1
244
243.2
243.1
243
242.5
242.4
242.3
242.2
242.1
242
241.7
241.2
241.1
241
240.4
240.3
240.2
240.1
240
239.7
239.6
239.4
239.3
239.2
239.1
239
238.6
238.5
238.4
238.3
238.2
238.1
238
237.3
237.2
237.1
233.2
233.1
233
232.3
232.2
232.1
232

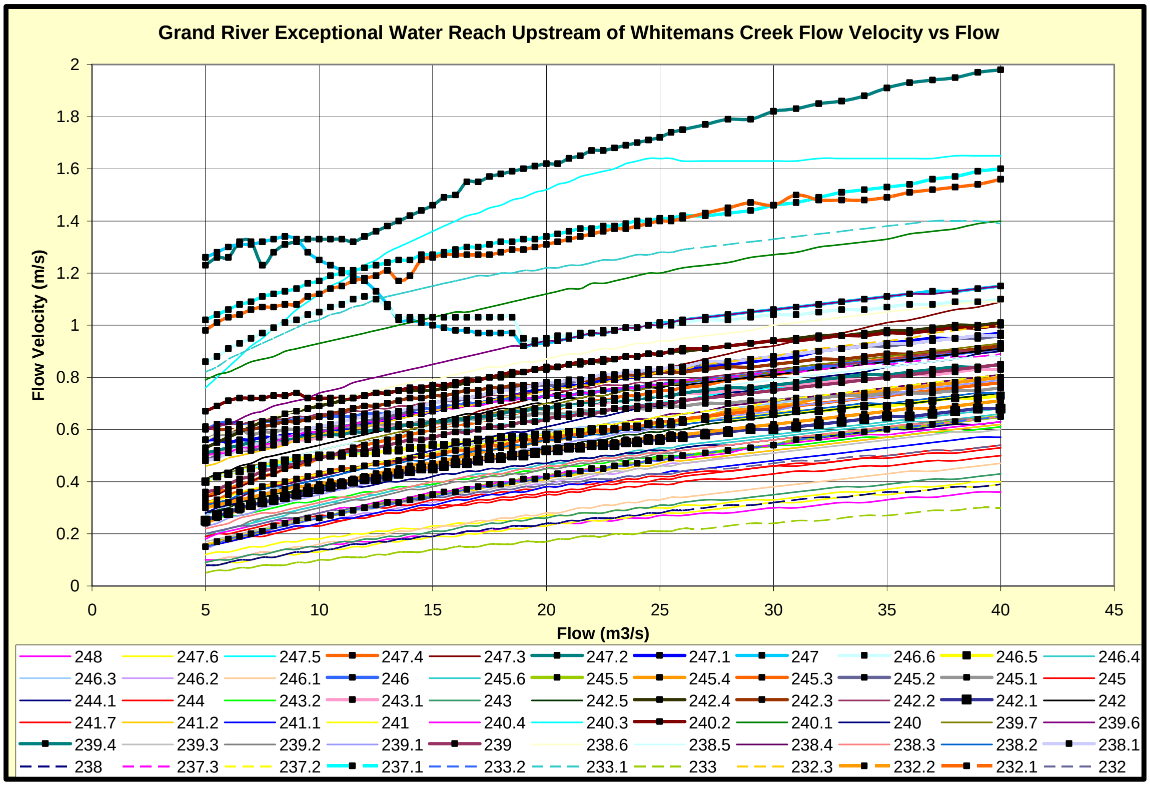

Grand River Exceptional Water Reach Upstream of Whitemans Creek Flow Area vs Flow
Flow Area (m^2)
150
125
100
75
50
25
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
248
247.6
247.5
247.4
247.3
247.2
247.1
247
246.6
246.5
246.4
246.3
246.2
246.1
246
245.6
245.5
245.4
245.3
245.2
245.1
245
244.1
244
243.2
243.1
243
242.5
242.4
242.3
242.2
242.1
242
241.7
241.2
241.1
241
240.4
240.3
240.2
240.1
240
239.7
239.6
239.4
239.3
239.2
239.1
239
238.6
238.5
238.4
238.3
238.2
238.1
238
237.3
237.2
237.1
233.2
233.1
233
232.3
232.2
232.1
232

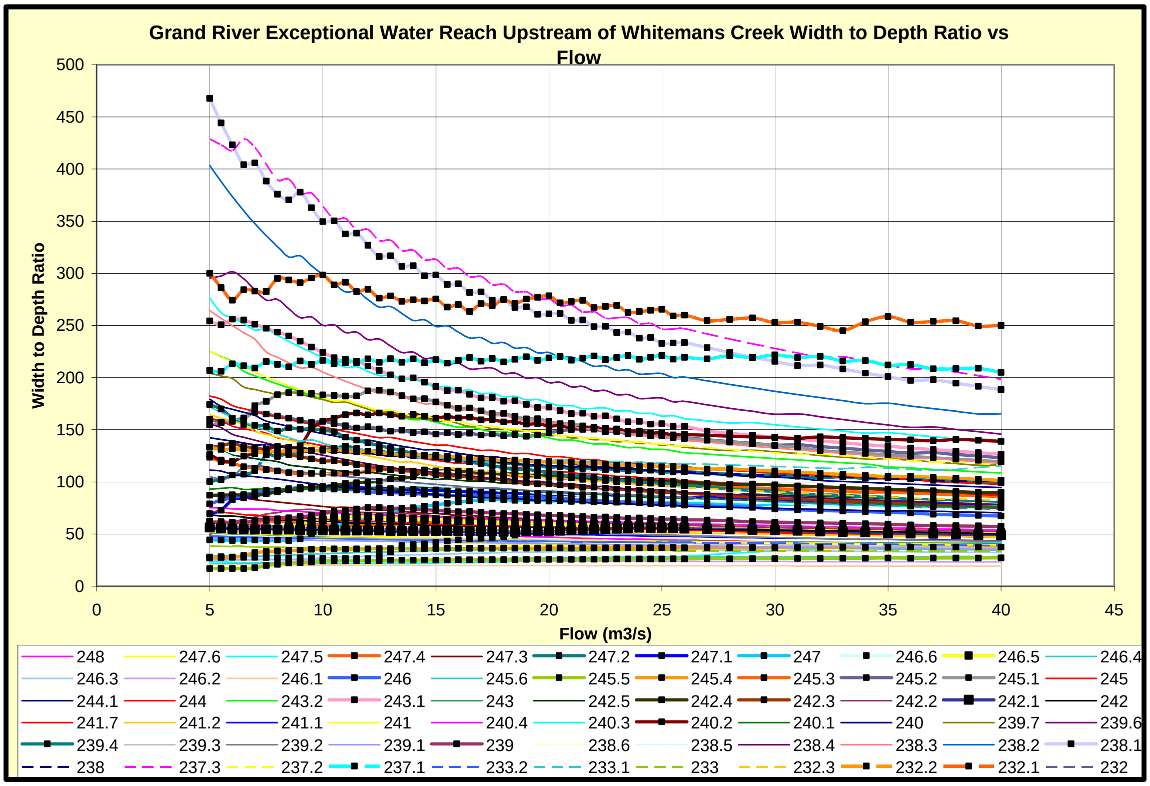

Grand River Exceptional Water Reach Upstream of Whitemans Creek Wetted Perimeter vs Flow
Wetted Perimeter (m)
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
248
247.6
247.5
247.4
247.3
247.2
247.1
247
246.6
246.5
246.4
246.3
246.2
246.1
246
245.6
245.5
245.4
245.3
245.2
245.1
245
244.1
244
243.2
243.1
243
242.5
242.4
242.3
242.2
242.1
242
241.7
241.2
241.1
241
240.4
240.3
240.2
240.1
240
239.7
239.6
239.4
239.3
239.2
239.1
239
238.6
238.5
238.4
238.3
238.2
238.1
238
237.3
237.2
237.1
233.2
233.1
233
232.3
232.2
232.1
232


Grand River Exceptional Water Reach Upstream of Whitemans Creek Topwidth vs Flow
Topwidth (m)
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
248
247.6
247.5
247.4
247.3
247.2
247.1
247
246.6
246.5
246.4
246.3
246.2
246.1
246
245.6
245.5
245.4
245.3
245.2
245.1
245
244.1
244
243.2
243.1
243
242.5
242.4
242.3
242.2
242.1
242
241.7
241.2
241.1
241
240.4
240.3
240.2
240.1
240
239.7
239.6
239.4
239.3
239.2
239.1
239
238.6
238.5
238.4
238.3
238.2
238.1
238
237.3
237.2
237.1
233.2
233.1
233
232.3
232.2
232.1
232


Grand River Exceptional Water Reach Upstream of Whitemans Creek Hydraulic Radius vs Flow
Radius (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
248
247.6
247.5
247.4
247.3
247.2
247.1
247
246.6
246.5
246.4
246.3
246.2
246.1
246
245.6
245.5
245.4
245.3
245.2
245.1
245
244.1
244
243.2
243.1
243
242.5
242.4
242.3
242.2
242.1
242
241.7
241.2
241.1
241
240.4
240.3
240.2
240.1
240
239.7
239.6
239.4
239.3
239.2
239.1
239
238.6
238.5
238.4
238.3
238.2
238.1
238
237.3
237.2
237.1
233.2
233.1
233
232.3
232.2
232.1
232

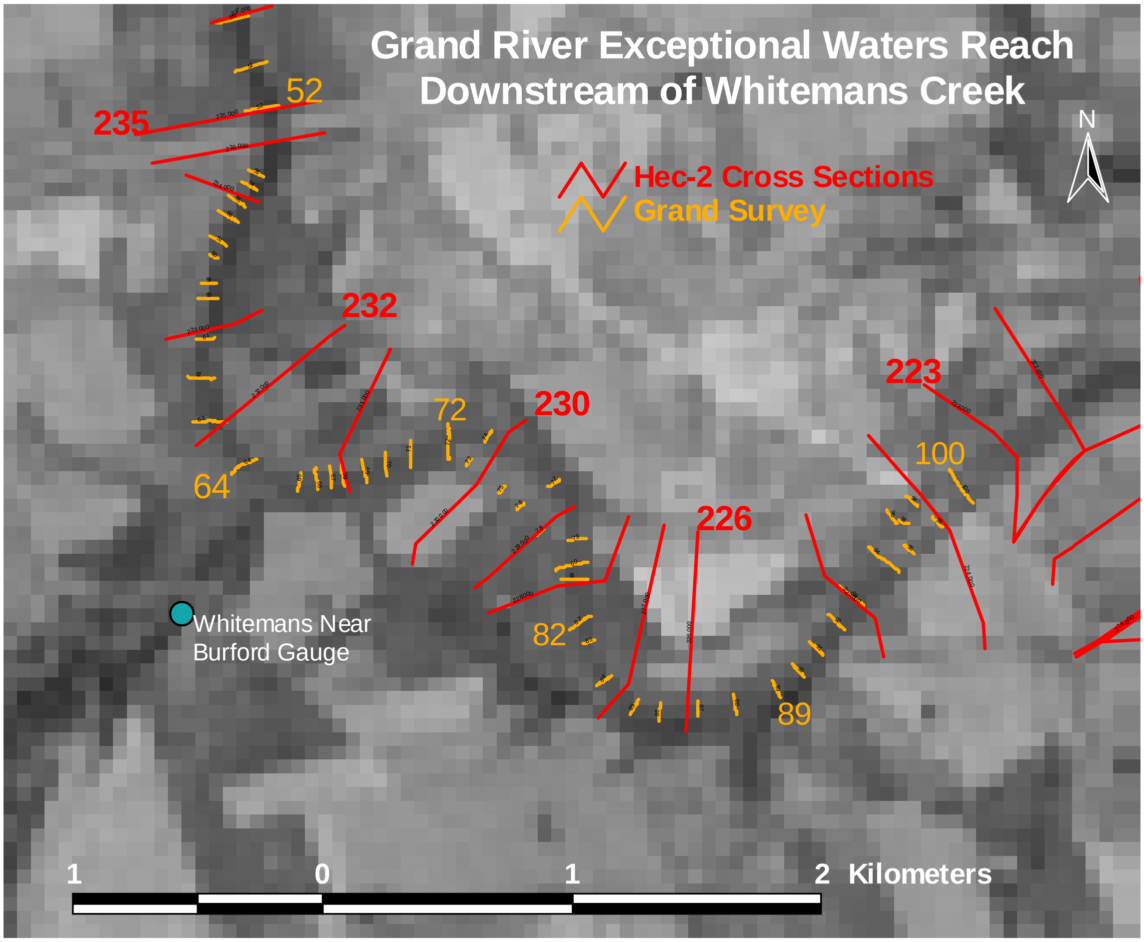

Grand River Exceptional Water Reach Upstream of Whitemans Creek Froude Number vs Flow
Froude Number
0
0.2
0.4
0.6
0.8
1
1.2
Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
248
247.6
247.5
247.4
247.3
247.2
247.1
247
246.6
246.5
246.4
246.3
246.2
246.1
246
245.6
245.5
245.4
245.3
245.2
245.1
245
244.1
244
243.2
243.1
243
242.5
242.4
242.3
242.2
242.1
242
241.7
241.2
241.1
241
240.4
240.3
240.2
240.1
240
239.7
239.6
239.4
239.3
239.2
239.1
239
238.6
238.5
238.4
238.3
238.2
238.1
238
237.3
237.2
237.1
233.2
233.1
233
232.3
232.2
232.1
232

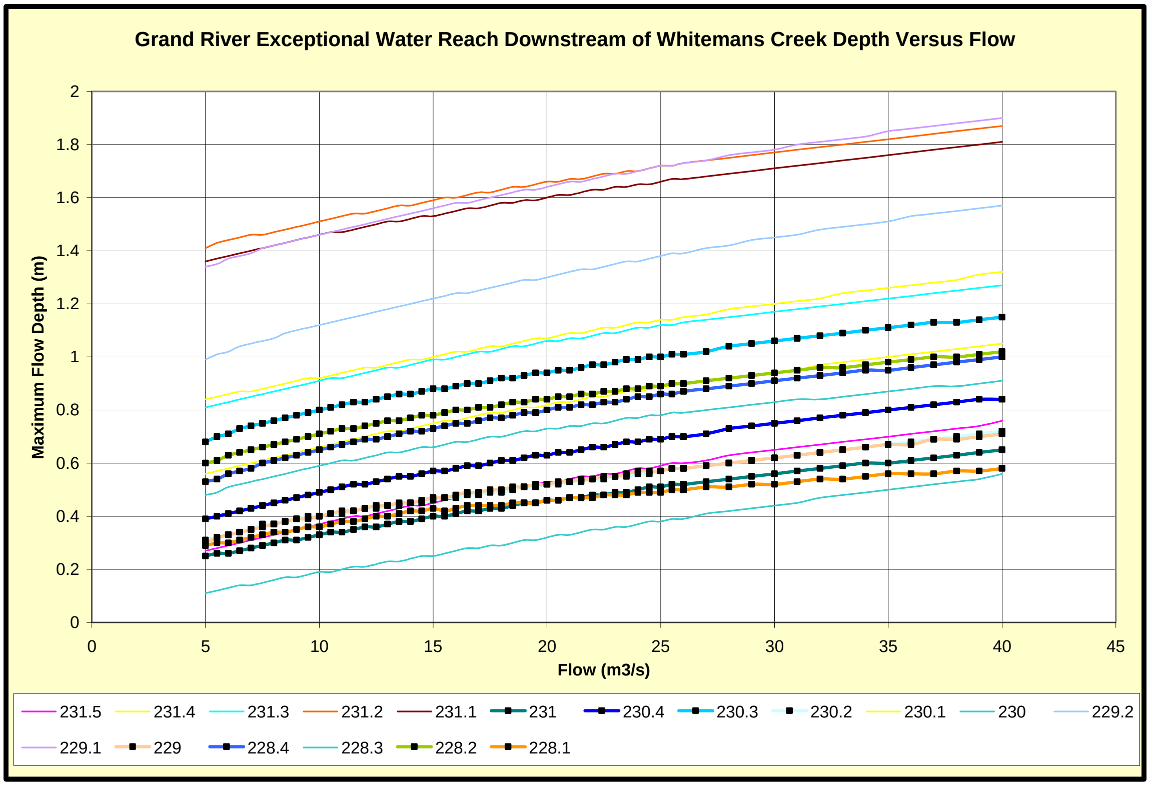

Grand River Exceptional Water Reach Upstream of Whitemans Creek Flow Velocity vs Flow
Flow Velocity (m/s)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
248 247.6 247.5 247.4 247.3 247.2 247.1 247 246.6 246.5 246.4
246.3 246.2 246.1 246 245.6 245.5 245.4 245.3 245.2 245.1 245
244.1 244 243.2 243.1 243 242.5 242.4 242.3 242.2 242.1 242
241.7 241.2 241.1 241 240.4 240.3 240.2 240.1 240 239.7 239.6
239.4 239.3 239.2 239.1 239 238.6 238.5 238.4 238.3 238.2 238.1
238 237.3 237.2 237.1 233.2 233.1 233 232.3 232.2 232.1 232

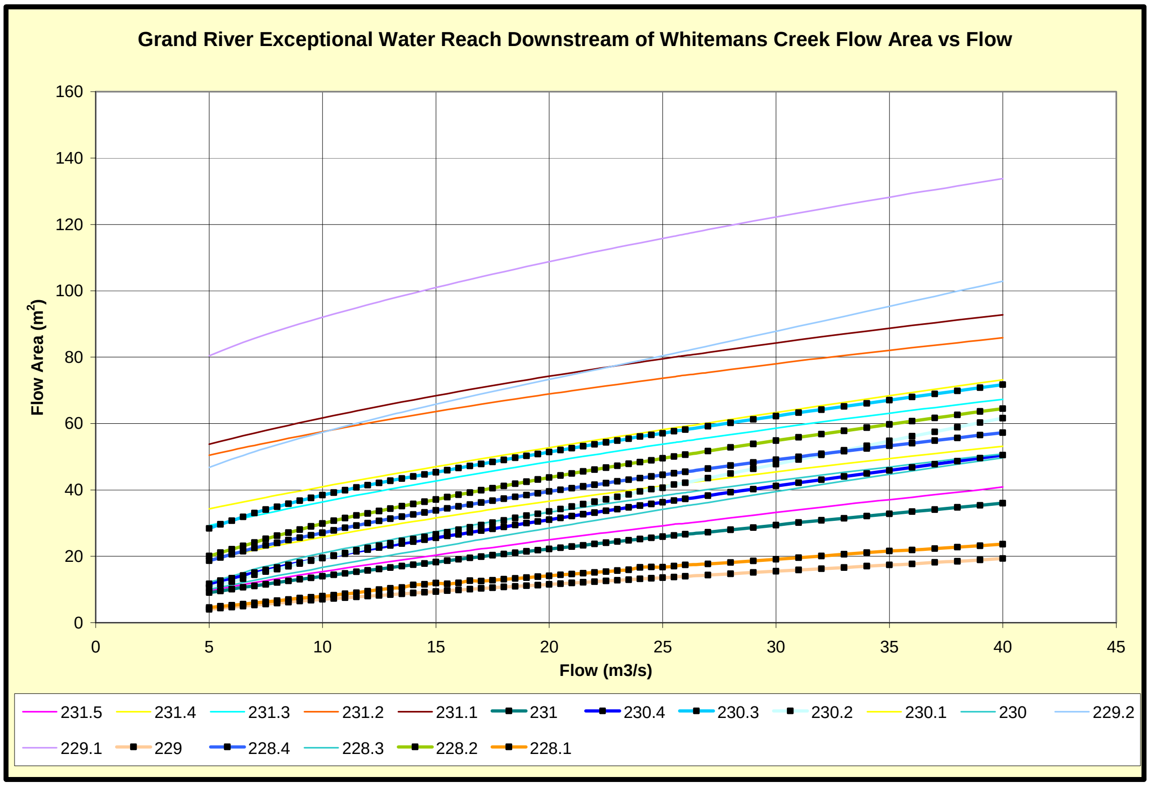

Grand River Exceptional Water Reach Upstream of Whitemans Creek Width to Depth Ratio vs Flow
Width to Depth Ratio
500
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
248 247.6 247.5 247.4 247.3 247.2 247.1 247 246.6 246.5 246.4
246.3 246.2 246.1 246 245.6 245.5 245.4 245.3 245.2 245.1 245
244.1 244 243.2 243.1 243 242.5 242.4 242.3 242.2 242.1 242
241.7 241.2 241.1 241 240.4 240.3 240.2 240.1 240 239.7 239.6
239.4 239.3 239.2 239.1 239 238.6 238.5 238.4 238.3 238.2 238.1
238 237.3 237.2 237.1 233.2 233.1 233 232.3 232.2 232.1 232

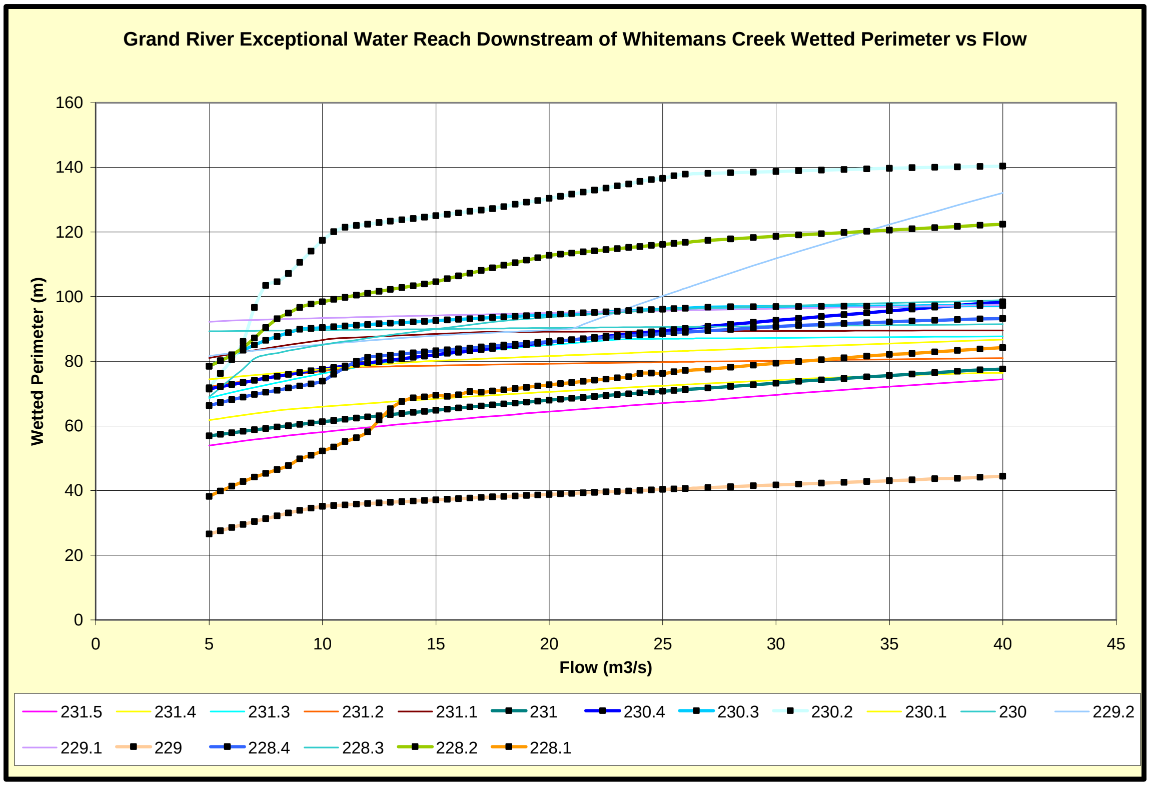
D-9: GRAND RIVER EXCEPTIONAL WATERS REACH – Downstream

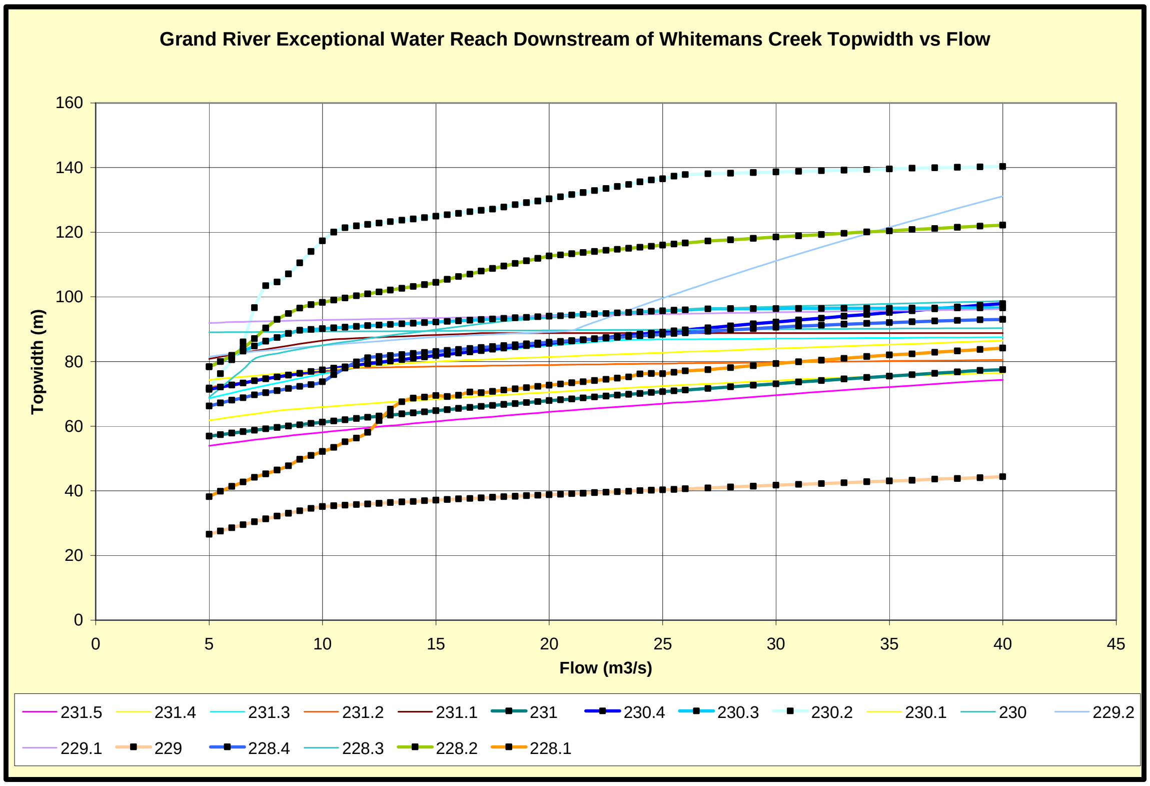
Downstream of Whiteman's Creek

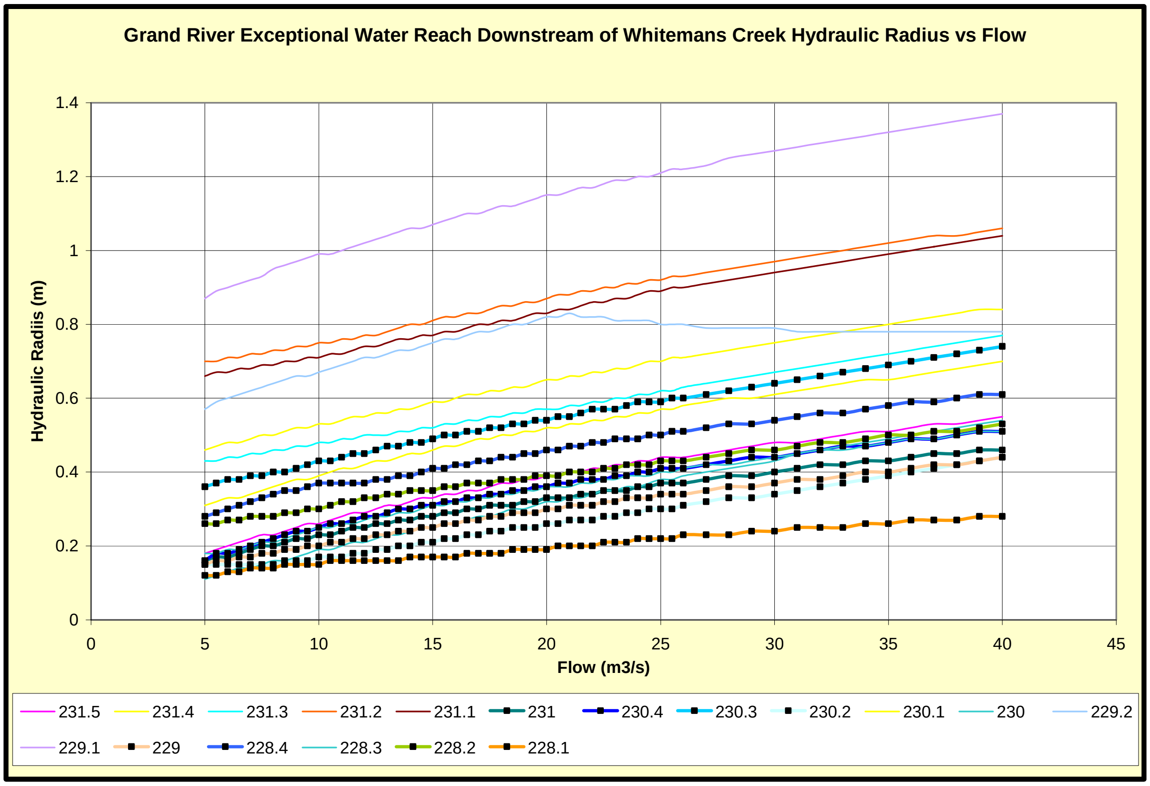


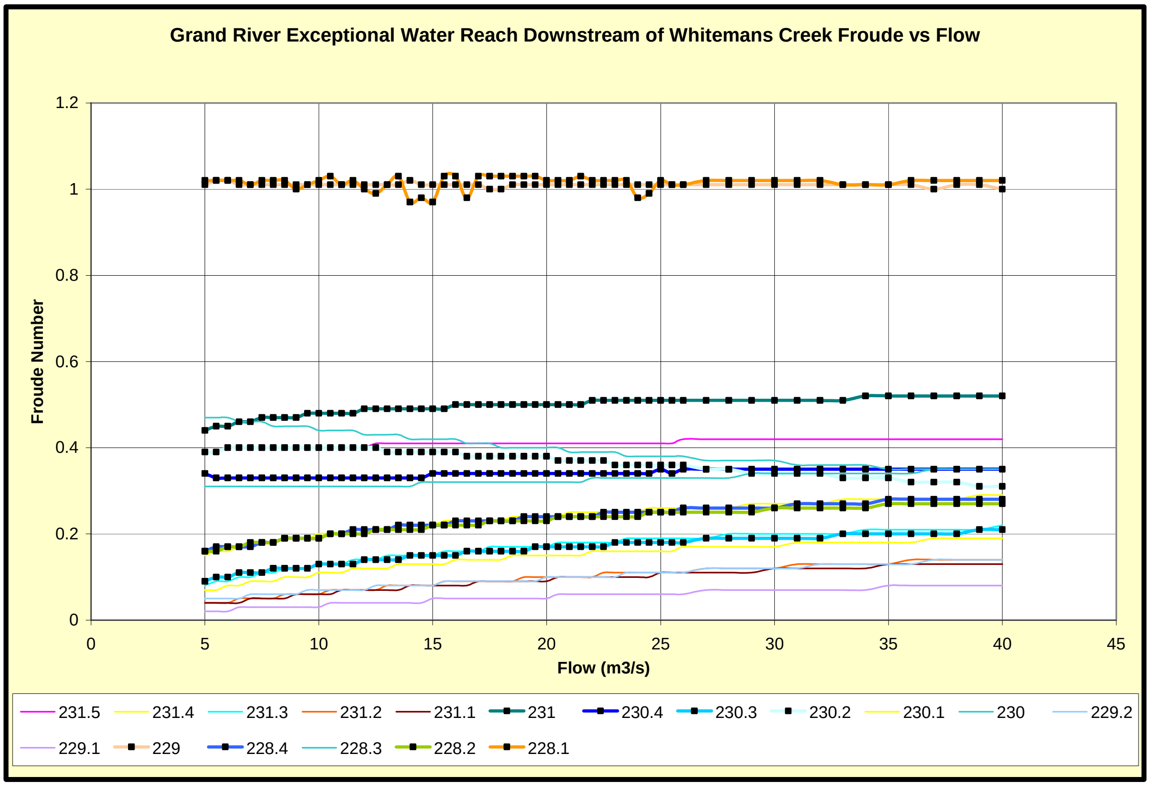

Grand River Exceptional Water Reach Downstream of Whitemans Creek Depth Versus Flow
Maximum Flow Depth (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
231.5
231.4
231.3
231.2
231.1
231
230.4
230.3
230.2
230.1
230
229.2
229.1
229
228.4
228.3
228.2
228.1

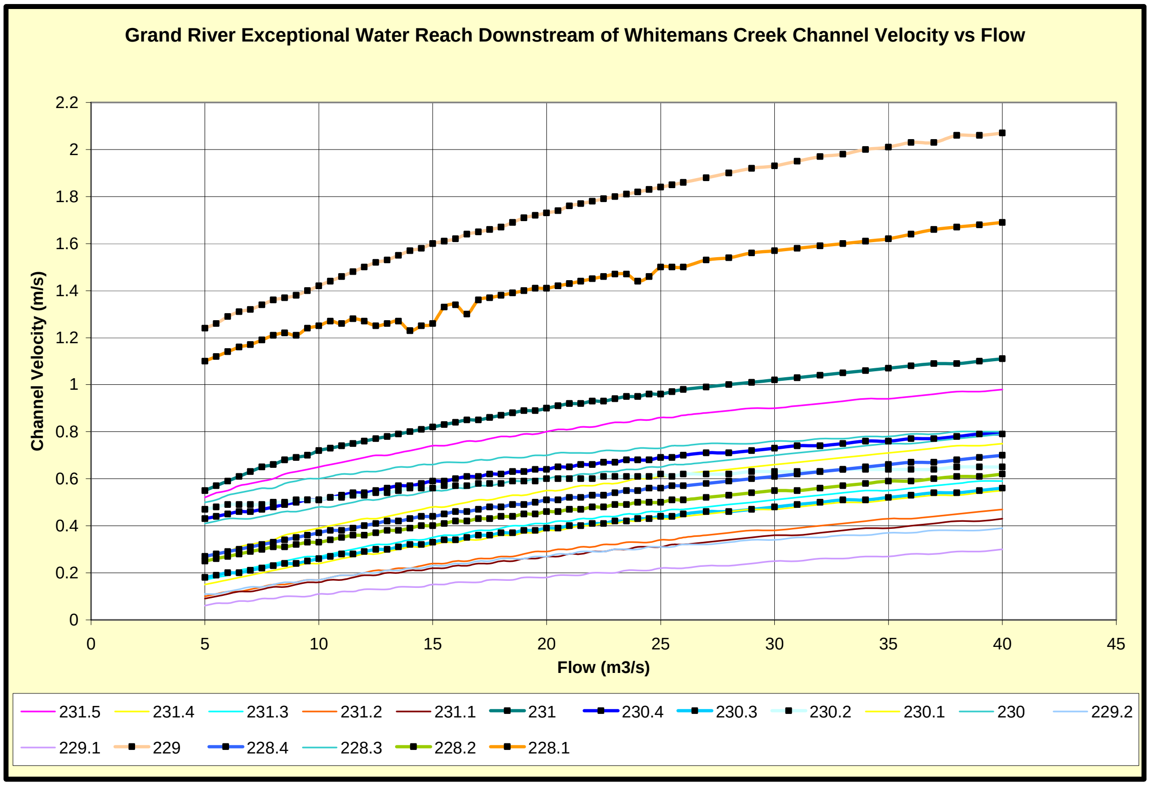

Grand River Exceptional Water Reach Downstream of Whitemans Creek Flow Area vs Flow
Flow Area (m²)
0
20
40
60
80
100
120
140
160
Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
231.5
231.4
231.3
231.2
231.1
231
230.4
230.3
230.2
230.1
230
229.2
229.1
229
228.4
228.3
228.2
228.1

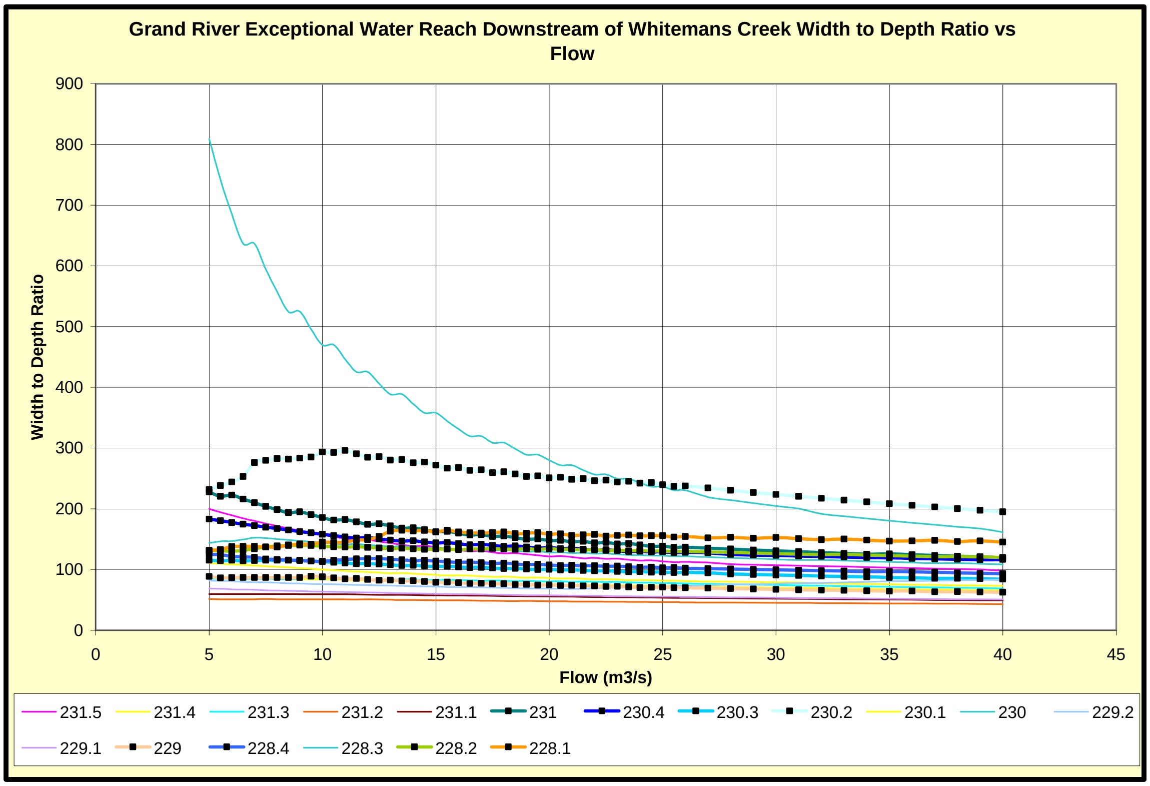

Grand River Exceptional Water Reach Downstream of Whitemans Creek Wetted Perimeter vs Flow
Wetted Perimeter (m)
0
20
40
60
80
100
120
140
160
Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
231.5
231.4
231.3
231.2
231.1
231
230.4
230.3
230.2
230.1
230
229.2
229.1
229
228.4
228.3
228.2
228.1


Grand River Exceptional Water Reach Downstream of Whitemans Creek Topwidth vs Flow
Topwidth (m)
0
20
40
60
80
100
120
140
160
Flow (m3/s)
0
5
10
15
20
25
30
35
40
45
231.5
231.4
231.3
231.2
231.1
231
230.4
230.3
230.2
230.1
230
229.2
229.1
229
228.4
228.3
228.2
228.1

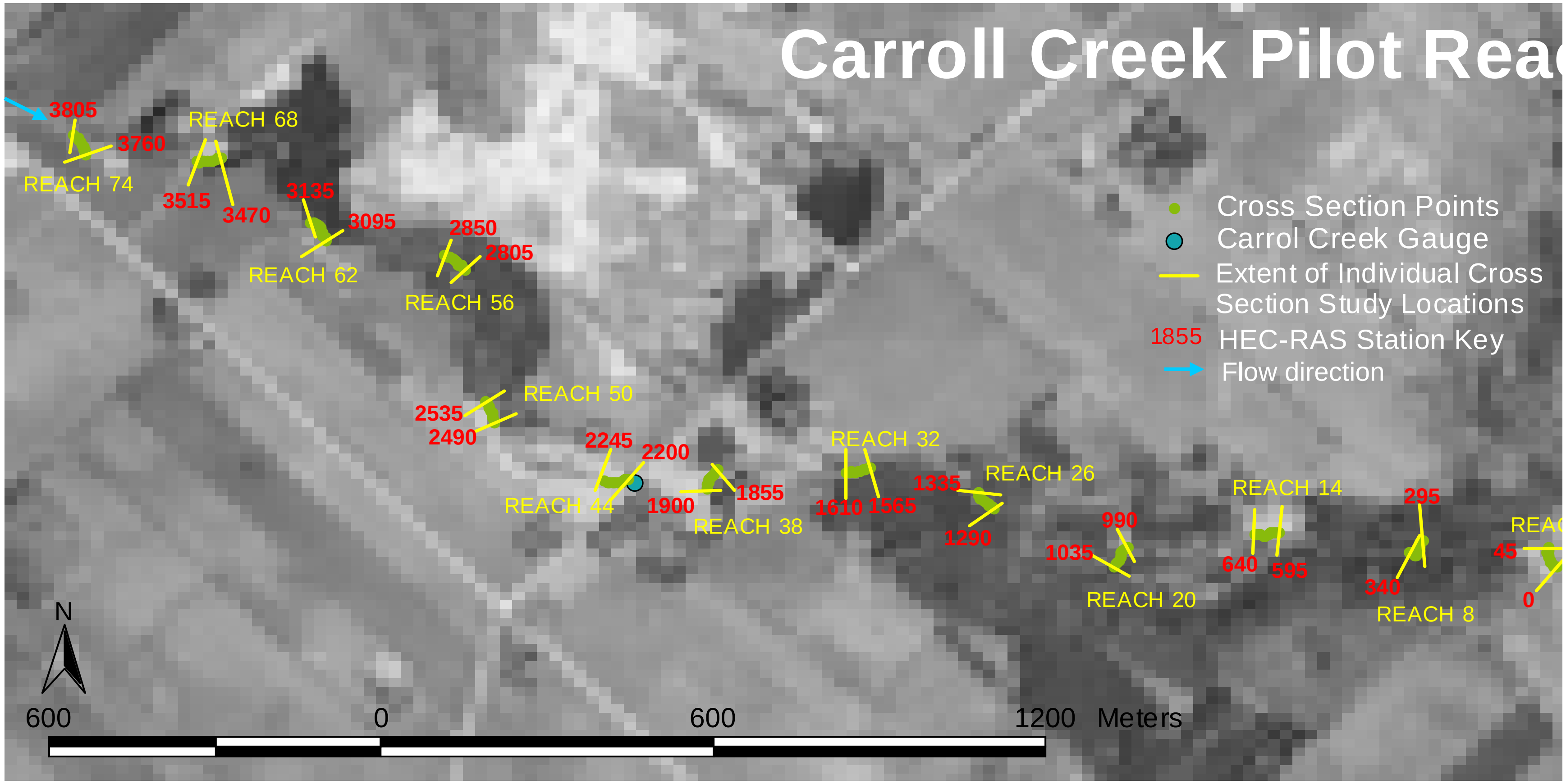

Grand River Exceptional Water Reach Downstream of Whitemans Creek Hydraulic Radius vs Flow
Hydraulic Radiis (m)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
231.5
231.4
231.3
231.2
231.1
231
230.4
230.3
230.2
230.1
230
229.2
229.1
229
228.4
228.3
228.2
228.1

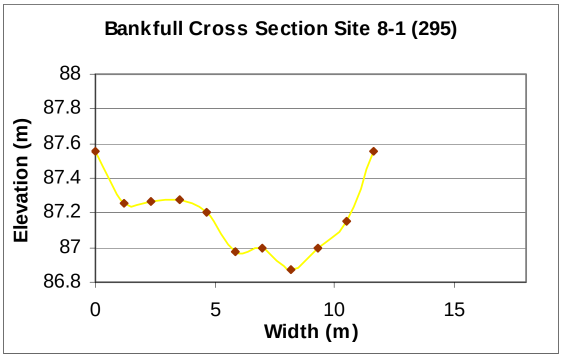

Grand River Exceptional Water Reach Downstream of Whitemans Creek Froude vs Flow
Froude Number
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
231.5
231.4
231.3
231.2
231.1
231
230.4
230.3
230.2
230.1
230
229.2
229.1
229
228.4
228.3
228.2
228.1


Grand River Exceptional Water Reach Downstream of Whitemans Creek Channel Velocity vs Flow
Channel Velocity (m/s)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
231.5
231.4
231.3
231.2
231.1
231
230.4
230.3
230.2
230.1
230
229.2
229.1
229
228.4
228.3
228.2
228.1

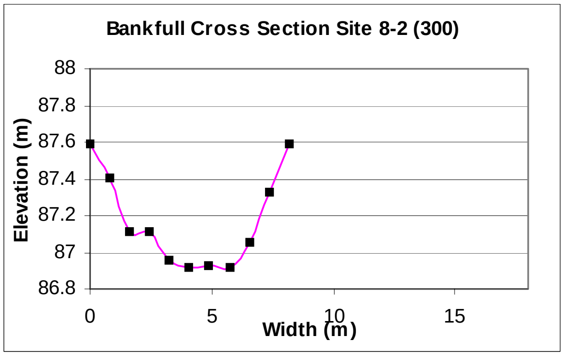

Grand River Exceptional Water Reach Downstream of Whitemans Creek Width to Depth Ratio vs Flow
Width to Depth Ratio
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
45
Flow (m3/s)
231.5
231.4
231.3
231.2
231.1
231
230.4
230.3
230.2
230.1
230
229.2
229.1
229
228.4
228.3
228.2
228.1

D-10: CARROLL CREEK REACH

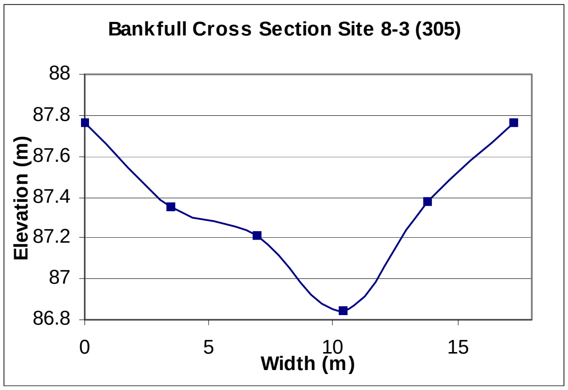




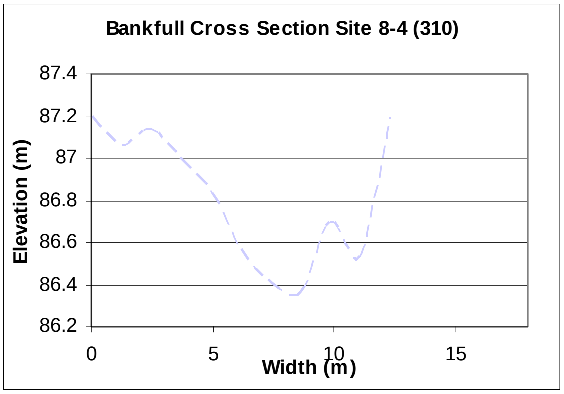
Bankfull Cross Section Site 8-1 (295)



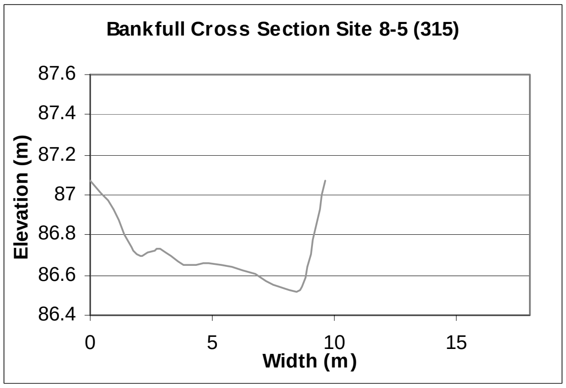
Bankfull Cross Section Site 8-2 (300)



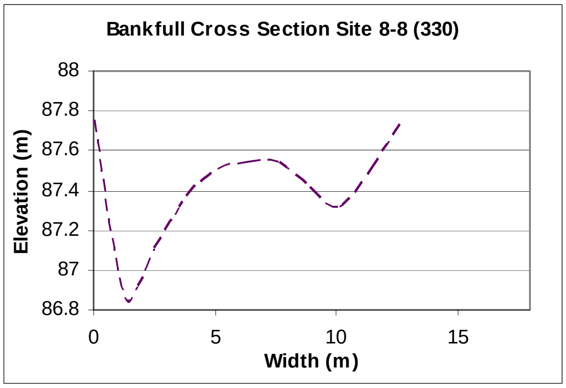
Bankfull Cross Section Site 8-3 (305)



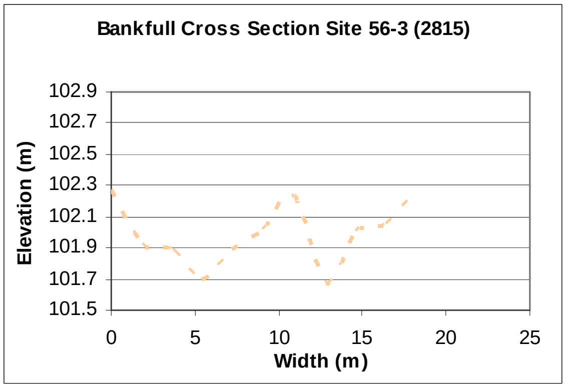
Bankfull Cross Section Site 8-4 (310)

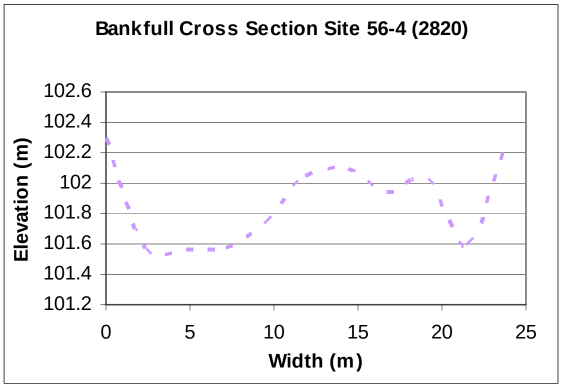


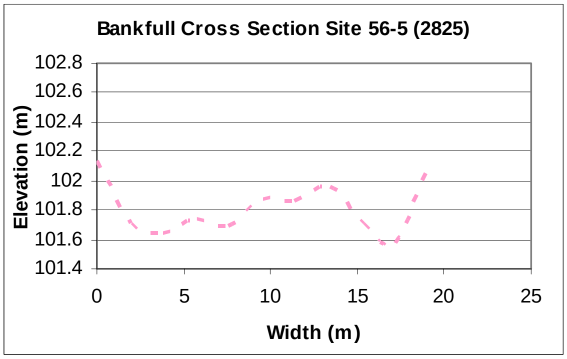
Bankfull Cross Section Site 8-5 (315)

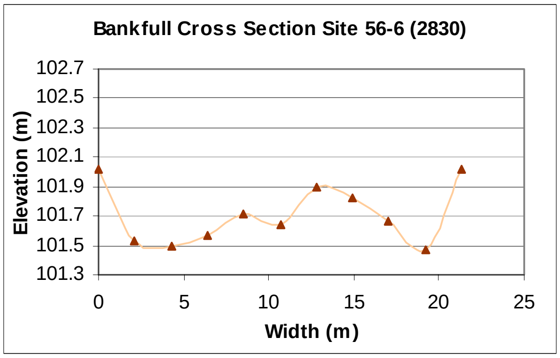


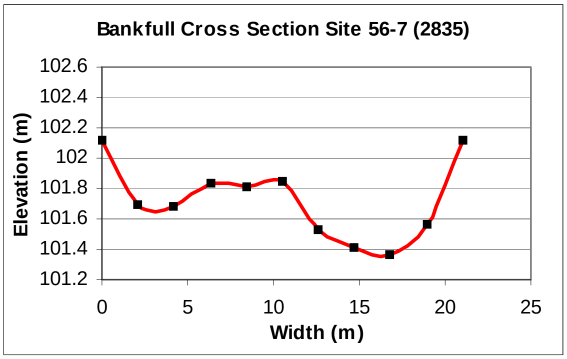
Bankfull Cross Section Site 8-8 (330)

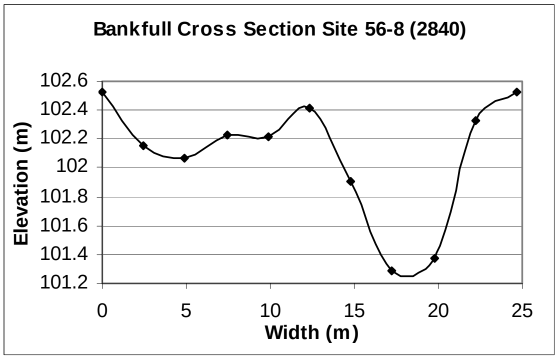

Bankfull Cross Section Site 56-3 (2815)
Elevation (m)
102.9
102.7
102.5
102.3
102.1
101.9
101.7
101.5
0
5
10
15
20
25
Width (m)

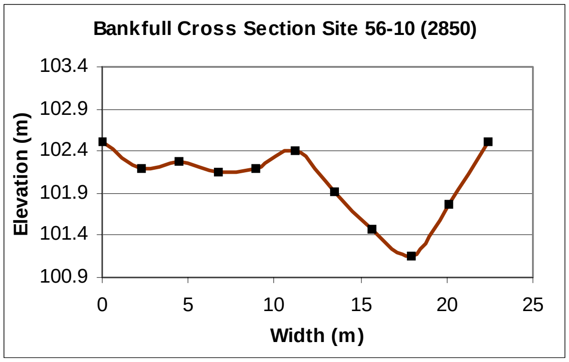

Bankfull Cross Section Site 56-4 (2820)
Elevation (m)
102.6
102.4
102.2
102
101.8
101.6
101.4
101.2
0
5
10
15
20
25
Width (m)

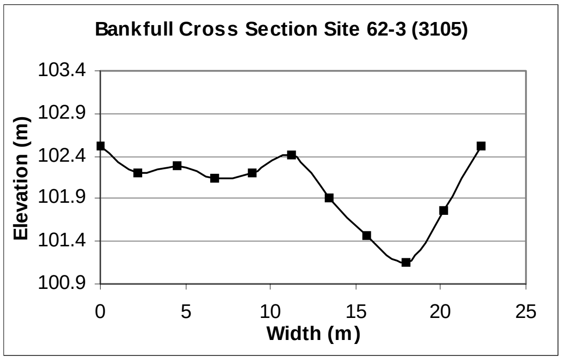

Bankfull Cross Section Site 56-5 (2825)
Elevation (m)
102.8
102.6
102.4
102.2
102
101.8
101.6
101.4
0
5
10
15
20
25
Width (m)

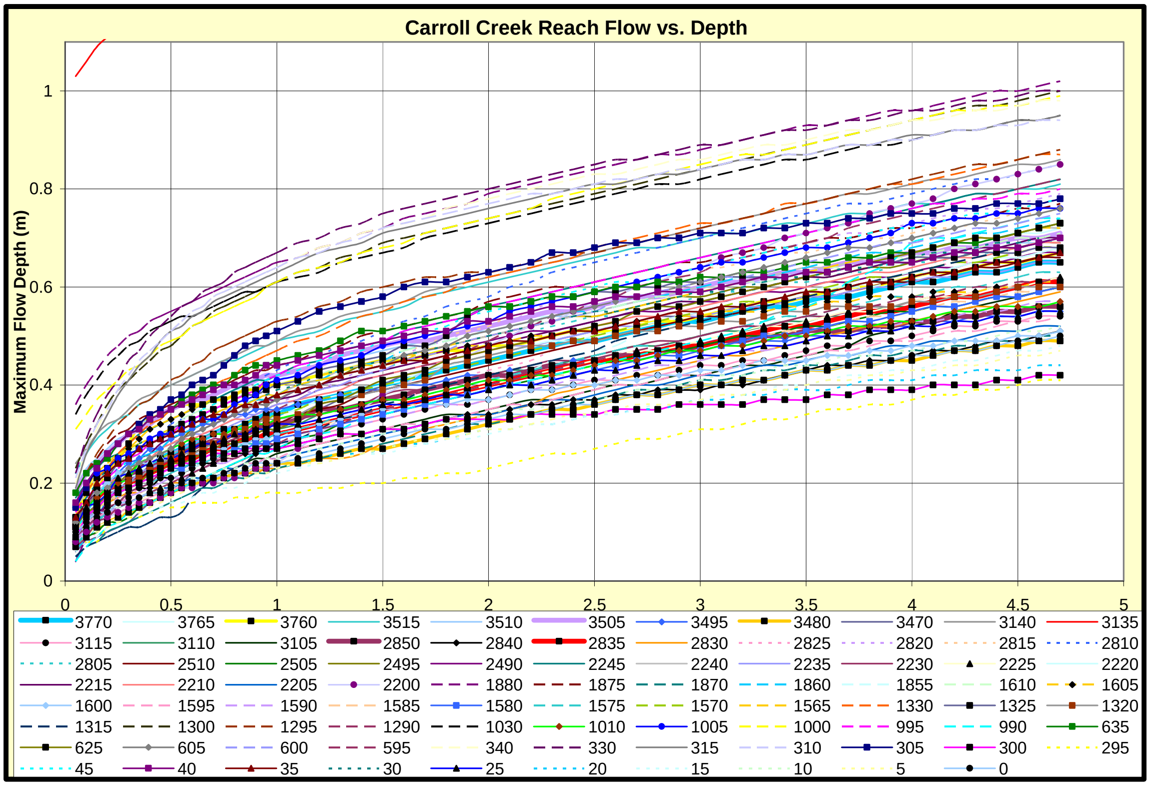

Bankfull Cross Section Site 56-6 (2830)
Elevation (m)
102.7
102.5
102.3
102.1
101.9
101.7
101.5
101.3
0
5
10
15
20
25
Width (m)

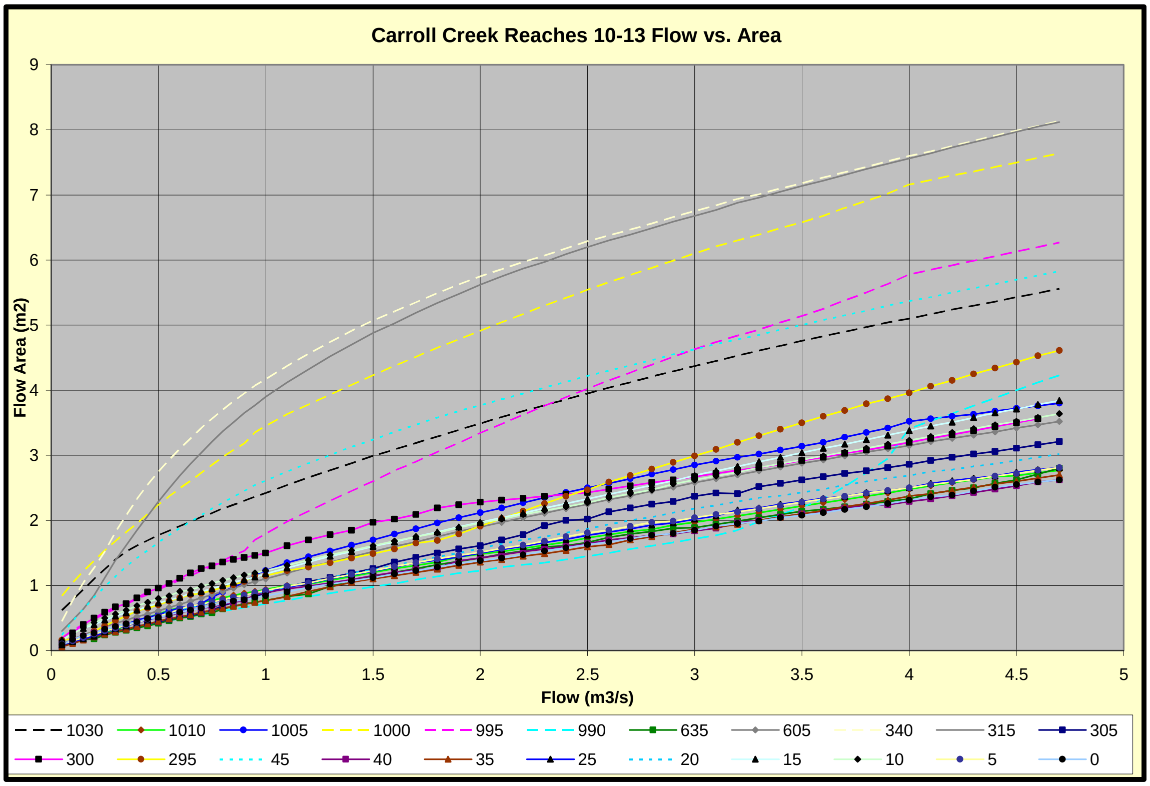

Bankfull Cross Section Site 56-7 (2835)
Elevation (m)
102.6
102.4
102.2
102
101.8
101.6
101.4
101.2
0
5
10
15
20
25
Width (m)

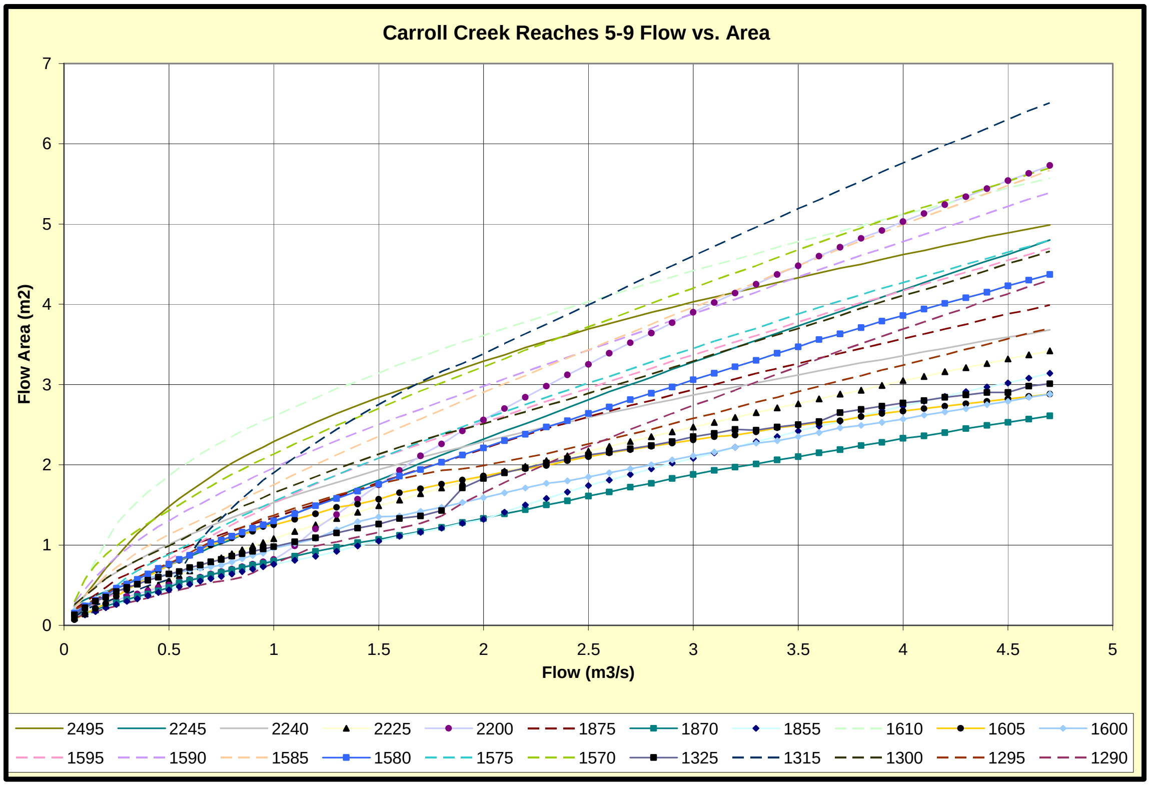

Bankfull Cross Section Site 56-8 (2840)
Elevation (m)
102.6
102.4
102.2
102
101.8
101.6
101.4
101.2
0
5
10
15
20
25
Width (m)

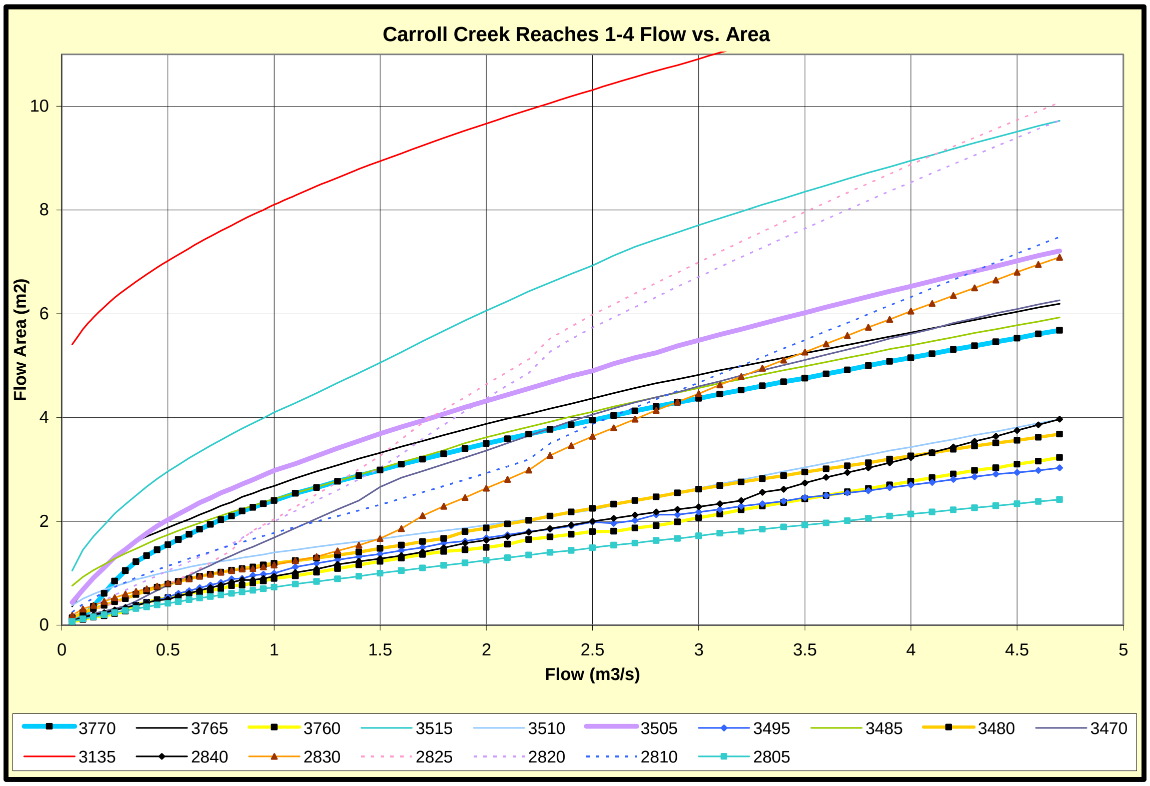

Bankfull Cross Section Site 56-10 (2850)
Elevation (m)
103.4
102.9
102.4
101.9
101.4
100.9
0
5
10
15
20
25
Width (m)

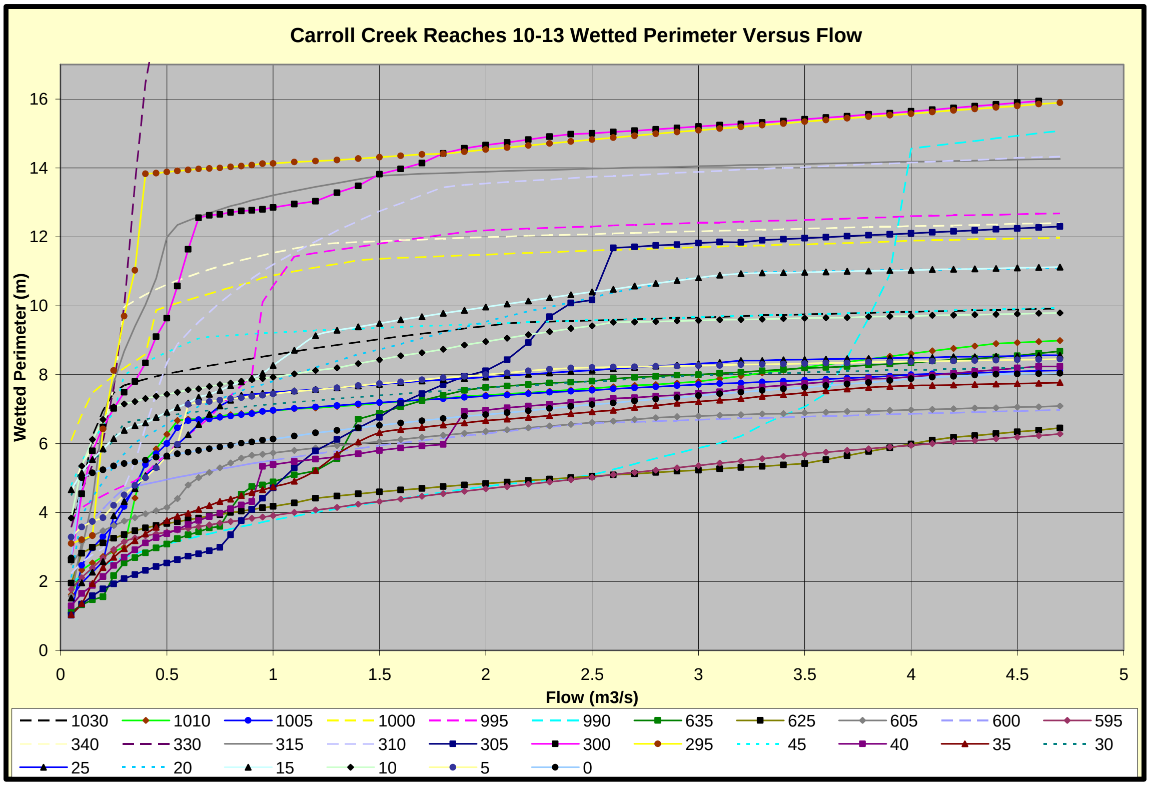

Bankfull Cross Section Site 62-3 (3105)
Elevation (m)
103.4
102.9
102.4
101.9
101.4
100.9
0
5
10
15
20
25
Width (m)

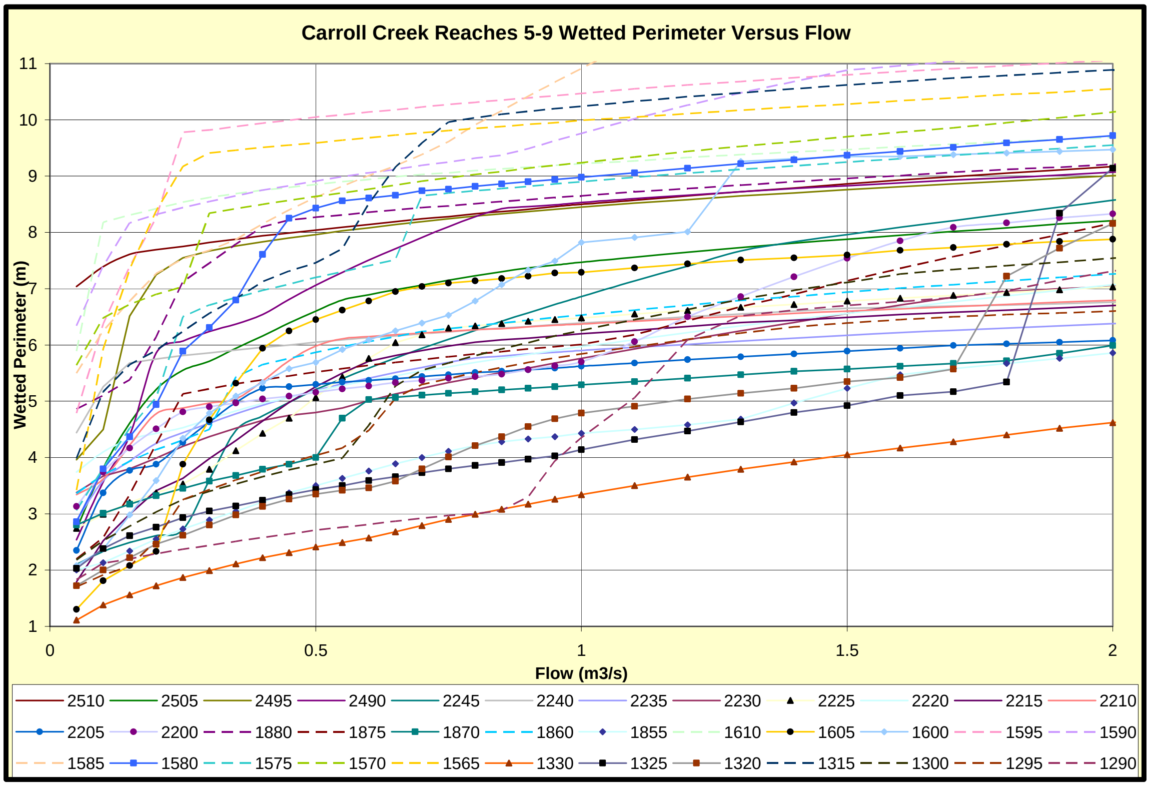

Carroll Creek Reach Flow vs. Depth
Maximum Flow Depth (m)
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
3770 3765 3760 3515 3510 3505 3495 3480 3470 3140 3135
3115 3110 3105 2850 2840 2835 2830 2825 2820 2815 2810
2805 2510 2505 2495 2490 2245 2240 2235 2230 2225 2220
2215 2210 2205 2200 1880 1875 1870 1860 1855 1610 1605
1600 1595 1590 1585 1580 1575 1570 1565 1330 1325 1320
1315 1300 1295 1290 1030 1010 1005 1000 995 990 635
625 605 600 595 340 330 315 310 305 300 295
45 40 35 30 25 20 15 10 5 0

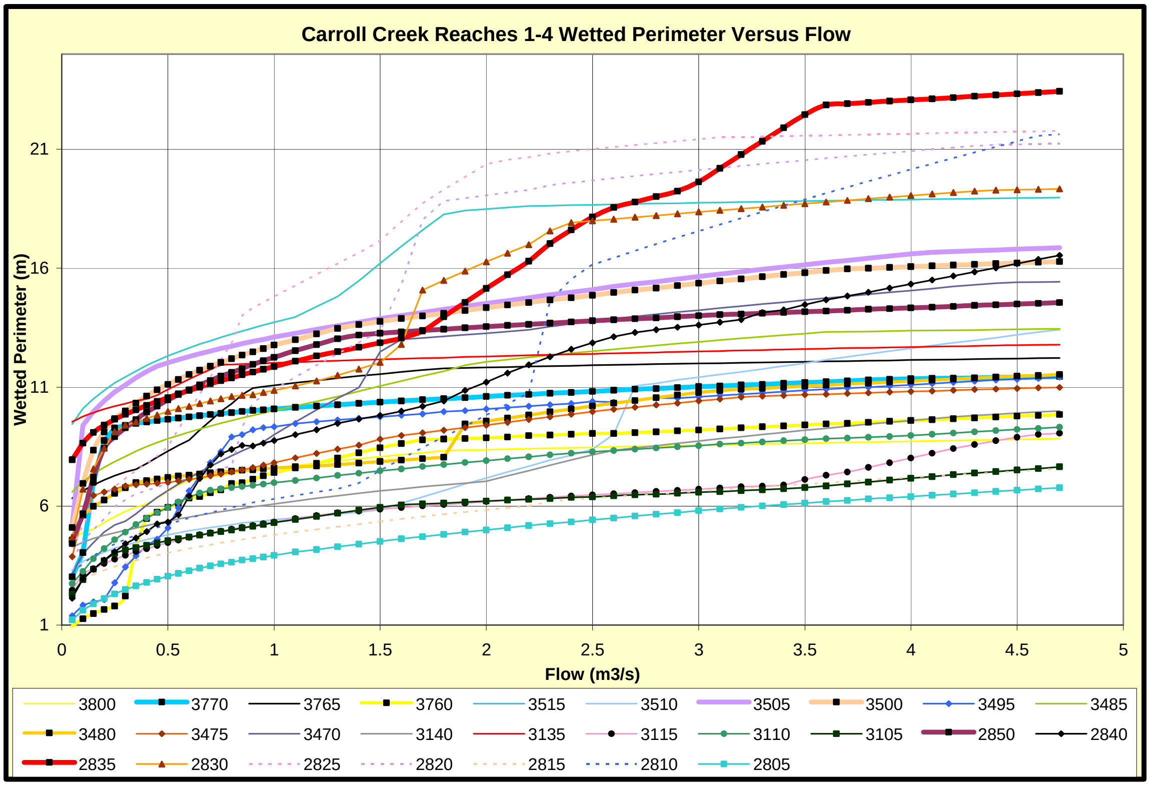

Carroll Creek Reaches 10-13 Flow vs. Area
Flow Area (m2)
Flow (m3/s)
0
1
2
3
4
5
6
7
8
9
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1030 1010 1005 1000 995 990 635 605 340 315 305
300 295 45 40 35 25 20 15 10 5 0

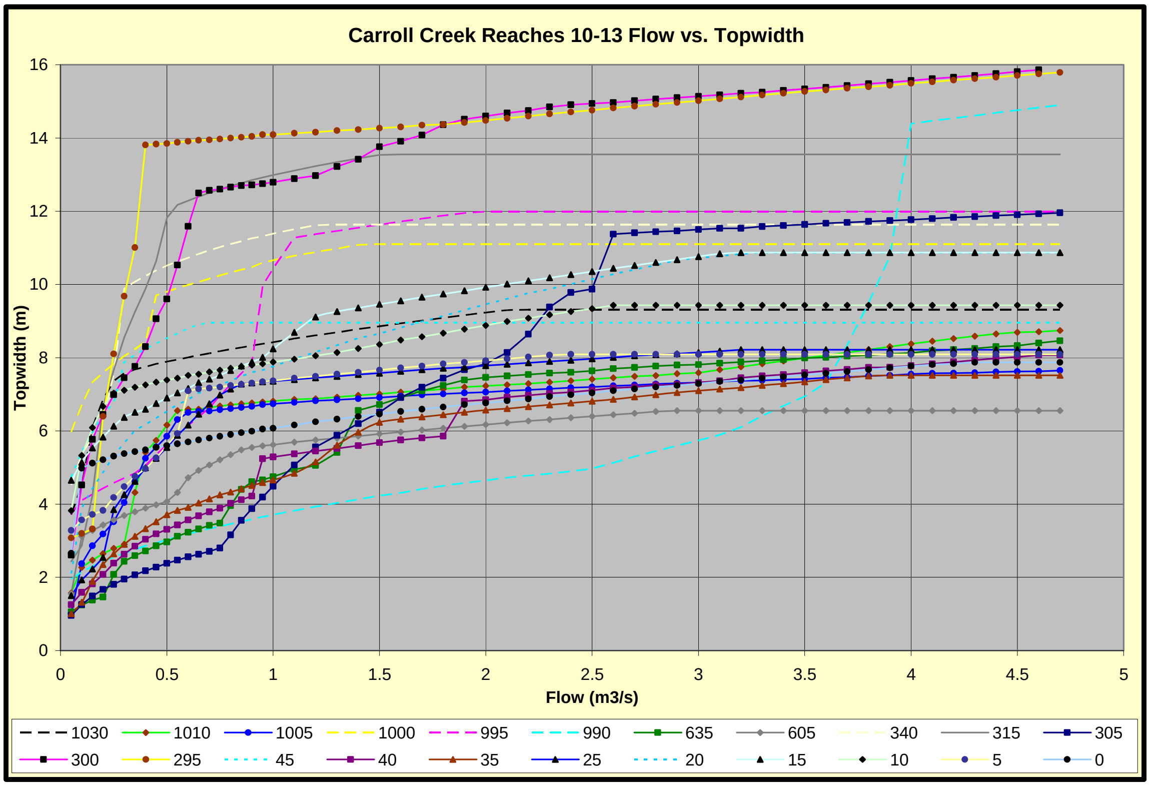

Carroll Creek Reaches 5-9 Flow vs. Area
Flow Area (m2)
0
1
2
3
4
5
6
7
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
2495
2245
2240
2225
2200
1875
1870
1855
1610
1605
1600
1595
1590
1585
1580
1575
1570
1325
1315
1300
1295
1290

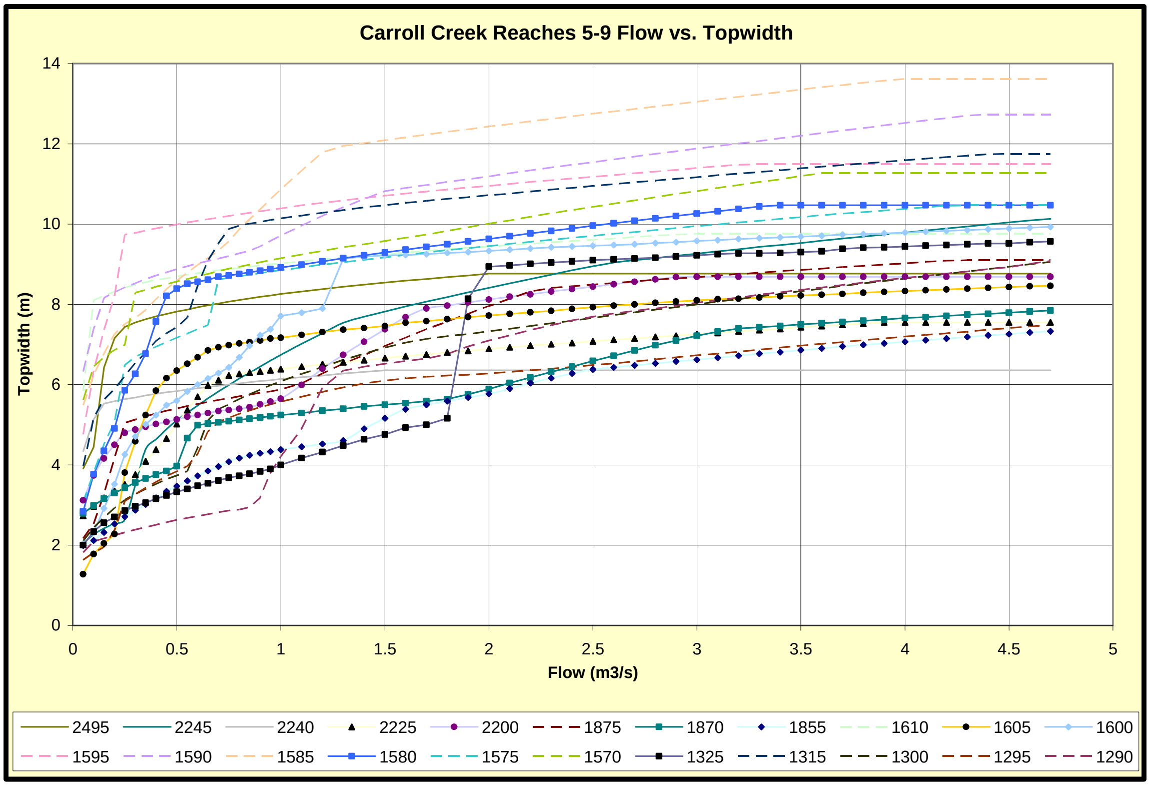

Carroll Creek Reaches 1-4 Flow vs. Area
Flow Area (m2)
0
2
4
6
8
10
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
3770
3765
3760
3515
3510
3505
3495
3485
3480
3470
3135
2840
2830
2825
2820
2810
2805

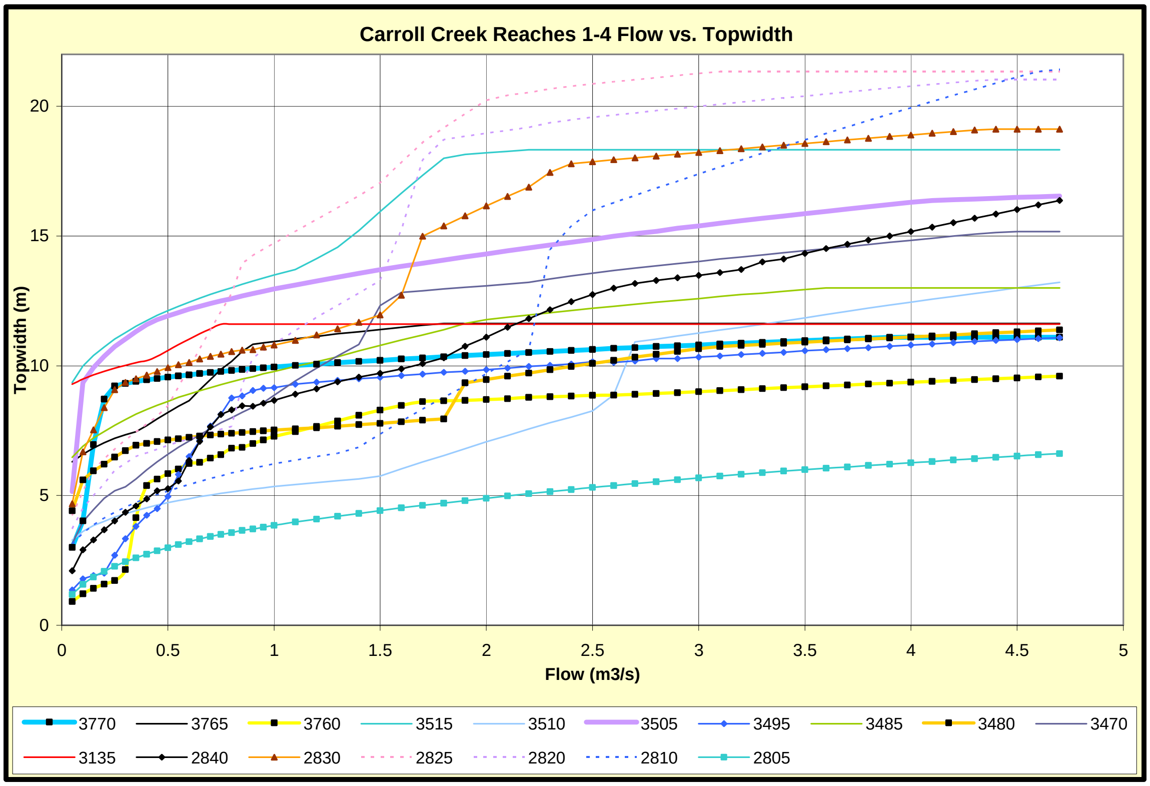

Carroll Creek Reaches 10-13 Wetted Perimeter Versus Flow
Wetted Perimeter (m)
Flow (m3/s)
0
2
4
6
8
10
12
14
16
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1030
1010
1005
1000
995
990
635
625
605
600
595
340
330
315
310
305
300
295
45
40
35
30
25
20
15
10
5
0

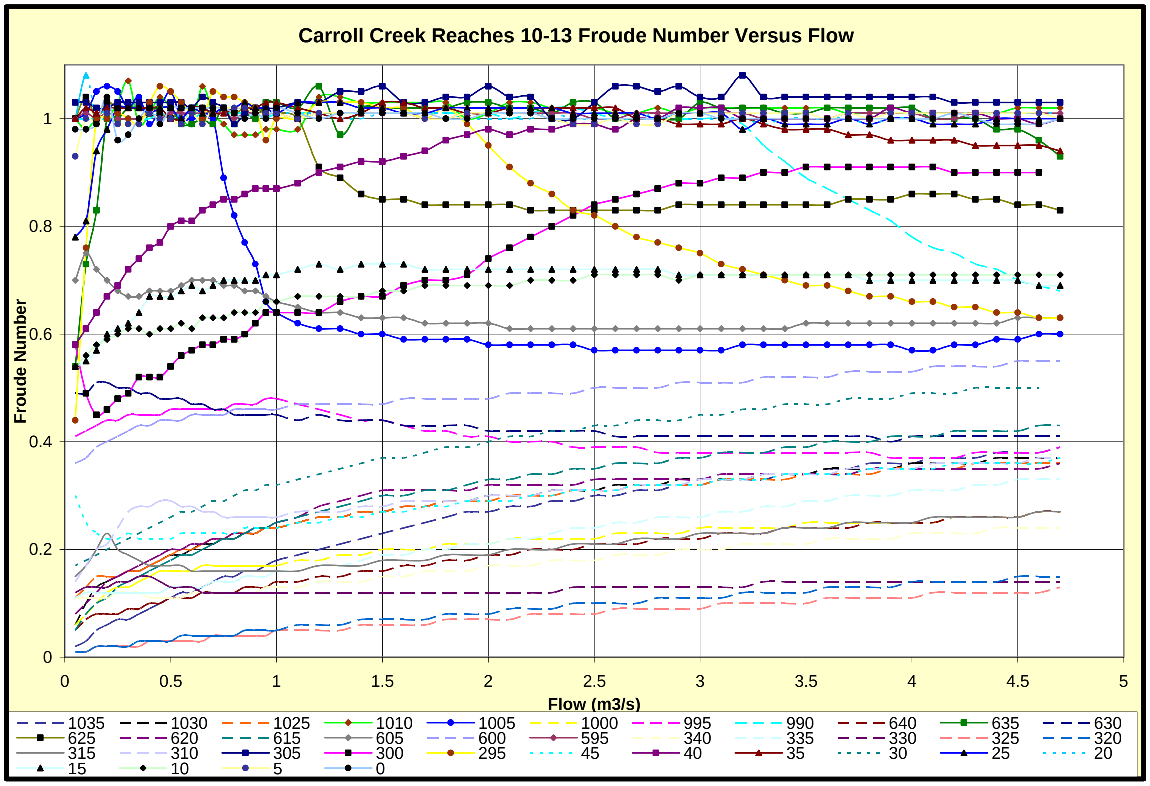

Carroll Creek Reaches 5-9 Wetted Perimeter Versus Flow
Wetted Perimeter (m)
Flow (m3/s)
1
2
3
4
5
6
7
8
9
10
11
0
0.5
1
1.5
2
2510
2505
2495
2490
2245
2240
2235
2230
2225
2220
2215
2210
2205
2200
1880
1875
1870
1860
1855
1610
1605
1600
1595
1590
1585
1580
1575
1570
1565
1330
1325
1320
1315
1300
1295
1290

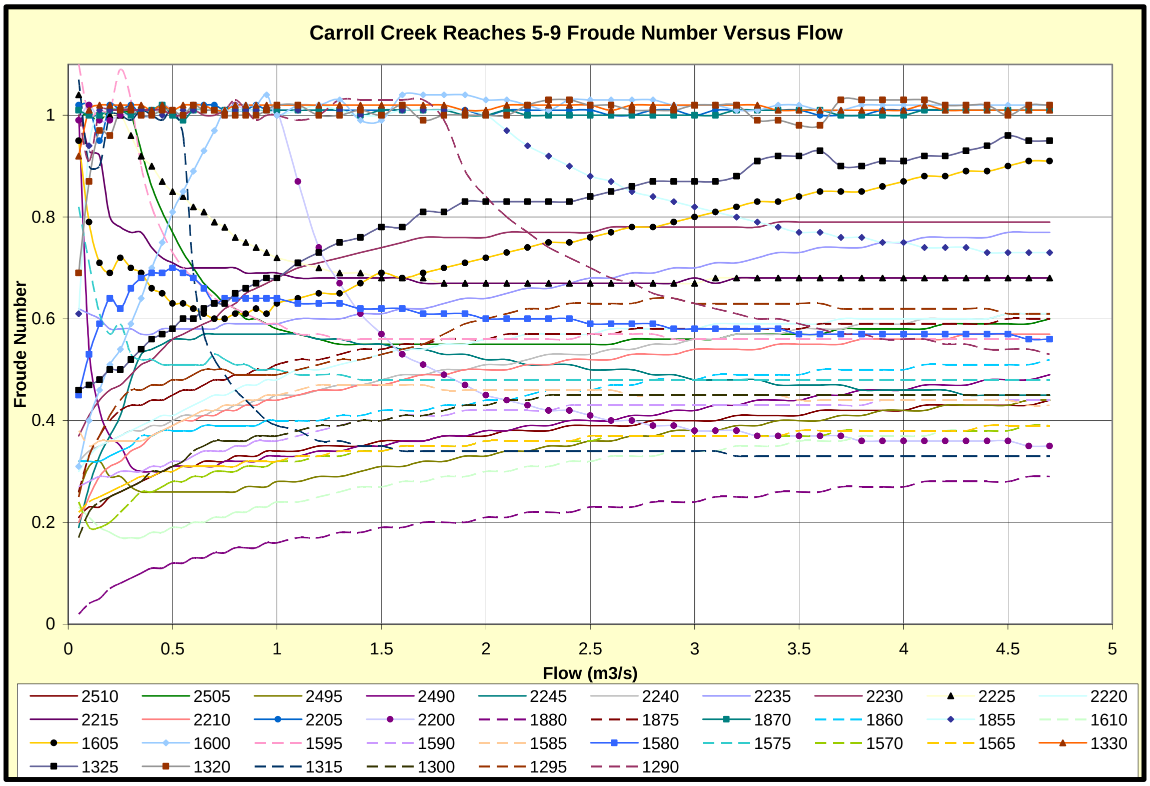

Carroll Creek Reaches 1-4 Wetted Perimeter Versus Flow
Wetted Perimeter (m)
1
6
11
16
21
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
3800
3770
3765
3760
3515
3510
3505
3500
3495
3485
3480
3475
3470
3140
3135
3115
3110
3105
2850
2840
2835
2830
2825
2820
2815
2810
2805

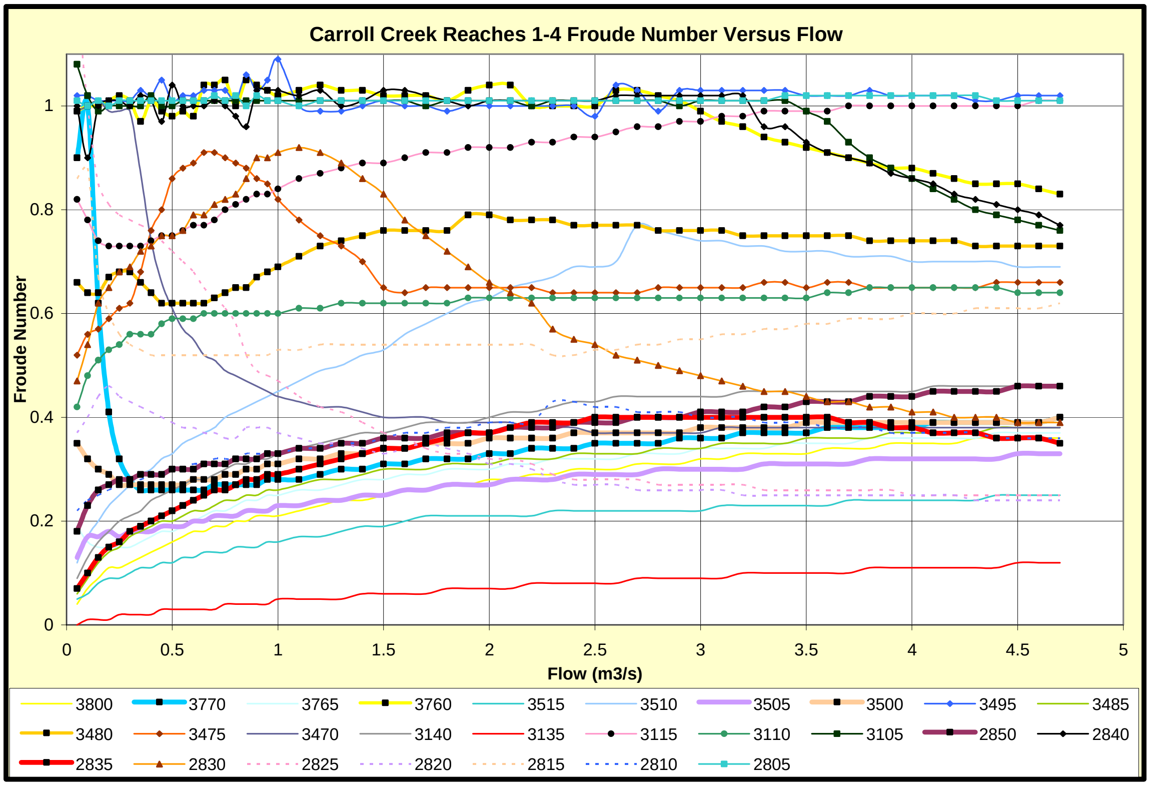

Carroll Creek Reaches 10-13 Flow vs. Topwidth
Topwidth (m)
0
2
4
6
8
10
12
14
16
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1030
1010
1005
1000
995
990
635
605
340
315
305
300
295
45
40
35
25
20
15
10
5
0

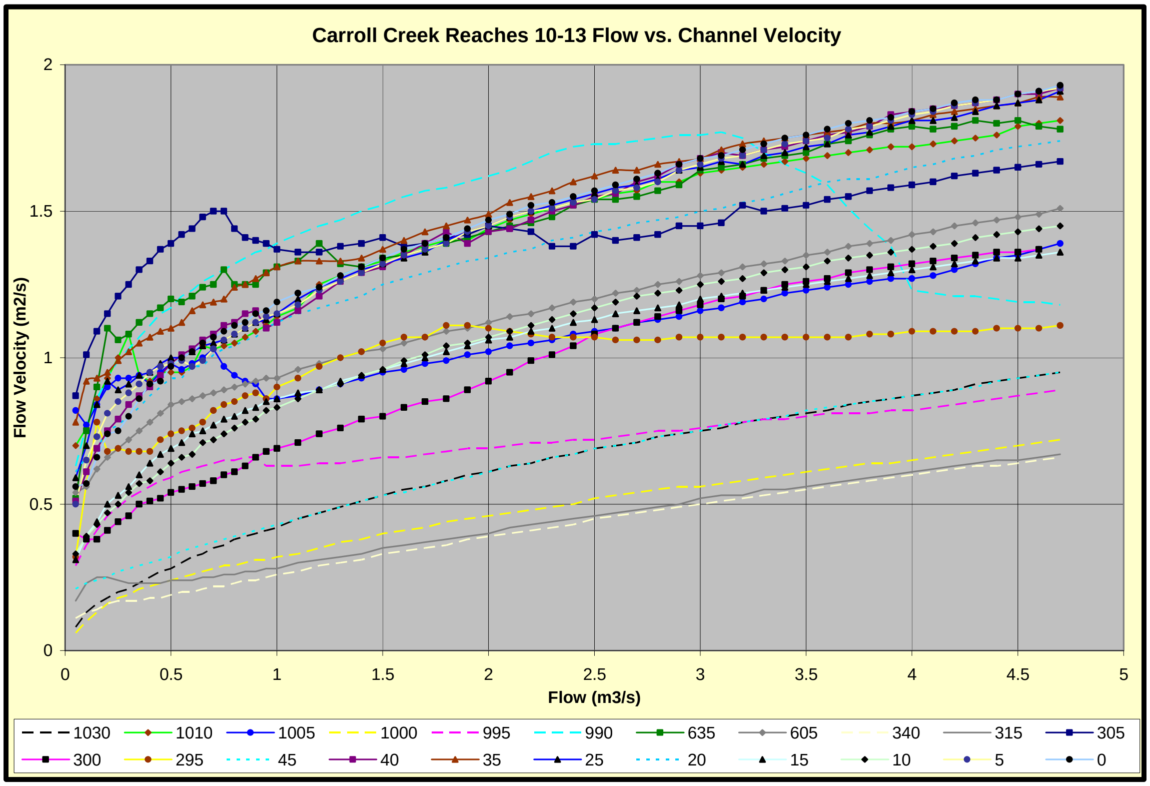

Carroll Creek Reaches 5-9 Flow vs. Topwidth
Topwidth (m)
0
2
4
6
8
10
12
14
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
2495
2245
2240
2225
2200
1875
1870
1855
1610
1605
1600
1595
1590
1585
1580
1575
1570
1325
1315
1300
1295
1290

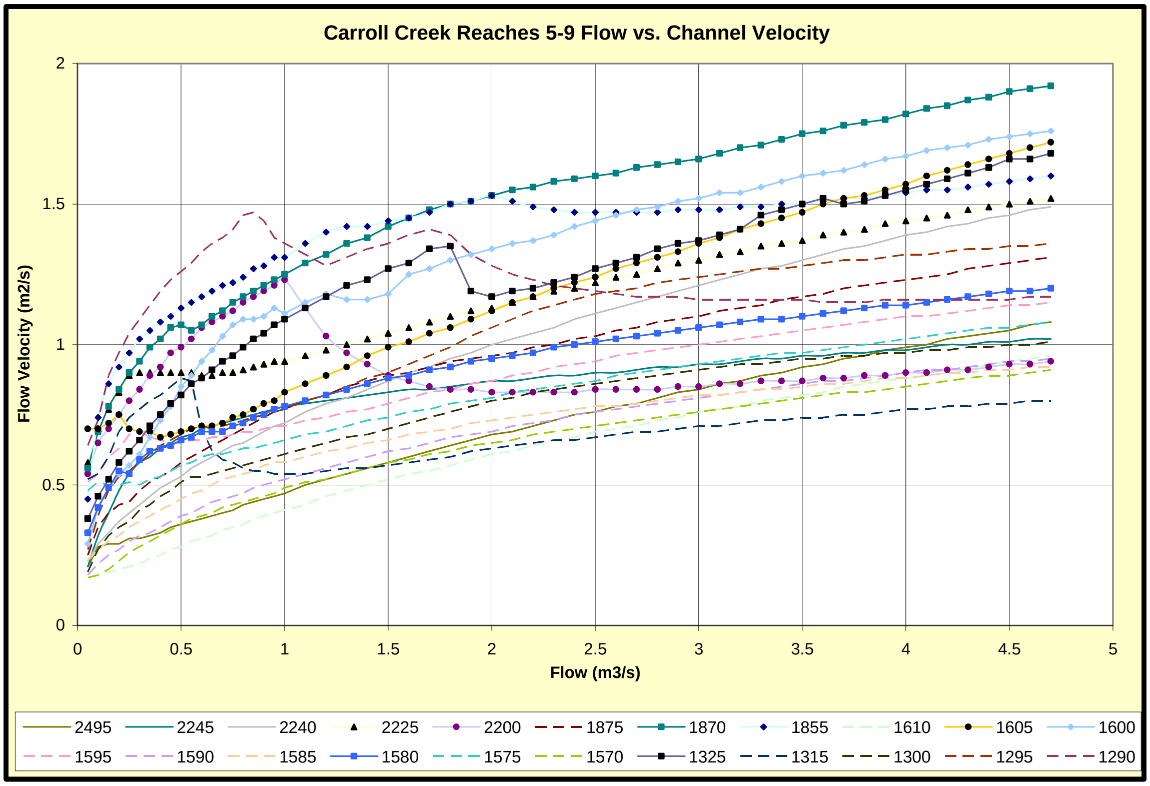

Carroll Creek Reaches 1-4 Flow vs. Topwidth
Topwidth (m)
0
5
10
15
20
Flow (m3/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
3770
3765
3760
3515
3510
3505
3495
3485
3480
3470
3135
2840
2830
2825
2820
2810
2805


Carroll Creek Reaches 10-13 Froude Number Versus Flow
Froude Number
Flow (m3/s)
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1035
1030
1025
1010
1005
1000
995
990
640
635
630
625
620
615
605
600
595
340
335
330
325
320
315
310
305
300
295
45
40
35
30
25
20
15
10
5
0

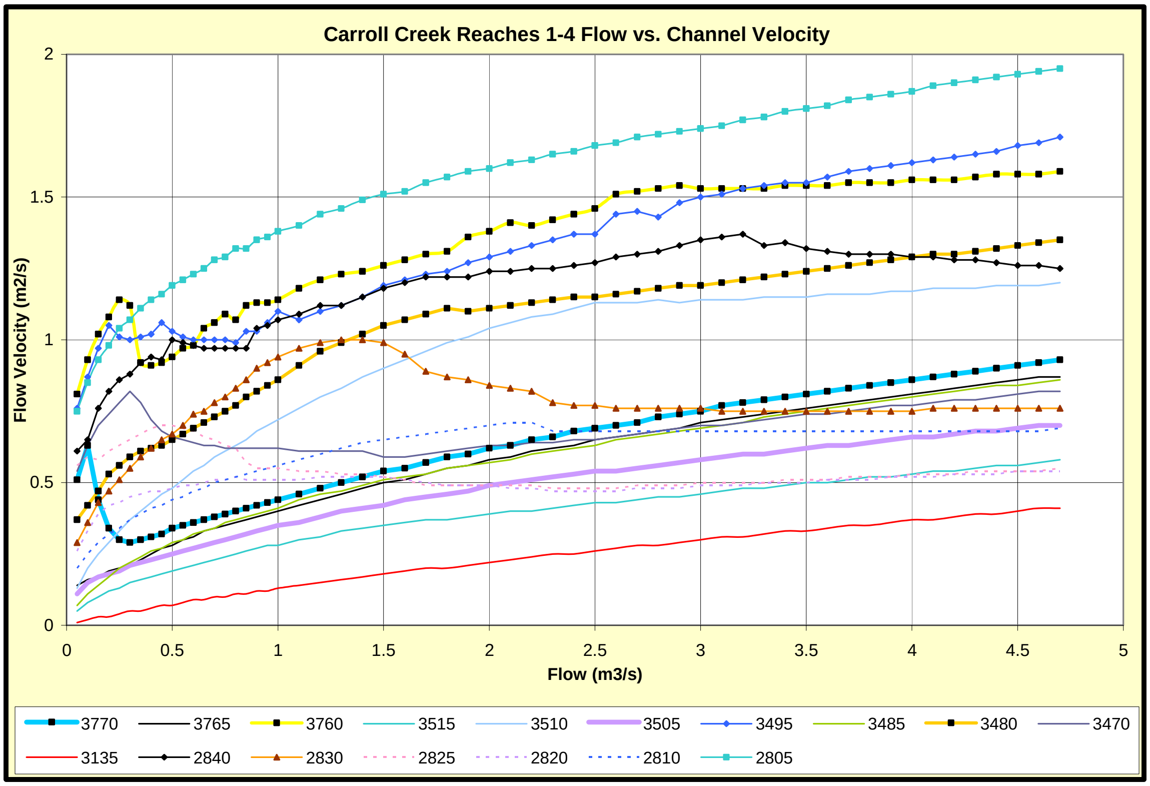

Carroll Creek Reaches 5-9 Froude Number Versus Flow
Froude Number
Flow (m3/s)
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
2510
2505
2495
2490
2245
2240
2235
2230
2225
2220
2215
2210
2205
2200
1880
1875
1870
1860
1855
1610
1605
1600
1595
1590
1585
1580
1575
1570
1565
1330
1325
1320
1315
1300
1295
1290


Carroll Creek Reaches 1-4 Froude Number Versus Flow
Froude Number
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
3800
3770
3765
3760
3515
3510
3505
3500
3495
3485
3480
3475
3470
3140
3135
3115
3110
3105
2850
2840
2835
2830
2825
2820
2815
2810
2805

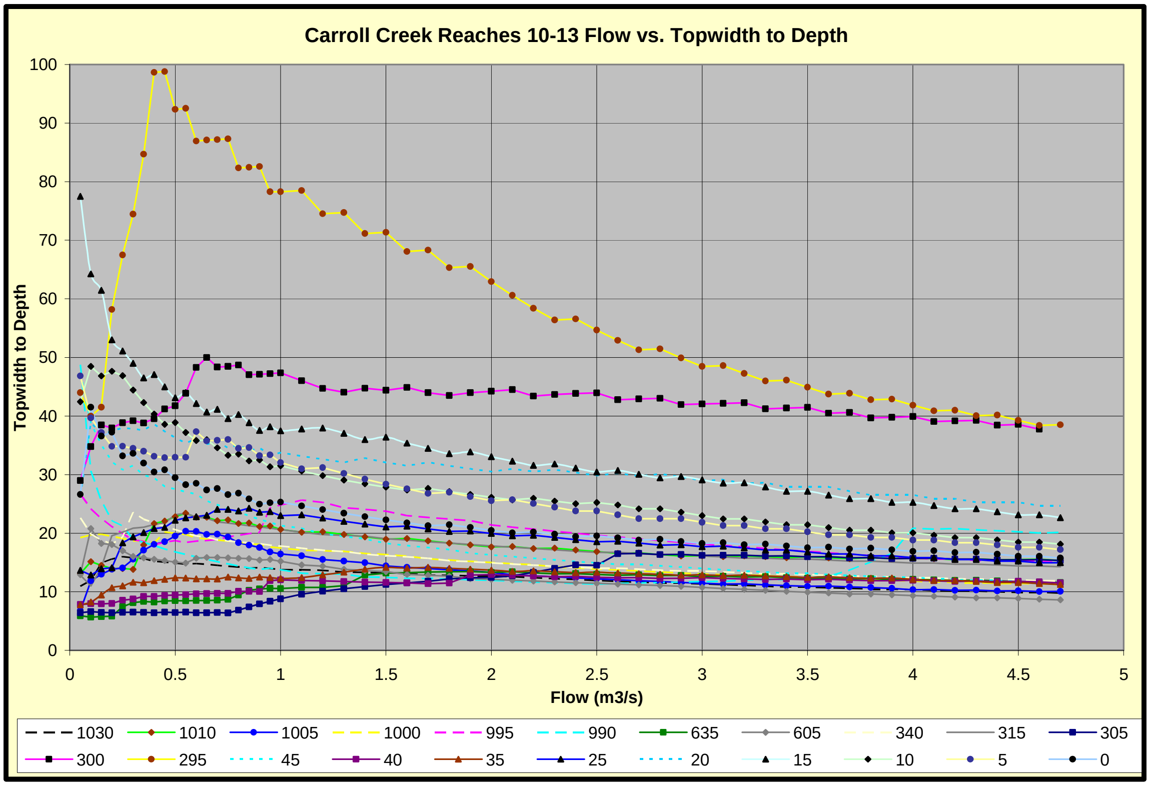

Carroll Creek Reaches 10-13 Flow vs. Channel Velocity
Flow Velocity (m2/s)
0
0.5
1
1.5
2
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
1030
1010
1005
1000
995
990
635
605
340
315
305
300
295
45
40
35
25
20
15
10
5
0

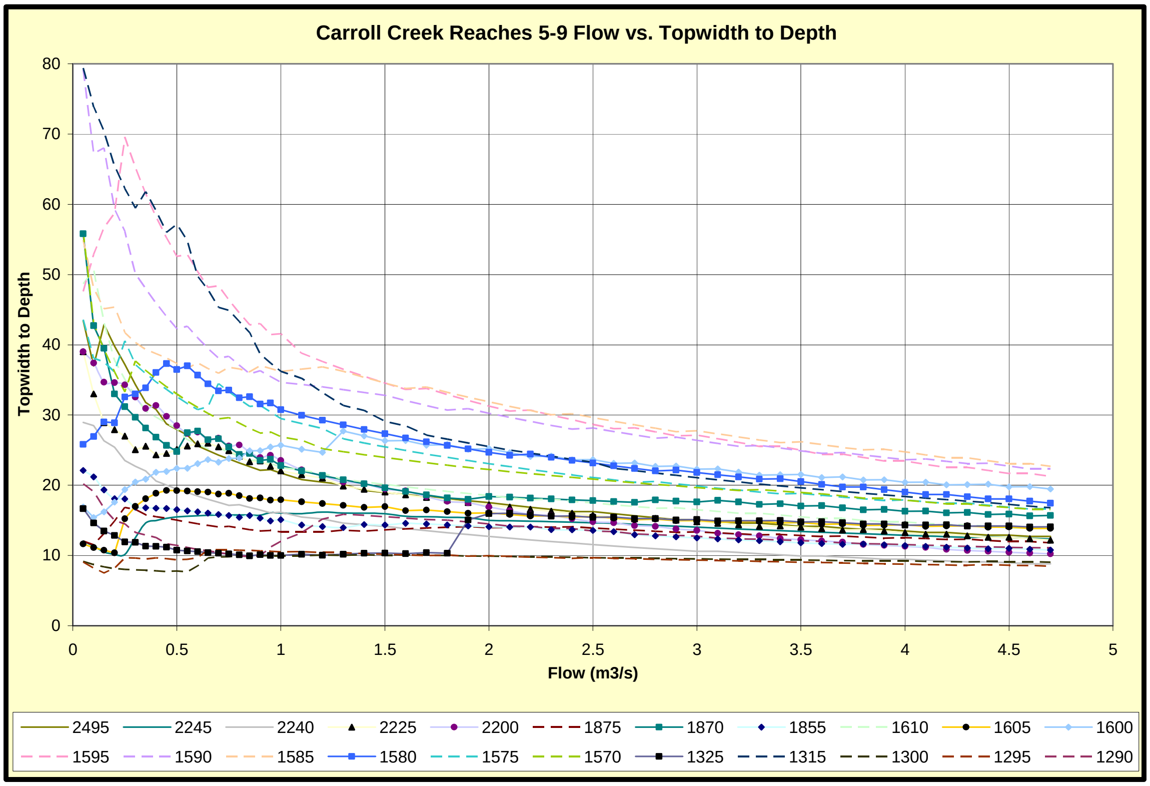


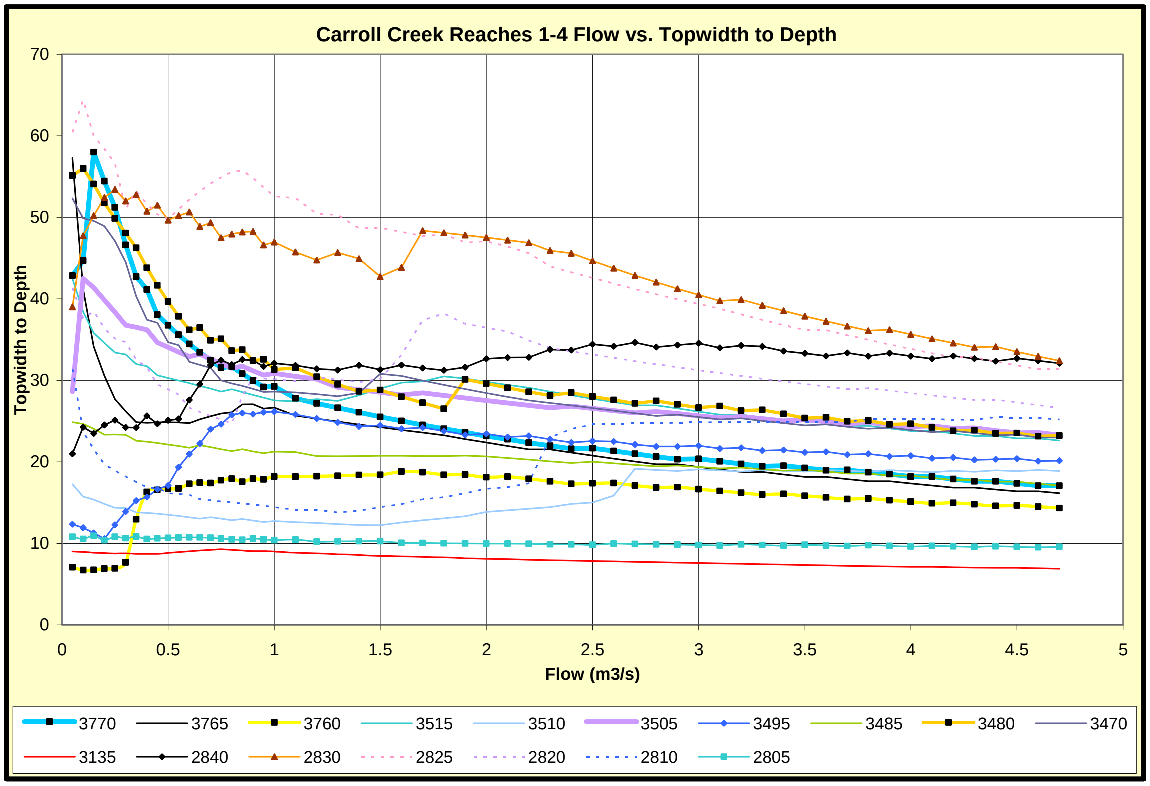
Carroll Creek Reaches 5-9 Flow vs. Channel Velocity



Carroll Creek Reaches 1-4 Flow vs. Channel Velocity


Carroll Creek Reaches 10-13 Flow vs. Topwidth to Depth
Topwidth to Depth
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1030
1010
1005
1000
995
990
635
605
340
315
305
300
295
45
40
35
25
20
15
10
5
0


Carroll Creek Reaches 5-9 Flow vs. Topwidth to Depth
Topwidth to Depth
Flow (m3/s)
0
10
20
30
40
50
60
70
80
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
2495
2245
2240
2225
2200
1875
1870
1855
1610
1605
1600
1595
1590
1585
1580
1575
1570
1325
1315
1300
1295
1290


Carroll Creek Reaches 1-4 Flow vs. Topwidth to Depth
Topwidth to Depth
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Flow (m3/s)
3770
3765
3760
3515
3510
3505
3495
3485
3480
3470
3135
2840
2830
2825
2820
2810
2805

APPENDIX E: GEOMORPHIC THRESHOLD RESULTS

Contents of this Appendix

1. Definitions of Geomorphic Thresholds
2. Tables of Geomorphic Thresholds for the Pilot Reaches
3. Chart of Daily Flow Series with Geomorphic Thresholds (for each pilot reach)
4. Geomorphic Protocols for Field Collection (under separate cover by Parish Geomorphic May 2005)

DEFINITIONS OF THRESHOLDS:

Bankfull Flow: also known as Channel maintenance flow. It is the flow stage that fills the stream channel. Any additional flow would spill over onto the floodplain. This is considered the flow that is required to maintain channel stability.

Mobilizing Flow: a periodic flow event which can mobilize a significant portion of the bed, generally the median (D_{50}) bed material is used.

Flushing Flow: the flow which provides sufficient energy to re-entrain the finer sediments which may become embedded within the coarse sediment matrix of riffles during low flow conditions, impacting the quality of aquatic habitat.

Residual Pool Flow: based on the channel cross-sectional geometry, the concept of a thalweg channel providing low flow refuge maintenance. A threshold calculated to simulate the point at which water levels were sufficiently low to isolate pools.

Table E.1 Percentage exceedance for geomorphic thresholds.

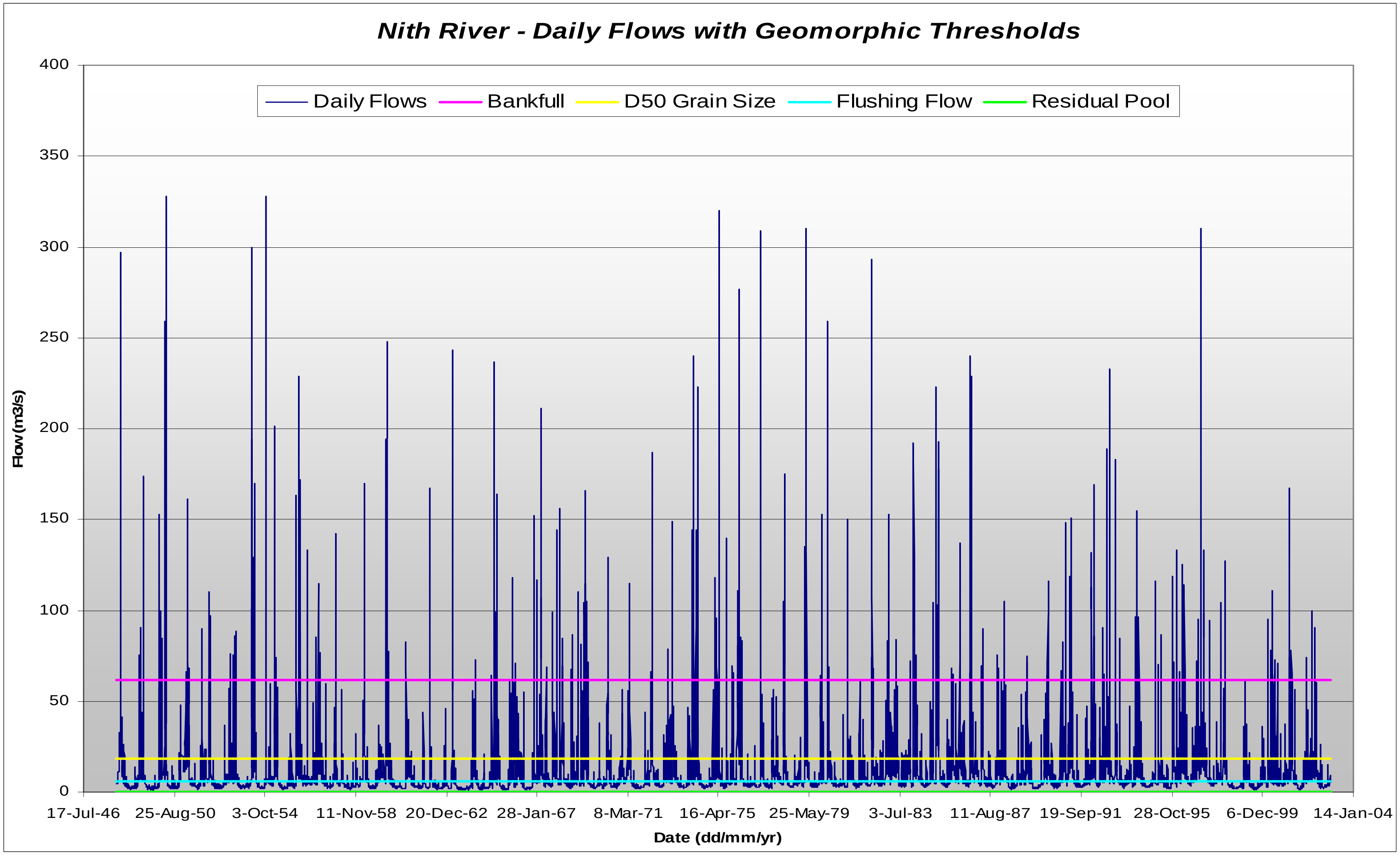
<table>
<tr><th>Threshold Exceedance</th><th>Bankfull Flow</th><th colspan="2">D_{50} Bed Mobilizing Threshold</th><th colspan="2">Low Flow Threshold (Residual Pool)</th><th>Flushing Flow Threshold</th><th>Bank Threshold</th></tr>
<tr><td colspan="8">Eramosa River - 14899 day record</td></tr>
<tr><td>Number of Days in Exceedance of Threshold</td><td>132</td><td colspan="2">61</td><td colspan="2">14243</td><td>1440</td><td>N/A</td></tr>
<tr><td>Exceedance (%)</td><td>0.89</td><td colspan="2">0.41</td><td colspan="2">95.60</td><td>9.67</td><td>--</td></tr>
<tr><td>Threshold (cms)</td><td>15.54</td><td colspan="2">21.83</td><td colspan="2">0.92</td><td>5.38</td><td>N/A</td></tr>
<tr><td colspan="8">Blair Creek – 1424 day record</td></tr>
<tr><td>Number of Days in Exceedance of Threshold</td><td>0</td><td>#147</td><td>^5</td><td>+31</td><td>*1424</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Exceedance (%)</td><td>0</td><td>#10.32</td><td>^0.35</td><td>+2.18</td><td>*100</td><td>--</td><td>--</td></tr>
<tr><td>Threshold (cms)</td><td>1.77</td><td>#0.32</td><td>^1.19</td><td>+0.69</td><td>*0.15</td><td>N/A</td><td>N/A</td></tr>
<tr><td colspan="8">Mill Creek – 4789 day record</td></tr>
<tr><td>Number of Days in Exceedance of Threshold</td><td>30</td><td colspan="2">1504</td><td colspan="2">4267</td><td>* Same as D_{50}</td><td>181</td></tr>
<tr><td>Exceedance (%)</td><td>0.63</td><td colspan="2">31.41</td><td colspan="2">89.10</td><td>* Same as D_{50}</td><td>3.78</td></tr>
<tr><td>Threshold (cms)</td><td>4.21</td><td colspan="2">1.05</td><td colspan="2">0.32</td><td>1.05</td><td>2.59</td></tr>
</table>

+Average *Typical #D_{50} threshold ^D_{84} threshold

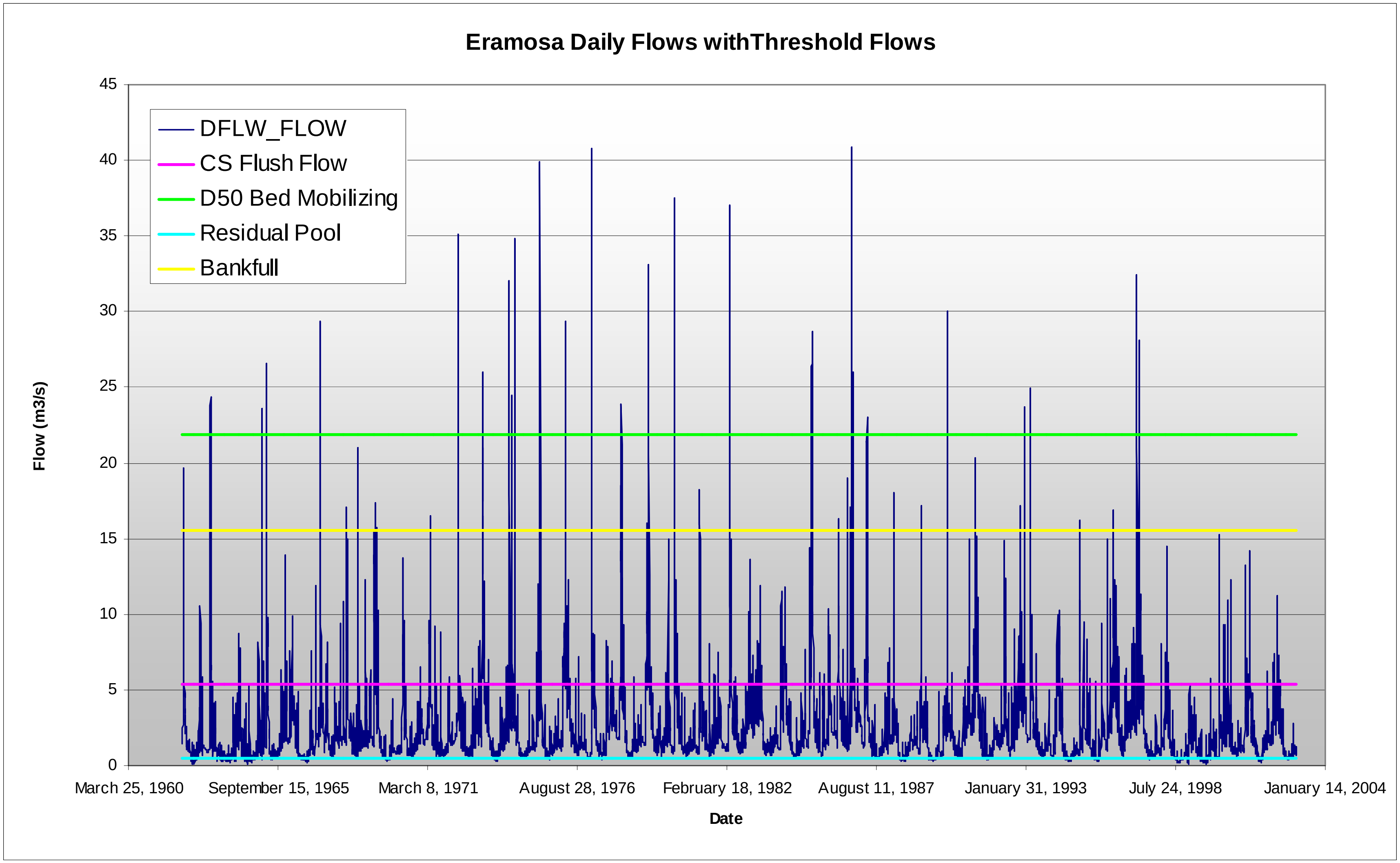
Table E.2 Percentage exceedance for geomorphic instream flow thresholds.

Threshold Exceedance	Bankfull Flow	D_{50} Bed Mobilizing Threshold	Flushing Flow Threshold	Low Flow Threshold (Residual Pool)
Nith River				
Threshold (cms)	61.5	18.3	9.1	0.21
Exceedance (%)	2.6	13.6	29.9	100
Whitemans Creek				
Threshold (cms)	24.5	3.06	2.50	1.18
Exceedance (%)	1.7	39.3	47.4	77.0
Grand River Blair Reach				
Threshold (cms)	395	187	150.8	6.7
Exceedance (%)	0.32	2.24	3.57	99.8
Grand River Exceptional Waters				
Threshold (cms)	405	161	126	0.68
Exceedance (%)	0.67	6.4	9.7	100
Carroll Creek				
Threshold (cms)	5.12		0.15	0.13
Exceedance (%)				

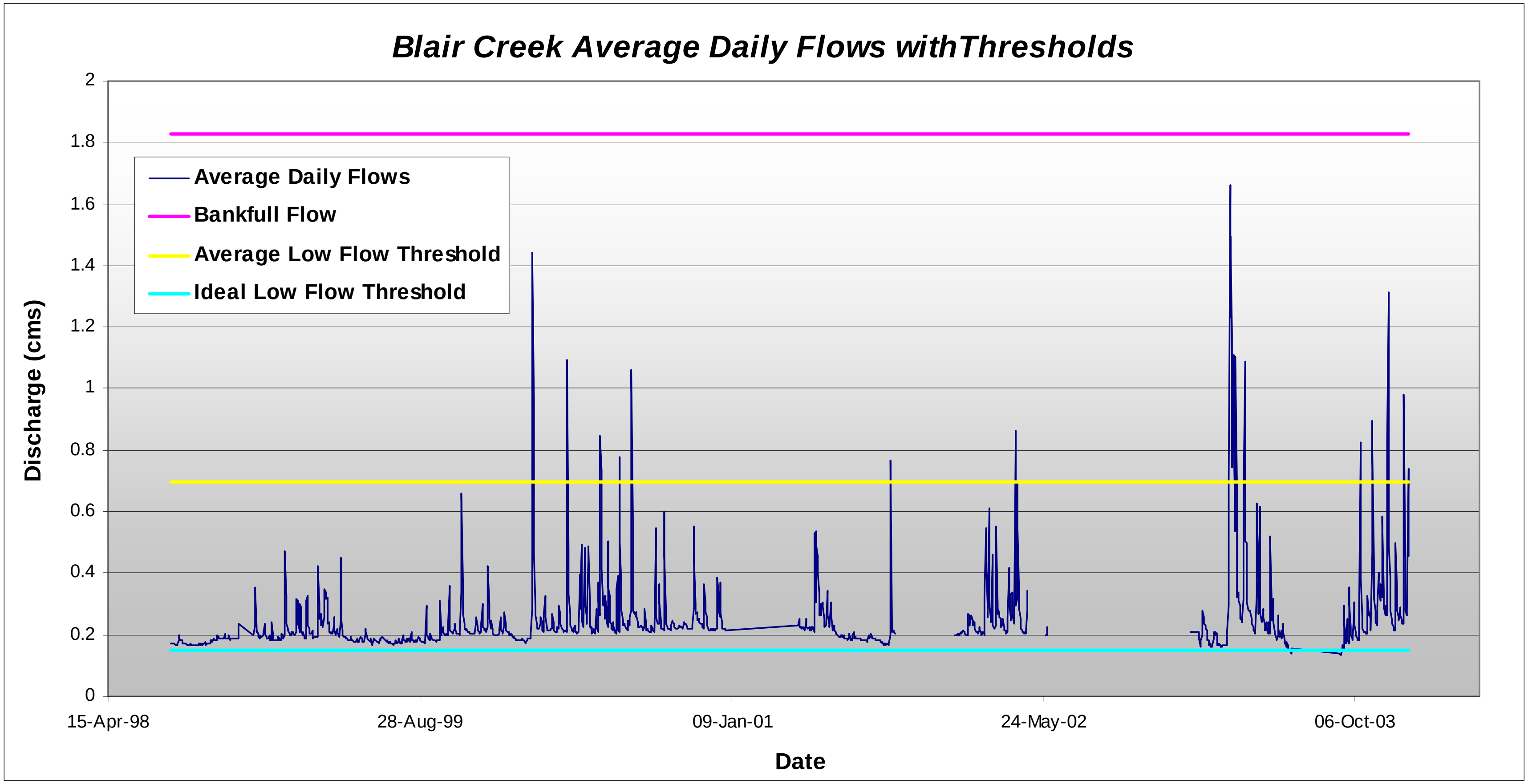
E-1: NITH RIVER AT CANNING



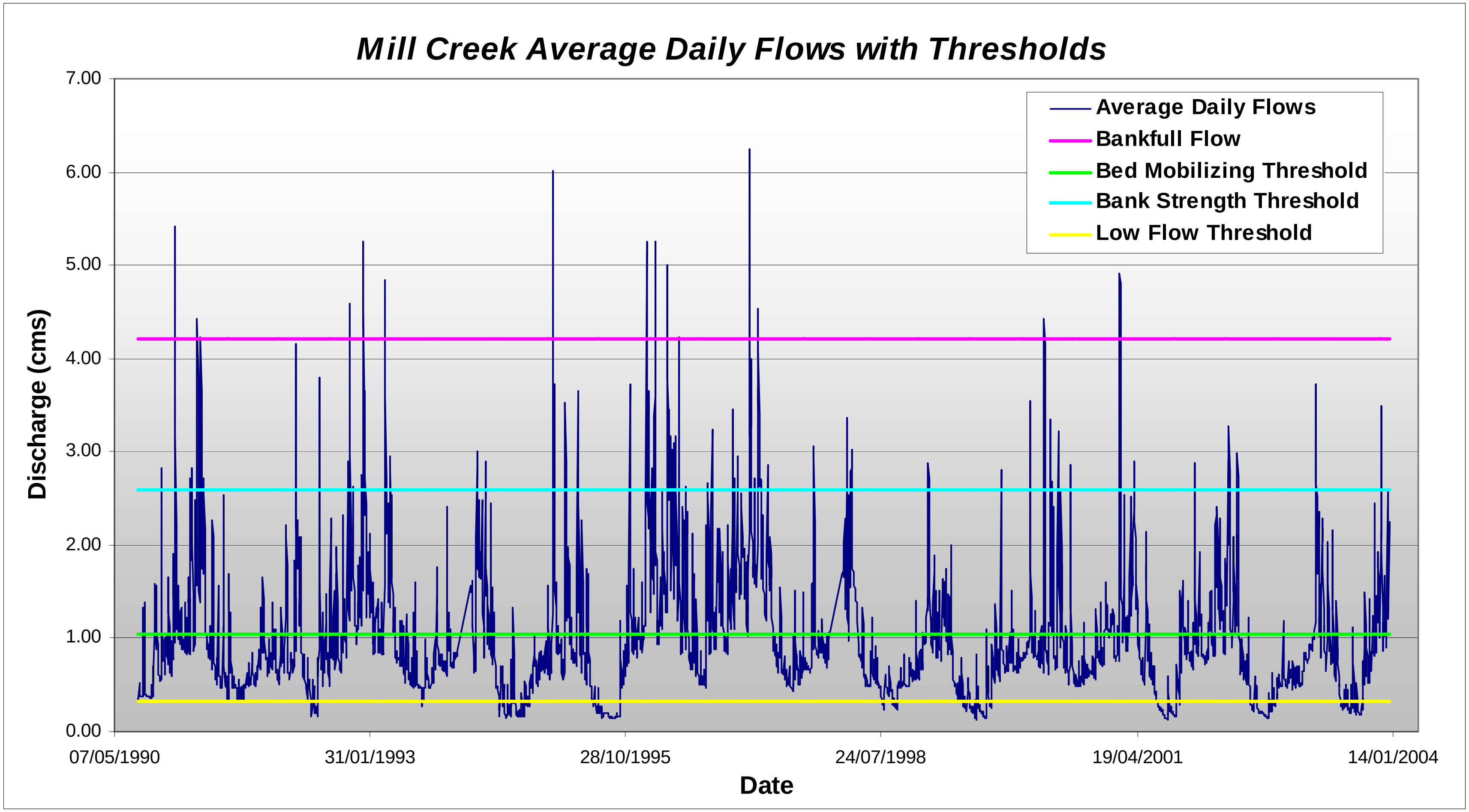
E-2: ERAMOSA RIVER



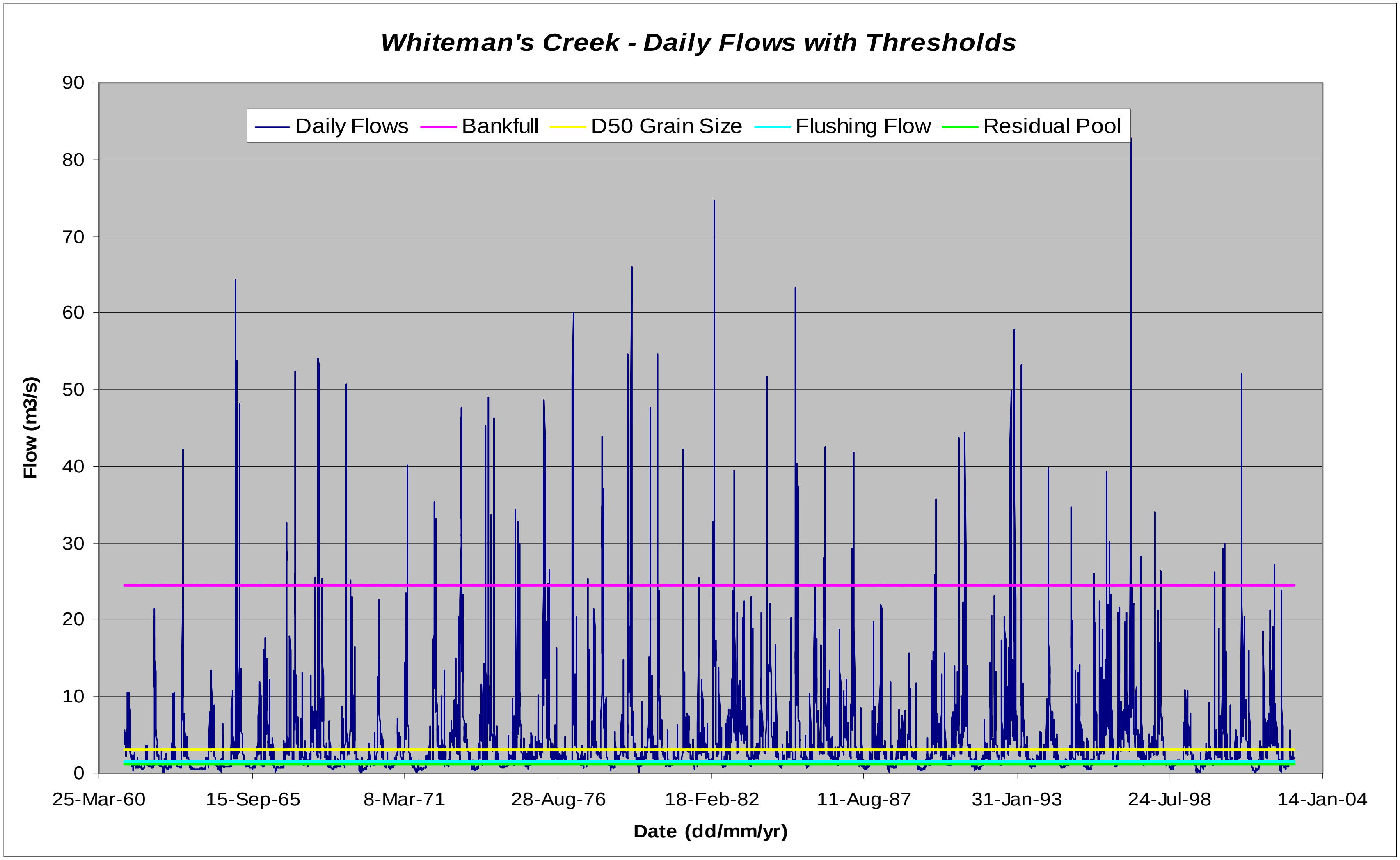
E-3: BLAIR CREEK



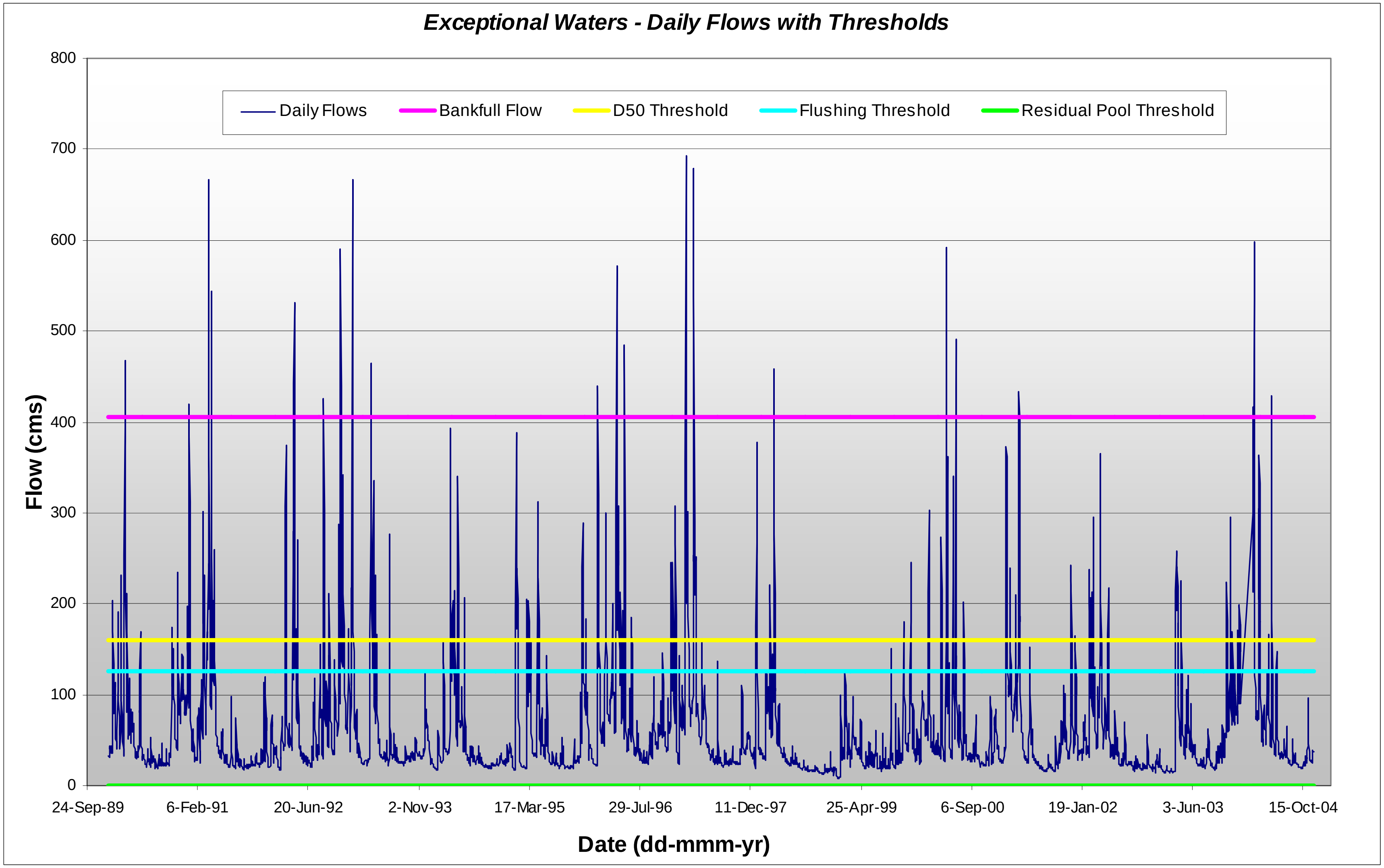
E-4: MILL CREEK



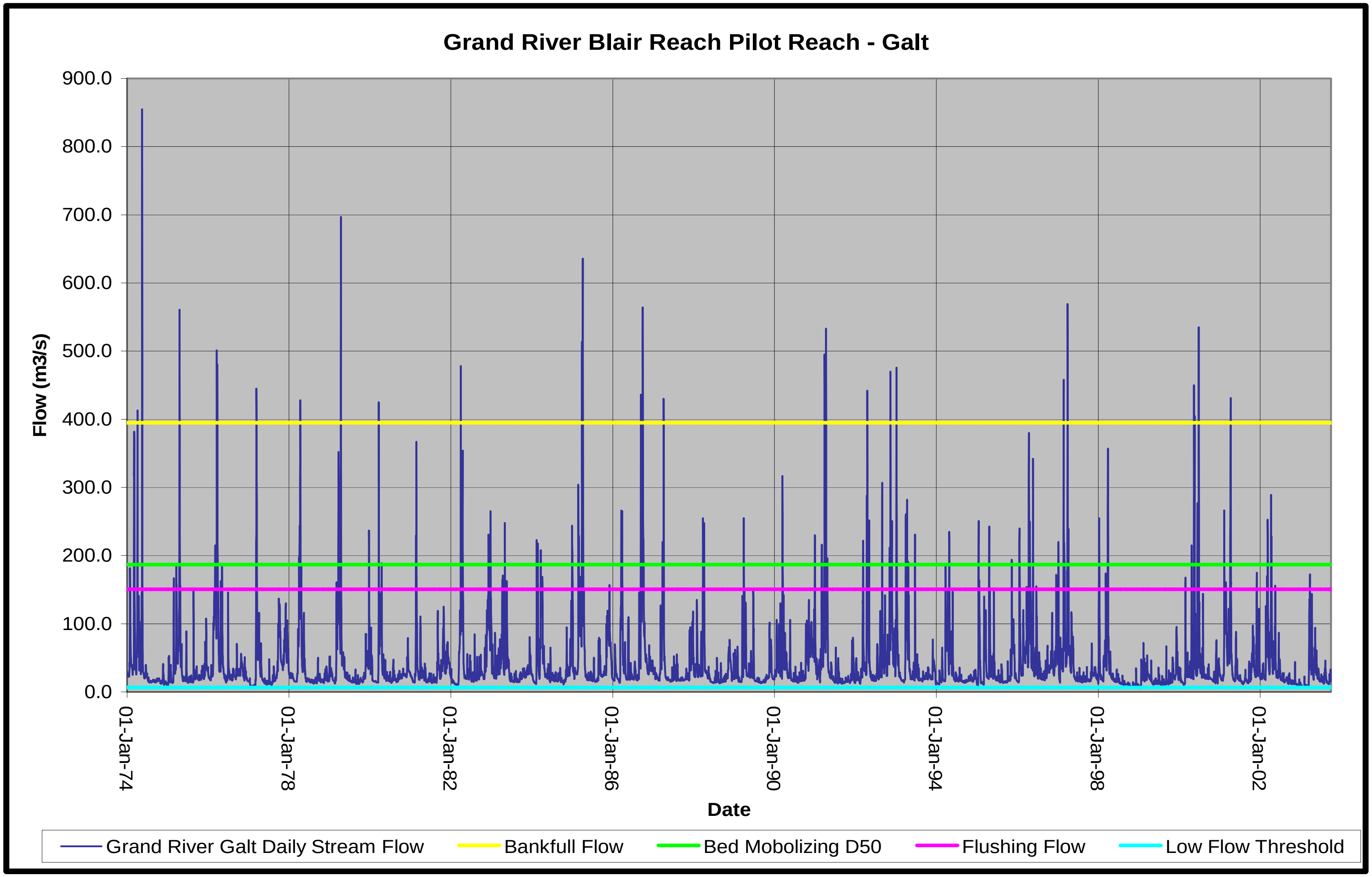
E-5: WHITEMANS CREEK

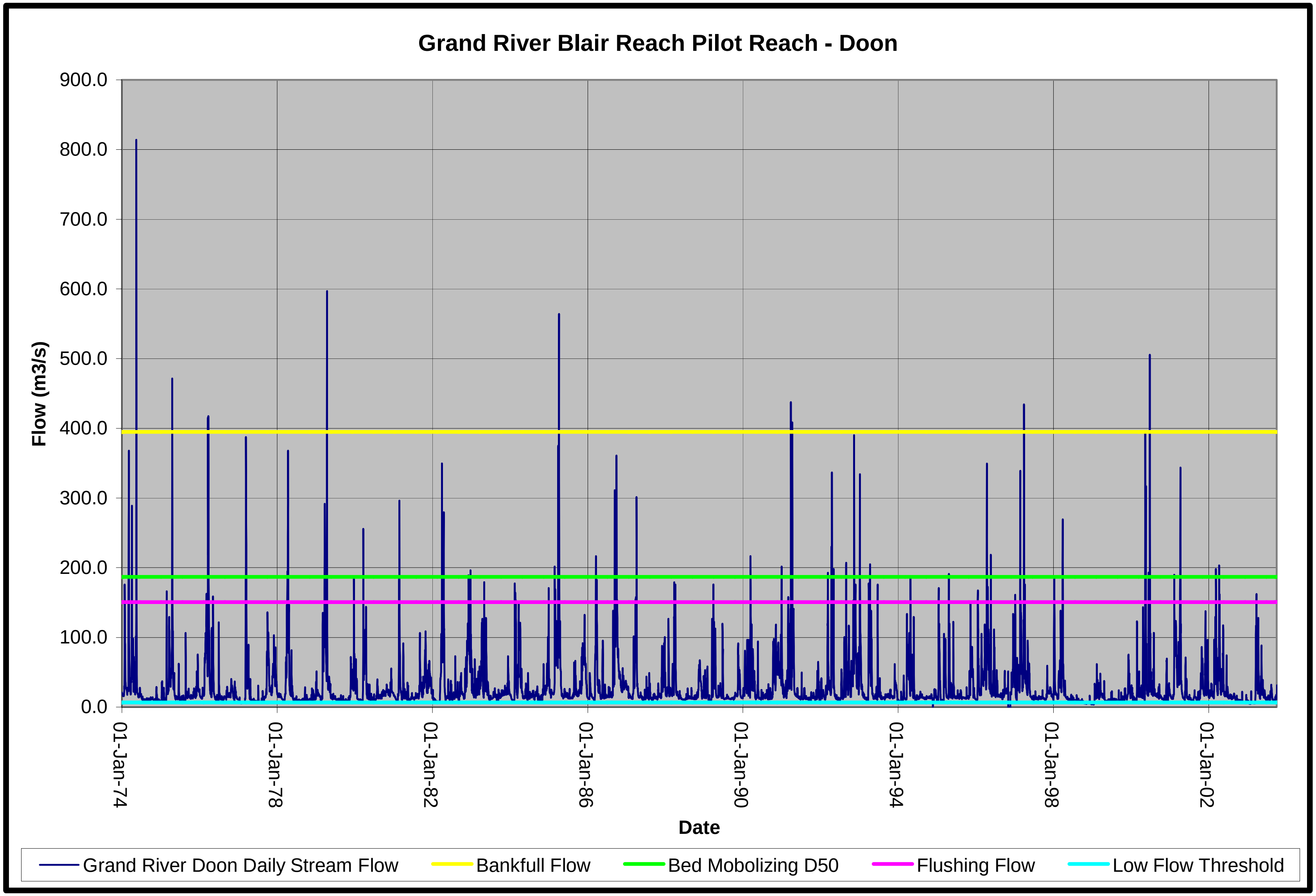


E-6: GRAND RIVER EXCEPTIONAL WATERS REACH



E-7: GRAND RIVER AT BLAIR REACH




Grand River Blair Reach Pilot Reach - Doon
Flow (m3/s)
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
01-Jan-74
01-Jan-78
01-Jan-82
01-Jan-86
01-Jan-90
01-Jan-94
01-Jan-98
01-Jan-02
Date
Grand River Doon Daily Stream Flow
Bankfull Flow
Bed Mobolizing D50
Flushing Flow
Low Flow Threshold

E-8:   CARROLL CREEK REACH

Not completed as a result of an unstable rating curve at the Caroll Creek gauge station. Rating subject to backwater from aquatic vegetation and ice resulting in unreliable daily flow estimates.

APPENDIX F: COMPARISONS OF THRESHOLDS, FLOW STATISTICS AND HYDRAULIC INFLECTION POINTS

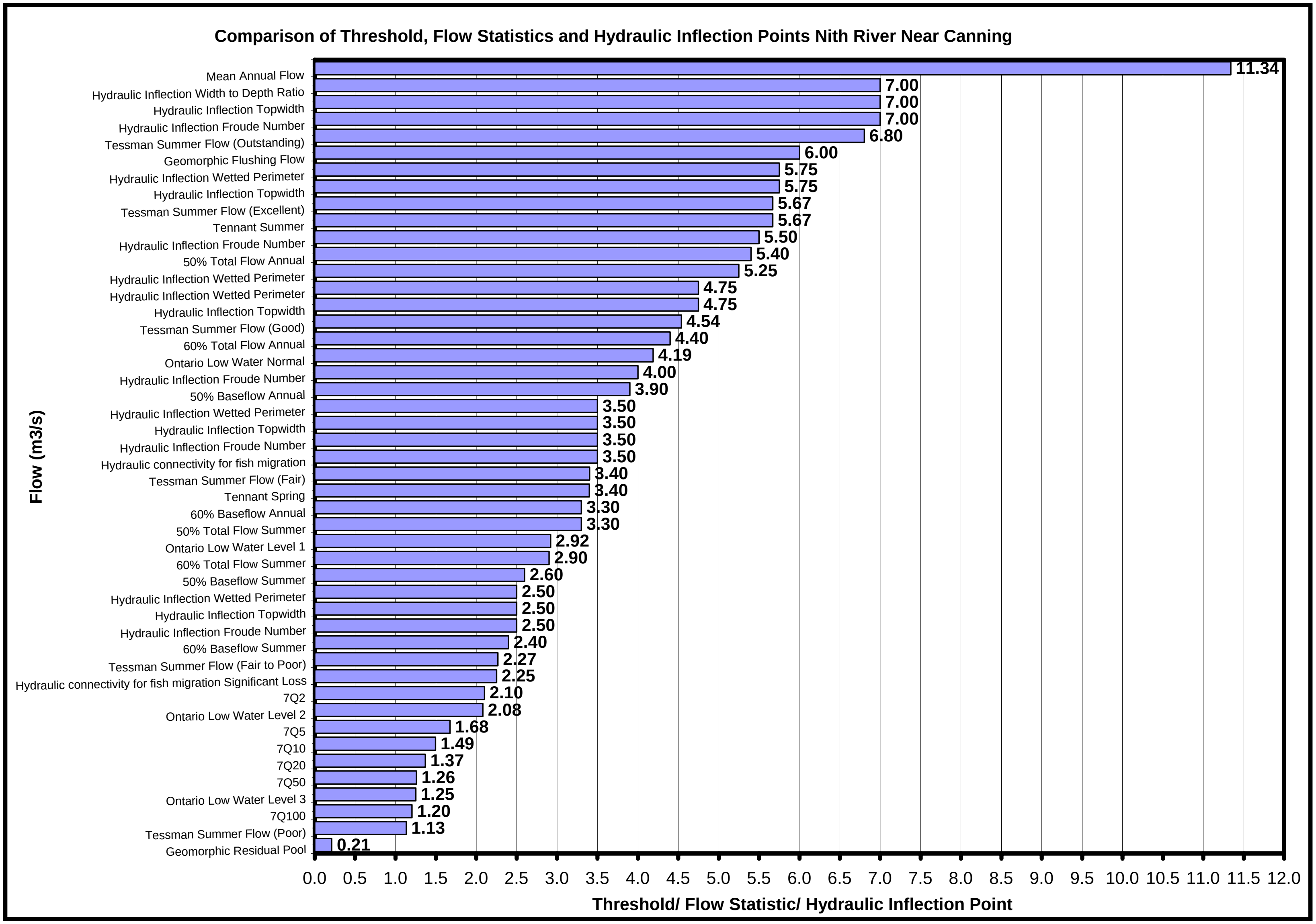
Order of Hydraulic Comparison Tables and Figures

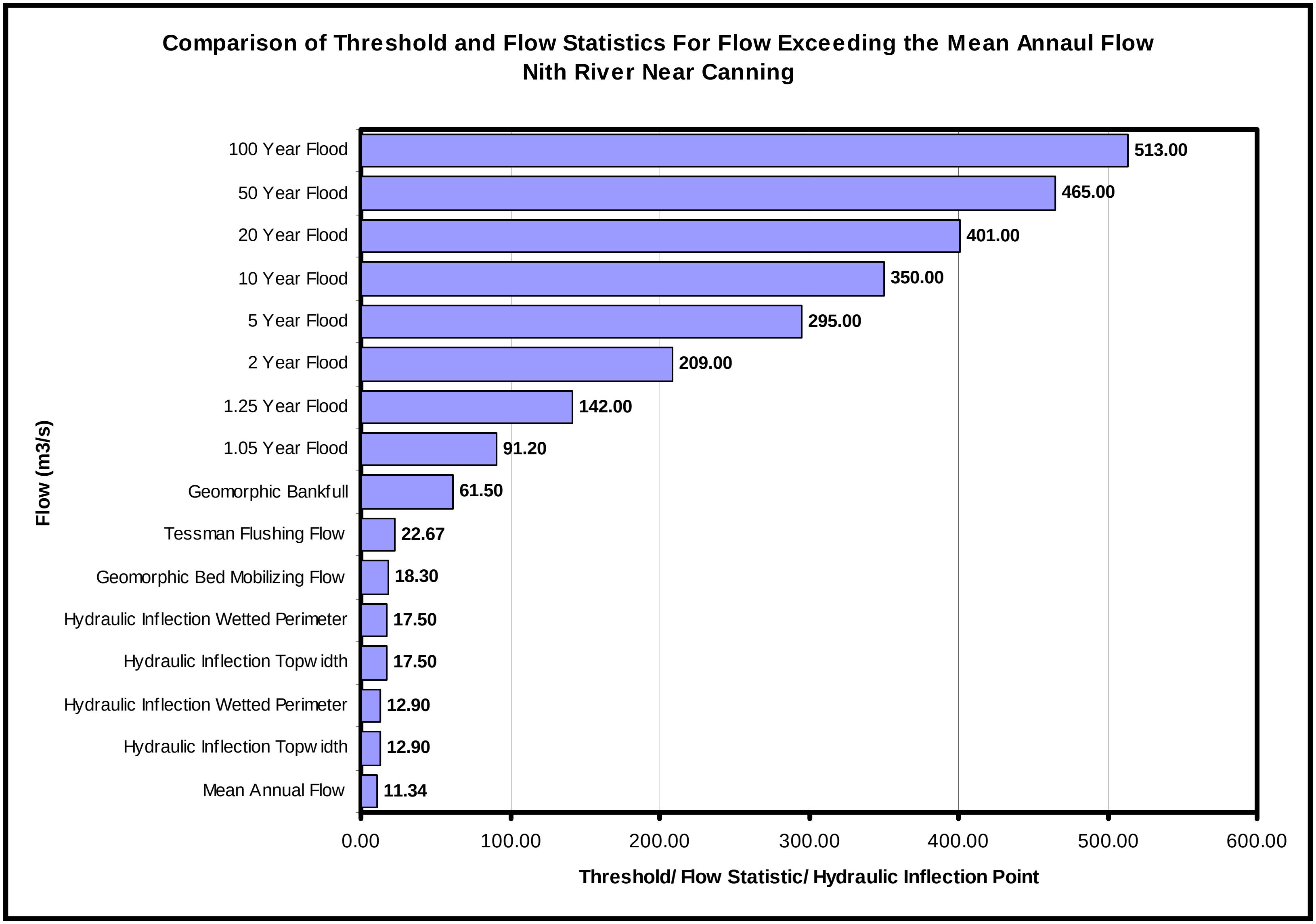
1. Table: Comparison of Thresholds, Statistics and Hydraulic Results
2. Figure: Comparison of Thresholds, Flow Statistics and Hydraulic Inflection Points
3. Figure: Comparison of Thresholds and Flow Statistics for Flows Exceeding the Mean Annual Flow
4. Figure: Comparison of Tennant, Tessman and OLWRP values
5. Table: Comparison for Tennant, Tessman and OLWRP values

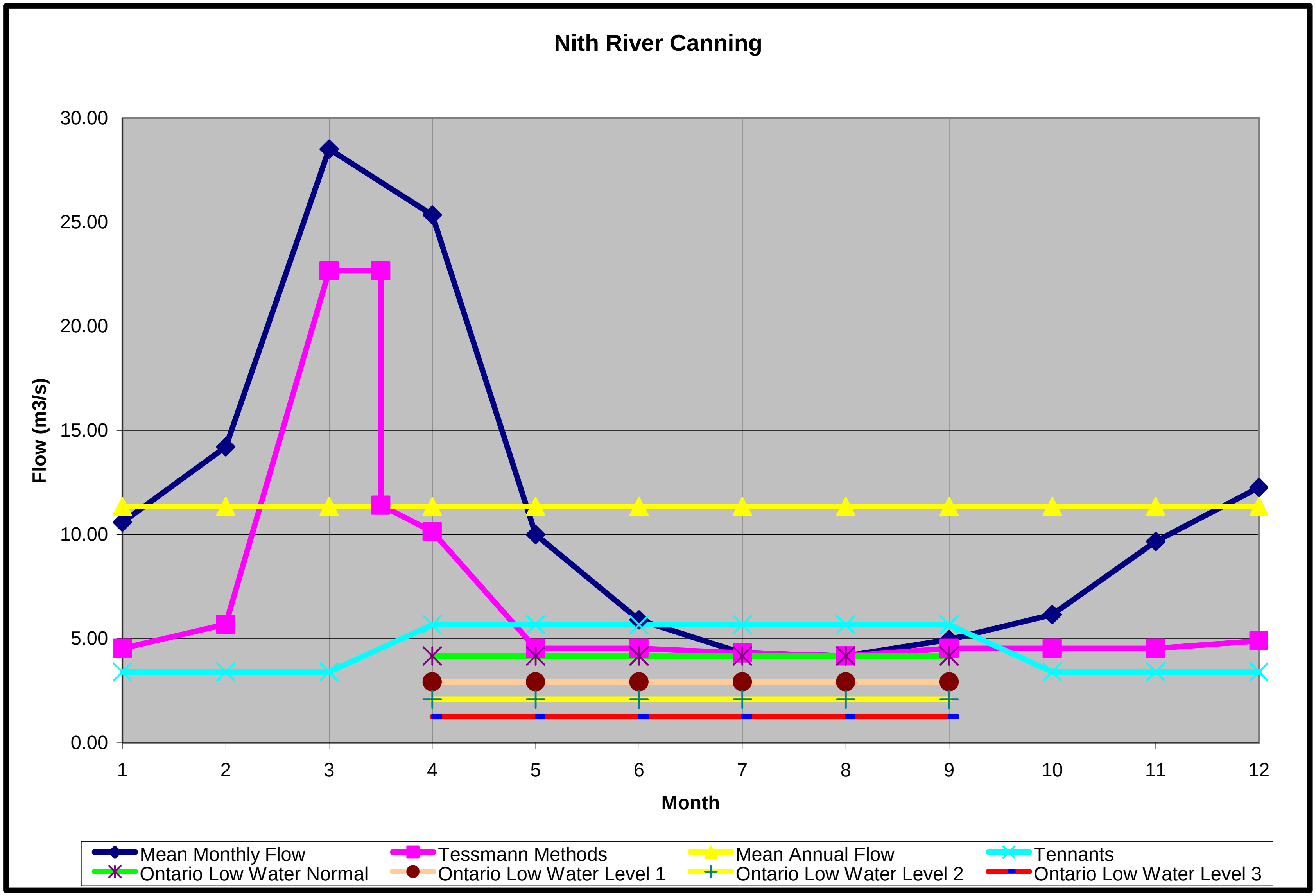
F-1: NITH RIVER AT CANNING

Nith River Near Canning		OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Geomorphic Residual Pool	0.21		
Tessman Summer Flow (Poor)	1.13		
7Q100	1.203	0.25	0.36
Ontario Low Water Level 3	1.25		
7Q50	1.260	0.28	0.39
7Q20	1.370	0.35	0.47
7Q10	1.494	0.44	0.55
7Q5	1.676	0.56	0.71
Ontario Low Water Level 2	2.08		
7Q2	2.103	0.88	1.16
Hydraulic connectivity for fish migration Significant Loss	2.25		
Tessman Summer Flow (Fair to Poor)	2.27		
60% Baseflow Summer	2.40		
Hydraulic Inflection Froude Number	2.50		
Hydraulic Inflection Topwidth	2.50		
Hydraulic Inflection Wetted Perimeter	2.50		
50% Baseflow Summer	2.60		
60% Total Flow Summer	2.90		
Ontario Low Water Level 1	2.92		
50% Total Flow Summer	3.30		
60% Baseflow Annual	3.30		
Tennant Spring	3.40		
Tessman Summer Flow (Fair)	3.40		
Hydraulic connectivity for fish migration	3.50		
Hydraulic Inflection Froude Number	3.50		
Hydraulic Inflection Topwidth	3.50		
Hydraulic Inflection Wetted Perimeter	3.50		
50% Baseflow Annual	3.90		
Hydraulic Inflection Froude Number	4.00		
Ontario Low Water Normal	4.19		
60% Total Flow Annual	4.40		

Nith River Near Canning		OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Tessman Summer Flow (Good)	4.53		
Hydraulic Inflection Topwidth	4.75		
Hydraulic Inflection Wetted Perimeter	4.75		
Hydraulic Inflection Wetted Perimeter	5.25		
50% Total Flow Annual	5.40		
Hydraulic Inflection Froude Number	5.50		
Tennant Summer	5.67		
Tessman Summer Flow (Excellent)	5.67		
Hydraulic Inflection Topwidth	5.75		
Hydraulic Inflection Wetted Perimeter	5.75		
Geomorphic Flushing Flow	6.00		
Tessman Summer Flow (Outstanding)	6.80		
Hydraulic Inflection Froude Number	7.00		
Hydraulic Inflection Topwidth	7.00		
Hydraulic Inflection Width to Depth Ratio	7.00		
Mean Annual Flow	11.34		
Hydraulic Inflection Topwidth	12.90		
Hydraulic Inflection Wetted Perimeter	12.90		
Hydraulic Inflection Topwidth	17.50		
Hydraulic Inflection Wetted Perimeter	17.50		
Geomorphic Bed Mobilizing Flow	18.30		
Tessman Flushing Flow	22.67		
Geomorphic Bankfull	61.50		
1.05 Year Flood	91.20		
1.25 Year Flood	142.00	217.50	221.36
2 Year Flood	209.00	151.12	422.63
5 Year Flood	295.00	215.94	609.89
10 Year Flood	350.00	259.70	723.42
20 Year Flood	401.00	301.65	826.63
50 Year Flood	465.00	314.99	955.02
100 Year Flood	513.00	356.23	1048.07


Comparison of Threshold, Flow Statistics and Hydraulic Inflection Points Nith River Near Canning
Mean Annual Flow 11.34
Hydraulic Inflection Width to Depth Ratio 7.00
Hydraulic Inflection Topwidth 7.00
Hydraulic Inflection Froude Number 7.00
Tessman Summer Flow (Outstanding) 6.80
Geomorphic Flushing Flow 6.00
Hydraulic Inflection Wetted Perimeter 5.75
Hydraulic Inflection Topwidth 5.75
Tessman Summer Flow (Excellent) 5.67
Tennant Summer 5.67
Hydraulic Inflection Froude Number 5.50
50% Total Flow Annual 5.40
Hydraulic Inflection Wetted Perimeter 5.25
Hydraulic Inflection Wetted Perimeter 4.75
Hydraulic Inflection Topwidth 4.75
Tessman Summer Flow (Good) 4.54
60% Total Flow Annual 4.40
Ontario Low Water Normal 4.19
Hydraulic Inflection Froude Number 4.00
50% Baseflow Annual 3.90
Hydraulic Inflection Wetted Perimeter 3.50
Hydraulic Inflection Topwidth 3.50
Hydraulic Inflection Froude Number 3.50
Hydraulic connectivity for fish migration 3.50
Tessman Summer Flow (Fair) 3.40
Tennant Spring 3.40
60% Baseflow Annual 3.30
50% Total Flow Summer 3.30
Ontario Low Water Level 1 2.92
60% Total Flow Summer 2.90
50% Baseflow Summer 2.60
Hydraulic Inflection Wetted Perimeter 2.50
Hydraulic Inflection Topwidth 2.50
Hydraulic Inflection Froude Number 2.50
60% Baseflow Summer 2.40
Tessman Summer Flow (Fair to Poor) 2.27
Hydraulic connectivity for fish migration Significant Loss 2.25
7Q2 2.10
Ontario Low Water Level 2 2.08
7Q5 1.68
7Q10 1.49
7Q20 1.37
7Q50 1.26
Ontario Low Water Level 3 1.25
7Q100 1.20
Tessman Summer Flow (Poor) 1.13
Geomorphic Residual Pool 0.21
Flow (m3/s)
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0
Threshold/ Flow Statistic/ Hydraulic Inflection Point


Comparison of Threshold and Flow Statistics For Flow Exceeding the Mean Annaul Flow
Nith River Near Canning
Flow (m3/s)
100 Year Flood
513.00
50 Year Flood
465.00
20 Year Flood
401.00
10 Year Flood
350.00
5 Year Flood
295.00
2 Year Flood
209.00
1.25 Year Flood
142.00
1.05 Year Flood
91.20
Geomorphic Bankfull
61.50
Tessman Flushing Flow
22.67
Geomorphic Bed Mobilizing Flow
18.30
Hydraulic Inflection Wetted Perimeter
17.50
Hydraulic Inflection Topw idth
17.50
Hydraulic Inflection Wetted Perimeter
12.90
Hydraulic Inflection Topw idth
12.90
Mean Annual Flow
11.34
0.00
100.00
200.00
300.00
400.00
500.00
600.00
Threshold/ Flow Statistic/ Hydraulic Inflection Point


Nith River Canning
Flow (m3/s)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1
2
3
4
5
6
7
8
9
10
11
12
Month
Mean Monthly Flow
Tessmann Methods
Mean Annual Flow
Tennants
Ontario Low Water Normal
Ontario Low Water Level 1
Ontario Low Water Level 2
Ontario Low Water Level 3

NITH RIVER AT CANNING

Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	40% MMF	(40% MAF)	(MMF < 40% MAF)	MMF>40% MAF and 40% MMF < 40% MAF	40% MMF > 40% MAF		Normal	Level 1	Level 2	Level 3
1	10.58	11.34	**3.40**	**1**	10.58	4.23	4.53	0.00	4.53	0.00	**4.53**				
2	14.20	11.34	**3.40**	**2**	14.20	5.68	4.53	0.00	0.00	5.68	**5.68**				
3	28.51	11.34	**3.40**	**3**	28.51	11.40	4.53	0.00	0.00	11.40	**22.67**				
4	25.35	11.34	**5.67**	**3.5**	28.51						**22.67**				
5	10.00	11.34	**5.67**	**3.5**	28.51						**11.40**				
6	5.89	11.34	**5.67**	**4.0**	25.35	10.14	4.53	0.00	0.00	10.14	**10.14**	4.17	2.92	2.08	1.25
7	4.31	11.34	**5.67**	**5**	10.00	4.00	4.53	0.00	4.53	0.00	**4.53**	4.17	2.92	2.08	1.25
8	4.17	11.34	**5.67**	**6**	5.89	2.36	4.53	0.00	4.53	0.00	**4.53**	4.17	2.92	2.08	1.25
9	4.95	11.34	**5.67**	**7**	4.31	1.72	4.53	4.31	0.00	0.00	**4.31**	4.17	2.92	2.08	1.25
10	6.15	11.34	**3.40**	**8**	4.17	1.67	4.53	4.17	0.00	0.00	**4.17**	4.17	2.92	2.08	1.25
11	9.66	11.34	**3.40**	**9**	4.95	1.98	4.53	0.00	4.53	0.00	**4.53**	4.17	2.92	2.08	1.25
12	12.26	11.34	**3.40**	**10**	6.15	2.46	4.53	0.00	4.53	0.00	**4.53**				
				11	9.66	3.86	4.53	0.00	4.53	0.00	**4.53**				
Annual	**11.34**			**12**	12.26	4.90	4.53	0.00	0.00	4.90	**4.90**				

Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Month	Tessmann Method 1980						Tessmann Method Flows (m3/s)	OLWRP Thresholds			
					MMF	30% MMF	(30% MAF)	(MMF < 30% MAF)	MMF>30% MAF and 30% MMF < 30% MAF	30% MMF > 30% MAF		Normal	Level 1	Level 2	Level 3
1	10.58	11.34	**3.40**	**1**	10.58	3.18	3.40	0.00	3.40	0.00	**3.40**				
2	14.20	11.34	**3.40**	**2**	14.20	4.26	3.40	0.00	0.00	4.26	**4.26**				
3	28.51	11.34	**3.40**	**3**	28.51	8.55	3.40	0.00	0.00	8.55	**22.67**				
4	25.35	11.34	**5.67**	**3.5**	28.51						**22.67**				
5	10.00	11.34	**5.67**	**3.5**	28.51						**11.40**				
6	5.89	11.34	**5.67**	**4.0**	25.35	7.60	3.40	0.00	0.00	7.60	**7.60**	4.17	2.92	2.08	1.25
7	4.31	11.34	**5.67**	**5**	10.00	3.00	3.40	0.00	3.40	0.00	**3.40**	4.17	2.92	2.08	1.25
8	4.17	11.34	**5.67**	**6**	5.89	1.77	3.40	0.00	3.40	0.00	**3.40**	4.17	2.92	2.08	1.25
9	4.95	11.34	**5.67**	**7**	4.31	1.29	3.40	0.00	3.40	0.00	**3.40**	4.17	2.92	2.08	1.25
10	6.15	11.34	**3.40**	**8**	4.17	1.25	3.40	0.00	3.40	0.00	**3.40**	4.17	2.92	2.08	1.25
11	9.66	11.34	**3.40**	**9**	4.95	1.48	3.40	0.00	3.40	0.00	**3.40**	4.17	2.92	2.08	1.25
12	12.26	11.34	**3.40**	**10**	6.15	1.85	3.40	0.00	3.40	0.00	**3.40**				
				11	9.66	2.90	3.40	0.00	3.40	0.00	**3.40**				
Annual	**11.34**			**12**	12.26	3.68	3.40	0.00	0.00	3.68	**3.68**				

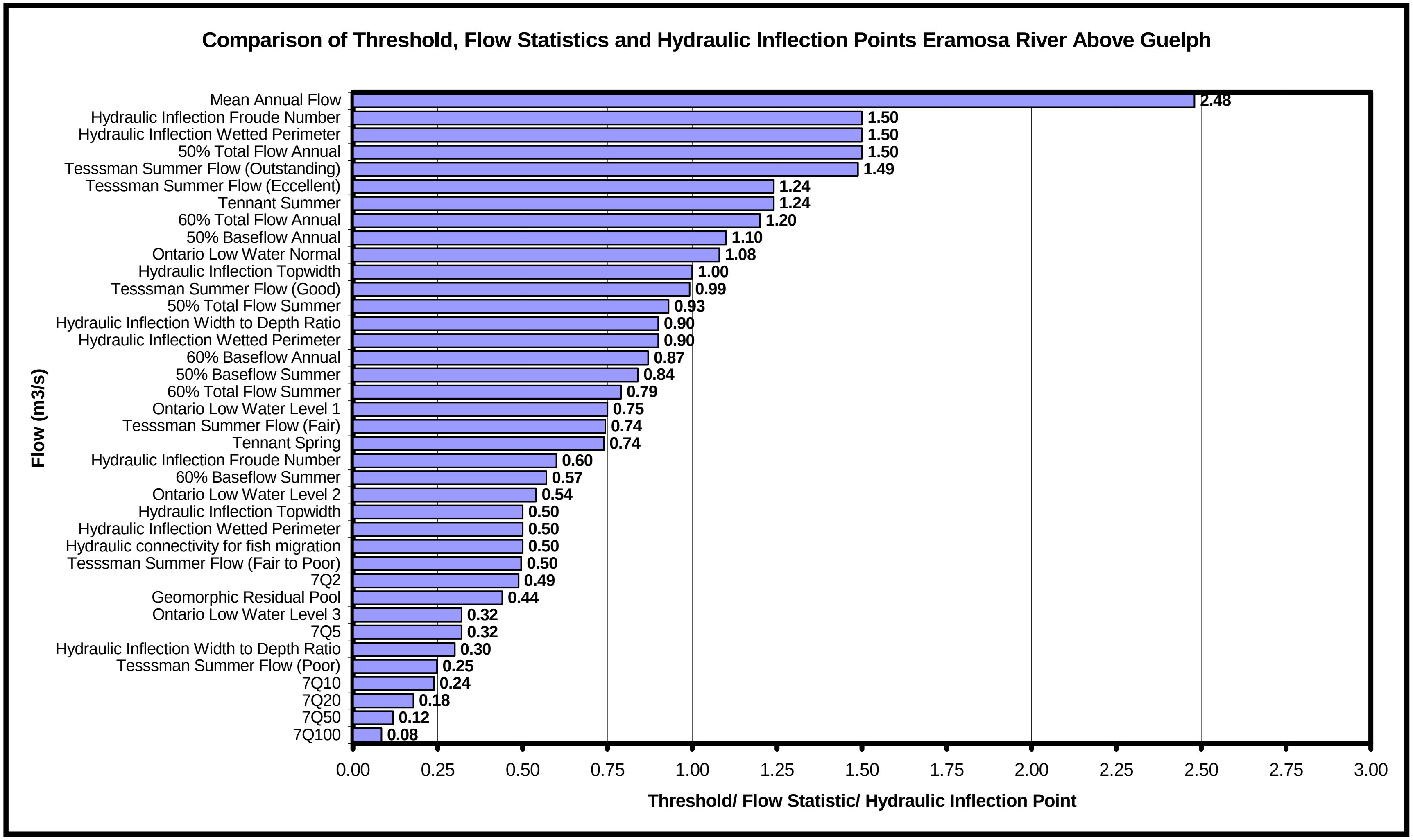
NITH RIVER AT CANNING

Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Month	Tessmann Method 1980						Tessmann Method Flows (m3/s)	OLWRP Thresholds			
					MMF	20% MMF	(20% MAF)	(MMF < 20% MAF)	MMF>20% MAF and 20% MMF < 20% MAF	20% MMF > 20% MAF		Normal	Level 1	Level 2	Level 3
1	10.58	11.34	**3.40**	**1**	10.58	2.12	2.27	0.00	2.27	0.00	**2.27**				
2	14.20	11.34	**3.40**	**2**	14.20	2.84	2.27	0.00	0.00	2.84	**2.84**				
3	28.51	11.34	**3.40**	**3**	28.51	5.70	2.27	0.00	0.00	5.70	**22.67**				
4	25.35	11.34	**5.67**	**3.5**	28.51						**22.67**				
5	10.00	11.34	**5.67**	**3.5**	28.51						**11.40**				
6	5.89	11.34	**5.67**	**4.0**	25.35	5.07	2.27	0.00	0.00	5.07	**5.07**	4.17	2.92	2.08	1.25
7	4.31	11.34	**5.67**	**5**	10.00	2.00	2.27	0.00	2.27	0.00	**2.27**	4.17	2.92	2.08	1.25
8	4.17	11.34	**5.67**	**6**	5.89	1.18	2.27	0.00	2.27	0.00	**2.27**	4.17	2.92	2.08	1.25
9	4.95	11.34	**5.67**	**7**	4.31	0.86	2.27	0.00	2.27	0.00	**2.27**	4.17	2.92	2.08	1.25
10	6.15	11.34	**3.40**	**8**	4.17	0.83	2.27	0.00	2.27	0.00	**2.27**	4.17	2.92	2.08	1.25
11	9.66	11.34	**3.40**	**9**	4.95	0.99	2.27	0.00	2.27	0.00	**2.27**	4.17	2.92	2.08	1.25
12	12.26	11.34	**3.40**	**10**	6.15	1.23	2.27	0.00	2.27	0.00	**2.27**				
				11	9.66	1.93	2.27	0.00	2.27	0.00	**2.27**				
Annual	**11.34**			**12**	12.26	2.45	2.27	0.00	0.00	2.45	**2.45**				

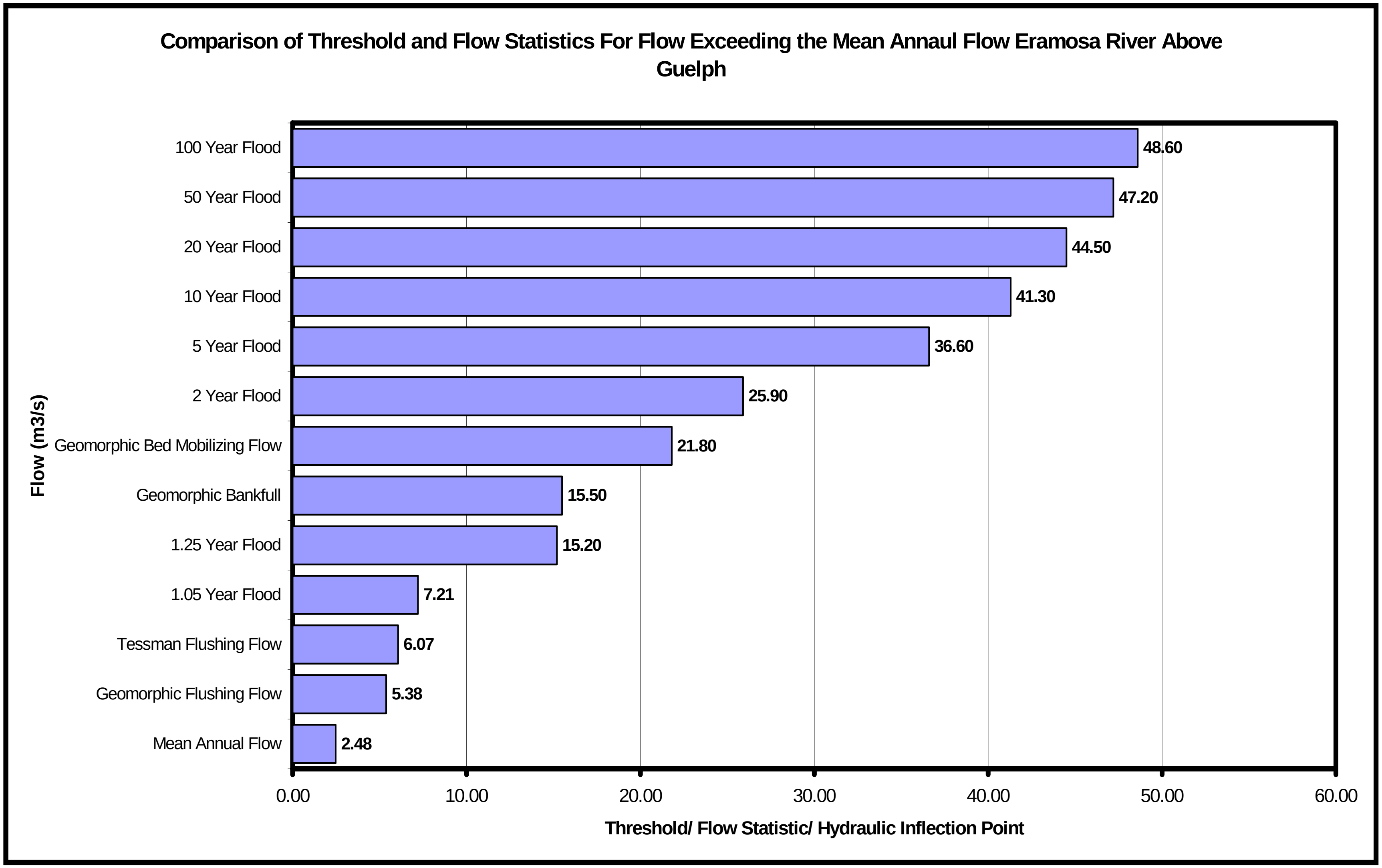
Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Month	Tessmann Method 1980						Tessmann Method Flows (m3/s)	OLWRP Thresholds			
					MMF	10% MMF	(10% MAF)	(MMF < 10% MAF)	MMF>10% MAF and 10% MMF < 10% MAF	10% MMF > 10% MAF		Normal	Level 1	Level 2	Level 3
1	10.58	11.34	**3.40**	**1**	10.58	1.06	1.13	0.00	1.13	0.00	**1.13**				
2	14.20	11.34	**3.40**	**2**	14.20	1.42	1.13	0.00	0.00	1.42	**1.42**				
3	28.51	11.34	**3.40**	**3**	28.51	2.85	1.13	0.00	0.00	2.85	**22.67**				
4	25.35	11.34	**5.67**	**3.5**	28.51						**22.67**				
5	10.00	11.34	**5.67**	**3.5**	28.51						**11.40**				
6	5.89	11.34	**5.67**	**4.0**	25.35	2.53	1.13	0.00	0.00	2.53	**2.53**	4.17	2.92	2.08	1.25
7	4.31	11.34	**5.67**	**5**	10.00	1.00	1.13	0.00	1.13	0.00	**1.13**	4.17	2.92	2.08	1.25
8	4.17	11.34	**5.67**	**6**	5.89	0.59	1.13	0.00	1.13	0.00	**1.13**	4.17	2.92	2.08	1.25
9	4.95	11.34	**5.67**	**7**	4.31	0.43	1.13	0.00	1.13	0.00	**1.13**	4.17	2.92	2.08	1.25
10	6.15	11.34	**3.40**	**8**	4.17	0.42	1.13	0.00	1.13	0.00	**1.13**	4.17	2.92	2.08	1.25
11	9.66	11.34	**3.40**	**9**	4.95	0.49	1.13	0.00	1.13	0.00	**1.13**	4.17	2.92	2.08	1.25
12	12.26	11.34	**3.40**	**10**	6.15	0.62	1.13	0.00	1.13	0.00	**1.13**				
				11	9.66	0.97	1.13	0.00	1.13	0.00	**1.13**				
Annual	**11.34**			**12**	12.26	1.23	1.13	0.00	0.00	1.23	**1.23**				

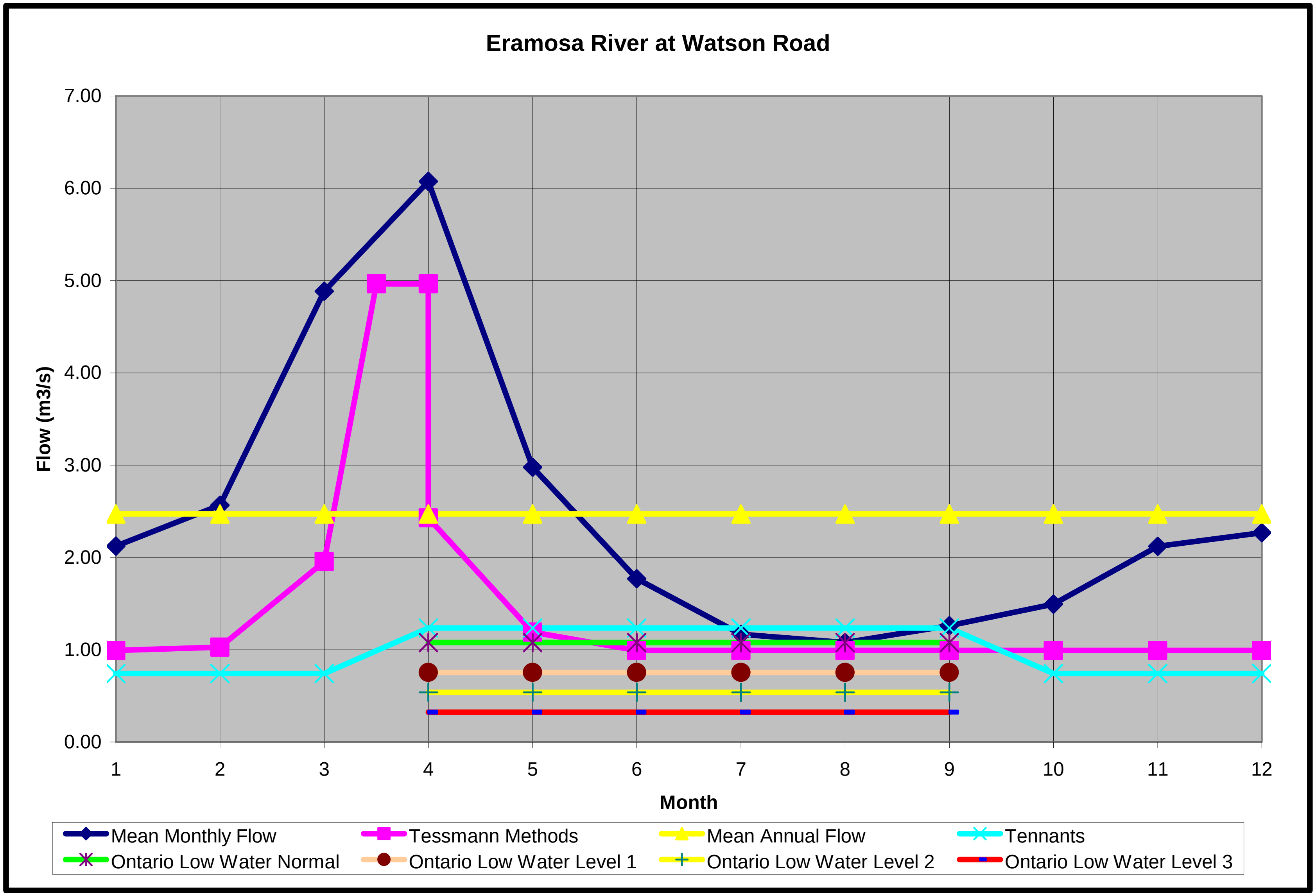
F-2: ERAMOSA RIVER REACH

Eramosa River Above Guelph		OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
7Q100	0.08	0.10	0.33
7Q50	0.12	0.10	0.35
7Q20	0.18	0.13	0.38
7Q10	0.24	0.15	0.42
Tessman Summer Flow (Poor)	0.25	0.26	
Hydraulic Inflection Width to Depth Ratio	0.30		
7Q5	0.32	0.19	0.48
Ontario Low Water Level 3	0.32		
Geomorphic Residual Pool	0.44		
7Q2	0.49	0.31	0.62
Tessman Summer Flow (Fair to Poor)	0.50		
Hydraulic connectivity for fish migration	0.50		
Hydraulic Inflection Wetted Perimeter	0.50		
Hydraulic Inflection Topwidth	0.50		
Ontario Low Water Level 2	0.54		
60% Baseflow Summer	0.57		
Hydraulic Inflection Froude Number	0.60		
Tennant Spring	0.74		
Tessman Summer Flow (Fair)	0.74		
Ontario Low Water Level 1	0.75		
60% Total Flow Summer	0.79		
50% Baseflow Summer	0.84		
60% Baseflow Annual	0.87		
Hydraulic Inflection Wetted Perimeter	0.90		
Hydraulic Inflection Width to Depth Ratio	0.90		
50% Total Flow Summer	0.93		
Tessman Summer Flow (Good)	0.99		
Hydraulic Inflection Topwidth	1.00		
Ontario Low Water Normal	1.08		
50% Baseflow Annual	1.10		
60% Total Flow Annual	1.20		
Tennant Summer	1.24		
Tessman Summer Flow (Excellent)	1.24		
Tessman Summer Flow (Outstanding)	1.49		
50% Total Flow Annual	1.50		
Hydraulic Inflection Wetted Perimeter	1.50		
Hydraulic Inflection Froude Number	1.50		
Mean Annual Flow	2.48		
Tessman Flushing Flow	4.96		
Geomorphic Flushing Flow	5.38		
1.05 Year Flood	7.21		
1.25 Year Flood	15.20	64.92	66.08
Geomorphic Bankfull	15.50		
Geomorphic Bed Mobilizing Flow	21.80		
2 Year Flood	25.90	42.35	72.14
5 Year Flood	36.60	63.02	98.34
10 Year Flood	41.30	75.73	120.47
20 Year Flood	44.50	87.31	142.07
50 Year Flood	47.20	101.96	167.94
100 Year Flood	48.60	112.41	193.15



Comparison of Threshold, Flow Statistics and Hydraulic Inflection Points Eramosa River Above Guelph


Comparison of Threshold and Flow Statistics For Flow Exceeding the Mean Annaul Flow Eramosa River Above Guelph
Flow (m3/s)
100 Year Flood
48.60
50 Year Flood
47.20
20 Year Flood
44.50
10 Year Flood
41.30
5 Year Flood
36.60
2 Year Flood
25.90
Geomorphic Bed Mobilizing Flow
21.80
Geomorphic Bankfull
15.50
1.25 Year Flood
15.20
1.05 Year Flood
7.21
Tessman Flushing Flow
6.07
Geomorphic Flushing Flow
5.38
Mean Annual Flow
2.48
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Threshold/ Flow Statistic/ Hydraulic Inflection Point


Eramosa River at Watson Road
Flow (m3/s)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1
2
3
4
5
6
7
8
9
10
11
12
Month
Mean Monthly Flow
Tessmann Methods
Mean Annual Flow
Tennants
Ontario Low Water Normal
Ontario Low Water Level 1
Ontario Low Water Level 2
Ontario Low Water Level 3

ERAMOSA RIVER REACH

Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	40% MMF	(40% MAF)	(MMF < 40% MAF)	MMF>40% MAF and 40% MMF < 40% MAF	(40% MMF > 40% MAF)		Normal	Level 1	Level 2	Level 3
1	2.12	2.47	0.74	1	2.12	0.85	0.99	0.00	0.99	0.00	0.99				
2	2.57	2.47	0.74	2	2.57	1.03	0.99	0.00	0.00	1.03	1.03				
3	4.89	2.47	0.74	3	4.89	1.95	0.99	0.00	0.00	1.95	1.95				
4	6.07	2.47	1.24	3.5	6.07						4.96				
5	2.98	2.47	1.24	4.0	6.07						4.96				
6	1.77	2.47	1.24	4.0	6.07	2.43	0.99	0.00	0.00	2.43	2.43	1.08	0.75	0.54	0.32
7	1.17	2.47	1.24	5	2.98	1.19	0.99	0.00	0.00	1.19	1.19	1.08	0.75	0.54	0.32
8	1.08	2.47	1.24	6	1.77	0.71	0.99	0.00	0.99	0.00	0.99	1.08	0.75	0.54	0.32
9	1.26	2.47	1.24	7	1.17	0.47	0.99	0.00	0.99	0.00	0.99	1.08	0.75	0.54	0.32
10	1.49	2.47	0.74	8	1.08	0.43	0.99	0.00	0.99	0.00	0.99	1.08	0.75	0.54	0.32
11	2.12	2.47	0.74	9	1.26	0.50	0.99	0.00	0.99	0.00	0.99	1.08	0.75	0.54	0.32
12	2.27	2.47	0.74	10	1.49	0.60	0.99	0.00	0.99	0.00	0.99				
				11	2.12	0.85	0.99	0.00	0.99	0.00	0.99				
Annual	2.48			12	2.27	0.91	0.99	0.00	0.99	0.00	0.99				

Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	30% MMF	(30% MAF)	(MMF < 30% MAF)	MMF>30% MAF and 30% MMF < 30% MAF	30% MMF > 30% MAF		Normal	Level 1	Level 2	Level 3
1	2.12	2.47	0.74	1	2.12	0.64	0.74	0.00	0.74	0.00	0.74				
2	2.57	2.47	0.74	2	2.57	0.77	0.74	0.00	0.00	0.77	0.77				
3	4.89	2.47	0.74	3	4.89	1.47	0.74	0.00	0.00	1.47	1.47				
4	6.07	2.47	1.24	3.5	6.07						4.96				
5	2.98	2.47	1.24	4.0	6.07						4.96				
6	1.77	2.47	1.24	4.0	6.07	1.82	0.74	0.00	0.00	1.82	1.82	1.08	0.75	0.54	0.32
7	1.17	2.47	1.24	5	2.98	0.89	0.74	0.00	0.00	0.89	0.89	1.08	0.75	0.54	0.32
8	1.08	2.47	1.24	6	1.77	0.53	0.74	0.00	0.74	0.00	0.74	1.08	0.75	0.54	0.32
9	1.26	2.47	1.24	7	1.17	0.35	0.74	0.00	0.74	0.00	0.74	1.08	0.75	0.54	0.32
10	1.49	2.47	0.74	8	1.08	0.32	0.74	0.00	0.74	0.00	0.74	1.08	0.75	0.54	0.32
11	2.12	2.47	0.74	9	1.26	0.38	0.74	0.00	0.74	0.00	0.74	1.08	0.75	0.54	0.32
12	2.27	2.47	0.74	10	1.49	0.45	0.74	0.00	0.74	0.00	0.74				
				11	2.12	0.64	0.74	0.00	0.74	0.00	0.74				
Annual	2.48			12	2.27	0.68	0.74	0.00	0.74	0.00	0.74				

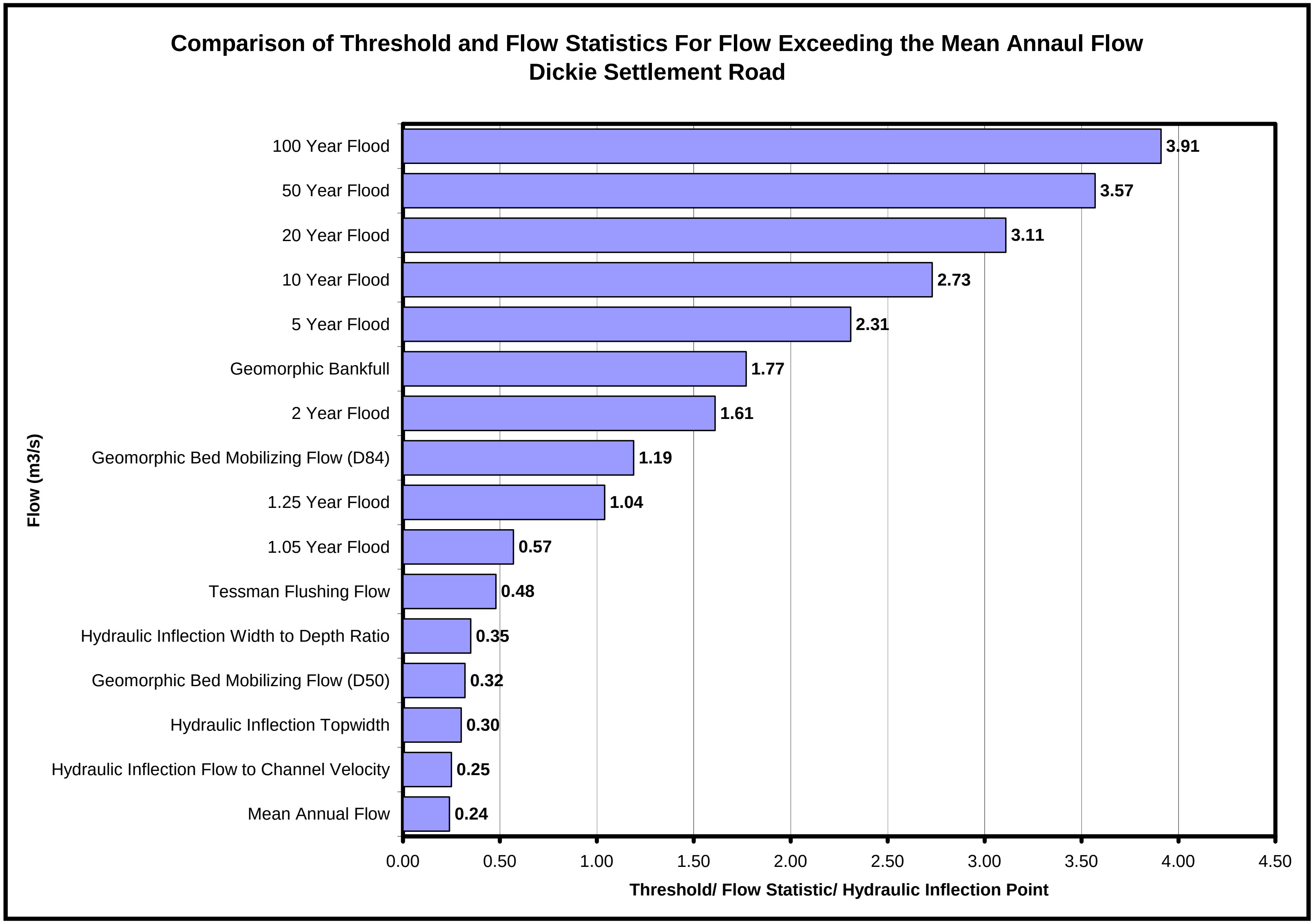
ERAMOSA RIVER REACH

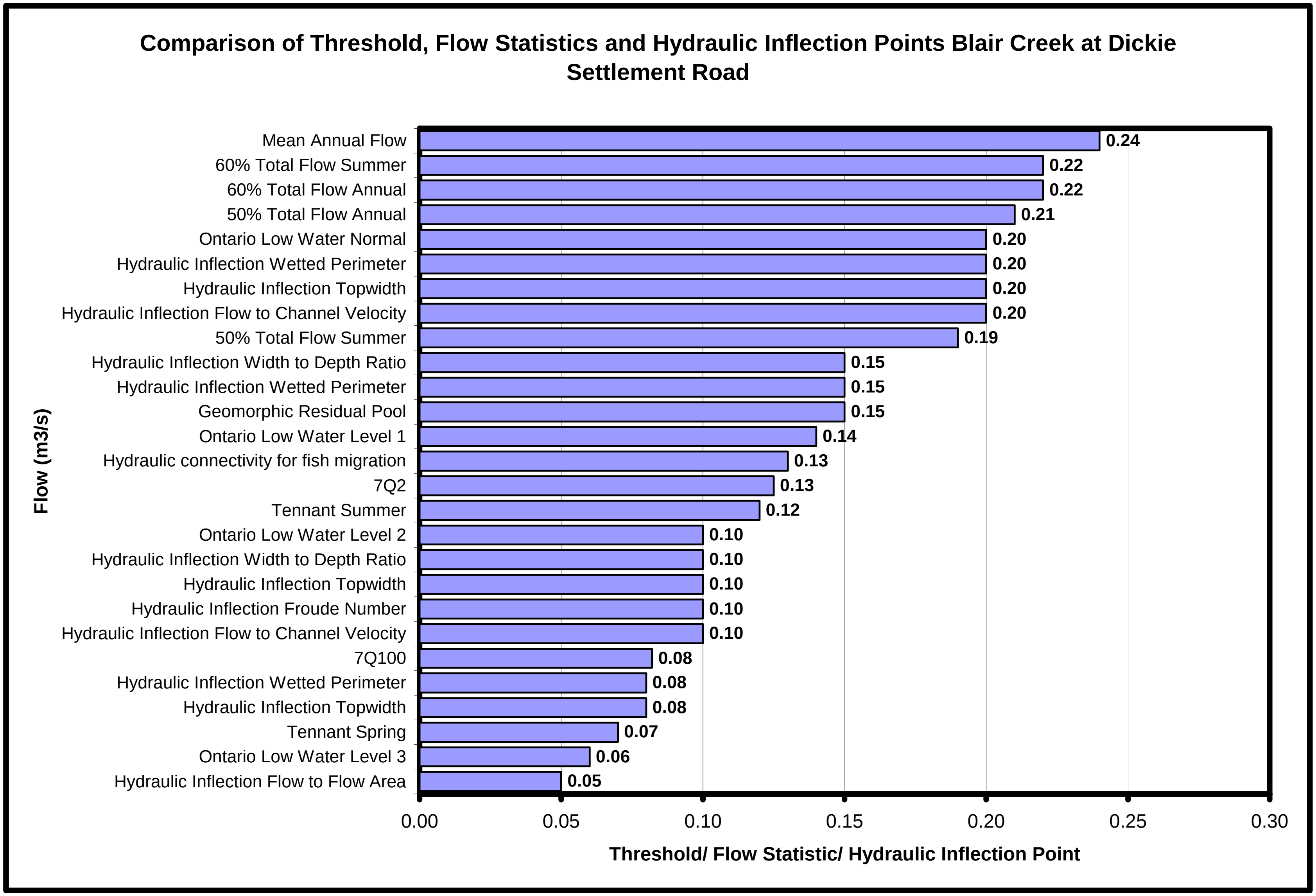
Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	20% MMF	(20% MAF)	(MMF < 20% MAF)	MMF>20% MAF and 20% MMF < 20% MAF	20% MMF > 20% MAF		Normal	Level 1	Level 2	Level 3
1	2.12	2.47	**0.74**	**1**	2.12	0.42	0.50	0.00	0.50	0.00	**0.50**				
2	2.57	2.47	**0.74**	**2**	2.57	0.51	0.50	0.00	0.00	0.51	**0.51**				
3	4.89	2.47	**0.74**	**3**	4.89	0.98	0.50	0.00	0.00	0.98	**0.98**				
4	6.07	2.47	**1.24**	**3.5**	6.07						**4.96**				
5	2.98	2.47	**1.24**	**4.0**	6.07						**4.96**				
6	1.77	2.47	**1.24**	**4.0**	6.07	1.21	0.50	0.00	0.00	1.21	**1.21**	1.08	0.75	0.54	0.32
7	1.17	2.47	**1.24**	**5**	2.98	0.60	0.50	0.00	0.00	0.60	**0.60**	1.08	0.75	0.54	0.32
8	1.08	2.47	**1.24**	**6**	1.77	0.35	0.50	0.00	0.50	0.00	**0.50**	1.08	0.75	0.54	0.32
9	1.26	2.47	**1.24**	**7**	1.17	0.23	0.50	0.00	0.50	0.00	**0.50**	1.08	0.75	0.54	0.32
10	1.49	2.47	**0.74**	**8**	1.08	0.22	0.50	0.00	0.50	0.00	**0.50**	1.08	0.75	0.54	0.32
11	2.12	2.47	**0.74**	**9**	1.26	0.25	0.50	0.00	0.50	0.00	**0.50**	1.08	0.75	0.54	0.32
12	2.27	2.47	**0.74**	**10**	1.49	0.30	0.50	0.00	0.50	0.00	**0.50**				
				11	2.12	0.42	0.50	0.00	0.50	0.00	**0.50**				
Annual	**2.48**			**12**	2.27	0.45	0.50	0.00	0.50	0.00	**0.50**				

Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	10% MMF	(10% MAF)	(MMF < 10% MAF)	MMF>10% MAF and 10% MMF < 10% MAF	10% MMF > 10% MAF		Normal	Level 1	Level 2	Level 3
1	2.12	2.47	**0.74**	**1**	2.12	0.21	0.25	0.00	0.25	0.00	**0.25**				
2	2.57	2.47	**0.74**	**2**	2.57	0.26	0.25	0.00	0.00	0.26	**0.26**				
3	4.89	2.47	**0.74**	**3**	4.89	0.49	0.25	0.00	0.00	0.49	**0.49**				
4	6.07	2.47	**1.24**	**3.5**	6.07						**4.96**				
5	2.98	2.47	**1.24**	**4.0**	6.07						**4.96**				
6	1.77	2.47	**1.24**	**4.0**	6.07	0.61	0.25	0.00	0.00	0.61	**0.61**	1.08	0.75	0.54	0.32
7	1.17	2.47	**1.24**	**5**	2.98	0.30	0.25	0.00	0.00	0.30	**0.30**	1.08	0.75	0.54	0.32
8	1.08	2.47	**1.24**	**6**	1.77	0.18	0.25	0.00	0.25	0.00	**0.25**	1.08	0.75	0.54	0.32
9	1.26	2.47	**1.24**	**7**	1.17	0.12	0.25	0.00	0.25	0.00	**0.25**	1.08	0.75	0.54	0.32
10	1.49	2.47	**0.74**	**8**	1.08	0.11	0.25	0.00	0.25	0.00	**0.25**	1.08	0.75	0.54	0.32
11	2.12	2.47	**0.74**	**9**	1.26	0.13	0.25	0.00	0.25	0.00	**0.25**	1.08	0.75	0.54	0.32
12	2.27	2.47	**0.74**	**10**	1.49	0.15	0.25	0.00	0.25	0.00	**0.25**				
				11	2.12	0.21	0.25	0.00	0.25	0.00	**0.25**				
Annual	**2.48**			**12**	2.27	0.23	0.25	0.00	0.25	0.00	**0.25**				

F-3: BLAIR CREEK

Blair Creek Cambridge		OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Hydraulic Inflection Flow to Flow Area	0.05		
Ontario Low Water Level 3	0.06		
Tennant Spring	0.07		
Hydraulic Inflection Topwidth	0.08		
Hydraulic Inflection Wetted Perimeter	0.08		
7Q100	0.08	0.007	0.019
Hydraulic Inflection Flow to Channel Velocity	0.10		
Hydraulic Inflection Froude Number	0.10		
Hydraulic Inflection Topwidth	0.10		
Hydraulic Inflection Width to Depth Ratio	0.10		
Ontario Low Water Level 2	0.10		
Tennant Summer	0.12		
7Q2	0.13	0.02	0.06
Hydraulic connectivity for fish migration	0.13		
Ontario Low Water Level 1	0.14		
Geomorphic Residual Pool	0.15		
Hydraulic Inflection Wetted Perimeter	0.15		
Hydraulic Inflection Width to Depth Ratio	0.15		
50% Total Flow Summer	0.19		
Hydraulic Inflection Flow to Channel Velocity	0.20		
Hydraulic Inflection Topwidth	0.20		
Hydraulic Inflection Wetted Perimeter	0.20		
Ontario Low Water Normal	0.20		
50% Total Flow Annual	0.21		
60% Total Flow Annual	0.22		
60% Total Flow Summer	0.22		
Mean Annual Flow	0.24	0.15	
Hydraulic Inflection Flow to Channel Velocity	0.25		
Hydraulic Inflection Topwidth	0.30		
Geomorphic Bed Mobilizing Flow (D50)	0.32		
Hydraulic Inflection Width to Depth Ratio	0.35		
Tessman Flushing Flow	0.48		
1.05 Year Flood	0.57		
1.25 Year Flood	1.04	6.199	6.309
Geomorphic Bed Mobilizing Flow (D84)	1.19		
2 Year Flood	1.61	4.977	6.888
Geomorphic Bankfull	1.77		
5 Year Flood	2.31	8.451	10.51
10 Year Flood	2.73	10.251	13.26
20 Year Flood	3.11	11.116	15.904
50 Year Flood	3.57	12.434	19.385
100 Year Flood	3.91	14.062	22.012
7Q10		0.01	0.03
7Q20		0.009	0.025
7Q5		0.014	0.04
7Q50		0.008	0.021


Comparison of Threshold and Flow Statistics For Flow Exceeding the Mean Annaul Flow
Dickie Settlement Road
Flow (m3/s)
100 Year Flood
3.91
50 Year Flood
3.57
20 Year Flood
3.11
10 Year Flood
2.73
5 Year Flood
2.31
Geomorphic Bankfull
1.77
2 Year Flood
1.61
Geomorphic Bed Mobilizing Flow (D84)
1.19
1.25 Year Flood
1.04
1.05 Year Flood
0.57
Tessman Flushing Flow
0.48
Hydraulic Inflection Width to Depth Ratio
0.35
Geomorphic Bed Mobilizing Flow (D50)
0.32
Hydraulic Inflection Topwidth
0.30
Hydraulic Inflection Flow to Channel Velocity
0.25
Mean Annual Flow
0.24
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
Threshold/ Flow Statistic/ Hydraulic Inflection Point

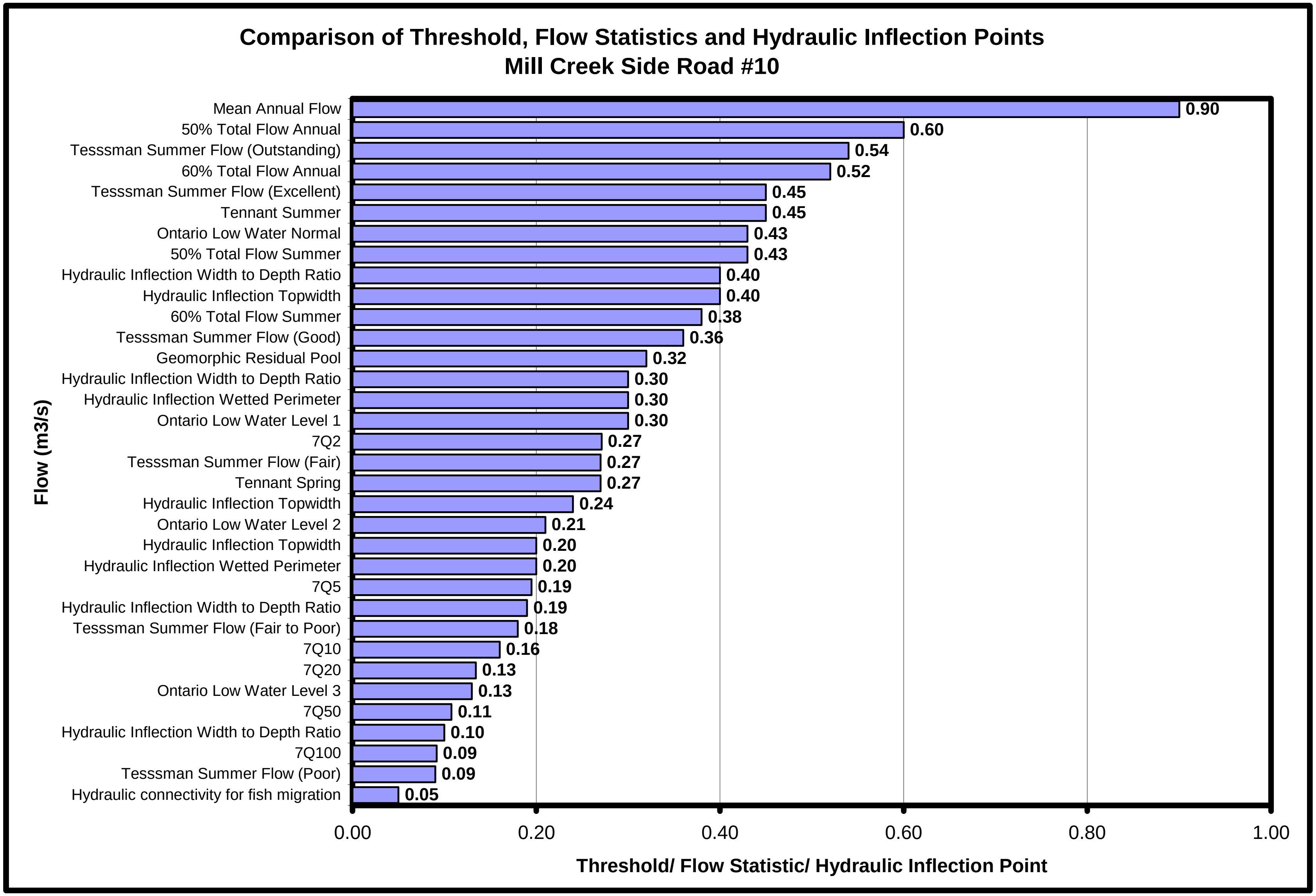


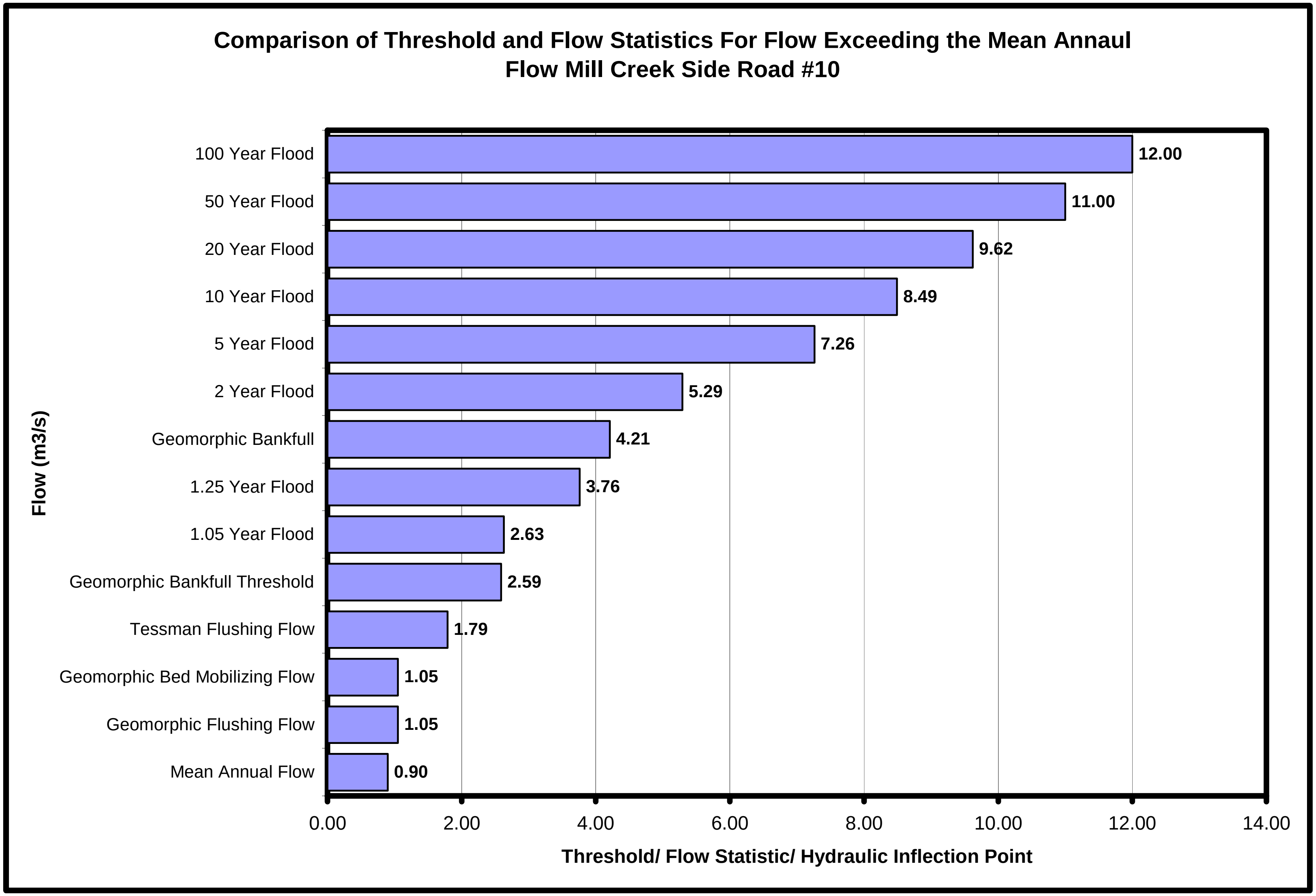
Comparison of Threshold, Flow Statistics and Hydraulic Inflection Points Blair Creek at Dickie Settlement Road

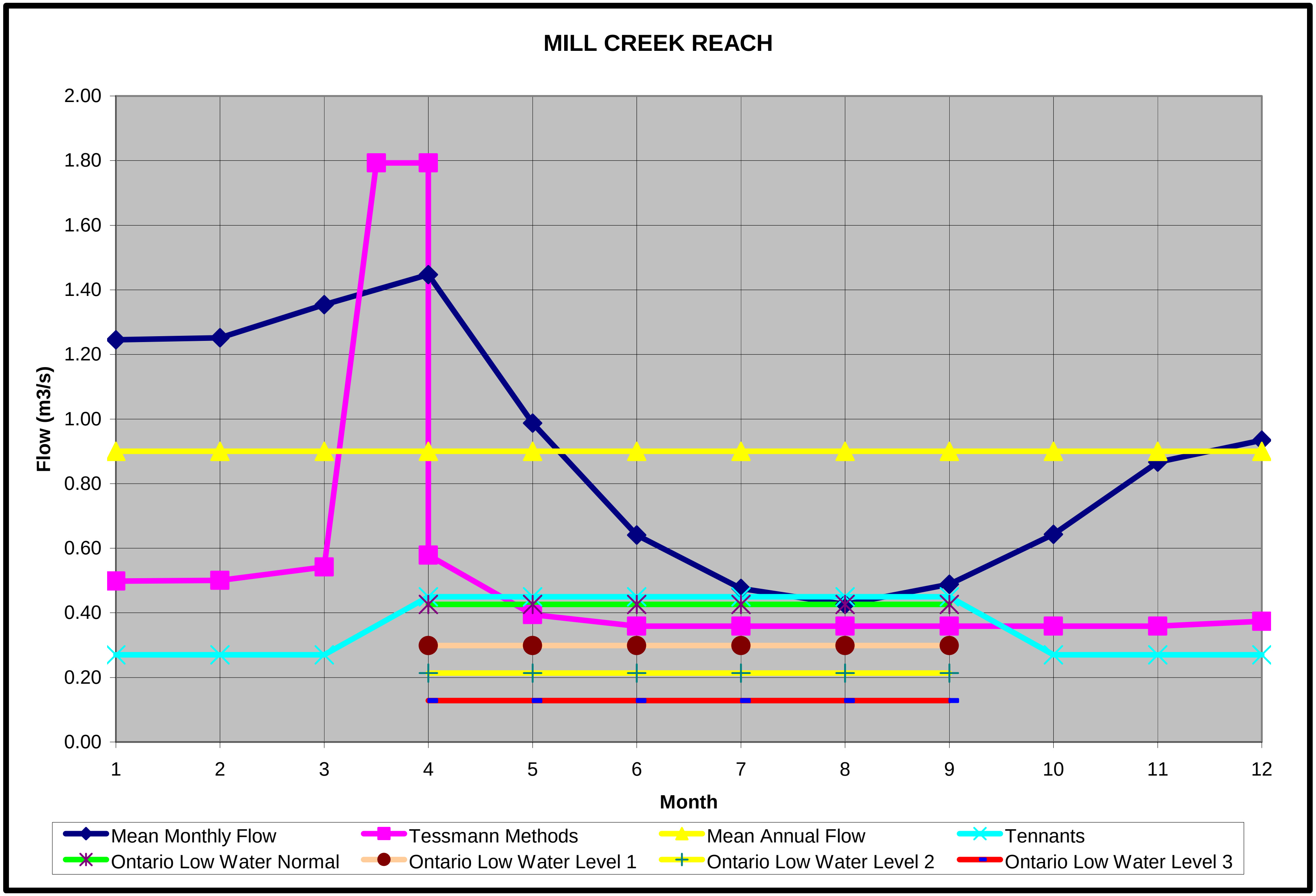
F-4: MILL CREEK

Last updated: 3 February 2005

Mill Creek Side Road 10		OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Hydraulic connectivity for fish migration	0.05		
Tessman Summer Flow (Poor)	0.09		
7Q100	0.09	0.04	0.08
Hydraulic Inflection Width to Depth Ratio	0.10		
7Q50	0.11	0.05	0.08
Ontario Low Water Level 3	0.13		
7Q20	0.13	0.06	0.09
7Q10	0.16	0.06	0.1
Tessman Summer Flow (Fair to Poor)	0.18		
Hydraulic Inflection Width to Depth Ratio	0.19		
7Q5	0.19	0.08	0.12
Hydraulic Inflection Topwidth	0.20		
Hydraulic Inflection Wetted Perimeter	0.20		
Ontario Low Water Level 2	0.21		
Hydraulic Inflection Topwidth	0.24		
Tennant Spring	0.27		
Tessman Summer Flow (Fair)	0.27		
7Q2	0.27	0.14	0.17
Root Zone Maintenance 30 cm Below Bankfull	0.28		
Hydraulic Inflection Wetted Perimeter	0.30		
Hydraulic Inflection Width to Depth Ratio	0.30		
Ontario Low Water Level 1	0.30		
Geomorphic Residual Pool	0.32		
Tessman Summer Flow (Good)	0.36		
60% Total Flow Summer	0.38		
Hydraulic Inflection Topwidth	0.40		
Hydraulic Inflection Width to Depth Ratio	0.40		
50% Total Flow Summer	0.43		
Ontario Low Water Normal	0.43		
Tennant Summer	0.45		
Tessman Summer Flow (Excellent)	0.45		
60% Total Flow Annual	0.52		
Tessman Summer Flow (Outstanding)	0.54		
50% Total Flow Annual	0.60		
Mean Annual Flow	0.90		
Geomorphic Bed Mobilizing Flow	1.05		
Geomorphic Flushing Flow	1.05		
Tessman Flushing Flow	1.79		
Geomorphic Bank Threshold	2.59		
1.05 Year Flood	2.63	26.7	
1.25 Year Flood	3.76	26.3	29.2
Geomorphic Bankfull	4.21		
2 Year Flood	5.29	15.4	39.0
5 Year Flood	7.26	23.8	46.2
10 Year Flood	8.49	29.9	52.9
20 Year Flood	9.62	36.0	62.4
50 Year Flood	11.00	41.6	69.1
100 Year Flood	12.00	46.9	76.9


Comparison of Threshold, Flow Statistics and Hydraulic Inflection Points
Mill Creek Side Road #10
Mean Annual Flow
0.90
50% Total Flow Annual
0.60
Tesssman Summer Flow (Outstanding)
0.54
60% Total Flow Annual
0.52
Tesssman Summer Flow (Excellent)
0.45
Tennant Summer
0.45
Ontario Low Water Normal
0.43
50% Total Flow Summer
0.43
Hydraulic Inflection Width to Depth Ratio
0.40
Hydraulic Inflection Topwidth
0.40
60% Total Flow Summer
0.38
Tesssman Summer Flow (Good)
0.36
Geomorphic Residual Pool
0.32
Hydraulic Inflection Width to Depth Ratio
0.30
Hydraulic Inflection Wetted Perimeter
0.30
Ontario Low Water Level 1
0.30
7Q2
0.27
Tesssman Summer Flow (Fair)
0.27
Tennant Spring
0.27
Hydraulic Inflection Topwidth
0.24
Ontario Low Water Level 2
0.21
Hydraulic Inflection Topwidth
0.20
Hydraulic Inflection Wetted Perimeter
0.20
7Q5
0.19
Hydraulic Inflection Width to Depth Ratio
0.19
Tesssman Summer Flow (Fair to Poor)
0.18
7Q10
0.16
7Q20
0.13
Ontario Low Water Level 3
0.13
7Q50
0.11
Hydraulic Inflection Width to Depth Ratio
0.10
7Q100
0.09
Tesssman Summer Flow (Poor)
0.09
Hydraulic connectivity for fish migration
0.05
Flow (m3/s)
0.00
0.20
0.40
0.60
0.80
1.00
Threshold/ Flow Statistic/ Hydraulic Inflection Point


Comparison of Threshold and Flow Statistics For Flow Exceeding the Mean Annaul Flow Mill Creek Side Road #10
100 Year Flood
50 Year Flood
20 Year Flood
10 Year Flood
5 Year Flood
2 Year Flood
Geomorphic Bankfull
1.25 Year Flood
1.05 Year Flood
Geomorphic Bankfull Threshold
Tessman Flushing Flow
Geomorphic Bed Mobilizing Flow
Geomorphic Flushing Flow
Mean Annual Flow
12.00
11.00
9.62
8.49
7.26
5.29
4.21
3.76
2.63
2.59
1.79
1.05
1.05
0.90
Flow (m3/s)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
Threshold/ Flow Statistic/ Hydraulic Inflection Point


MILL CREEK REACH
Flow (m3/s)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
7
8
9
10
11
12
Month
Mean Monthly Flow
Tessmann Methods
Mean Annual Flow
Tennants
Ontario Low Water Normal
Ontario Low Water Level 1
Ontario Low Water Level 2
Ontario Low Water Level 3

MILL CREEK REACH

Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	40% MMF	(40% MAF)	(MMF < 40% MAF)	MMF>40% MAF and 40% MMF < 40% MAF	(40% MMF > 40% MAF)		Normal	Level 1	Level 2	Level 3
1	1.25	0.90	**0.27**	**1**	1.25	0.50	0.36	0.00	0.00	0.50	**0.50**				
2	1.25	0.90	**0.27**	**2**	1.25	0.50	0.36	0.00	0.00	0.50	**0.50**				
3	1.35	0.90	**0.27**	**3**	1.35	0.54	0.36	0.00	0.00	0.54	**0.54**				
4	1.45	0.90	**0.45**	**3.5**	1.45						**1.79**				
5	0.99	0.90	**0.45**	**4.0**	1.45						**1.79**				
6	0.64	0.90	**0.45**	**4.0**	1.45	0.58	0.36	0.00	0.00	0.58	**0.58**	0.43	0.30	0.21	0.13
7	0.48	0.90	**0.45**	**5**	0.99	0.39	0.36	0.00	0.00	0.39	**0.39**	0.43	0.30	0.21	0.13
8	0.43	0.90	**0.45**	**6**	0.64	0.26	0.36	0.00	0.36	0.00	**0.36**	0.43	0.30	0.21	0.13
9	0.49	0.90	**0.45**	**7**	0.48	0.19	0.36	0.00	0.36	0.00	**0.36**	0.43	0.30	0.21	0.13
10	0.64	0.90	**0.27**	**8**	0.43	0.17	0.36	0.00	0.36	0.00	**0.36**	0.43	0.30	0.21	0.13
11	0.87	0.90	**0.27**	**9**	0.49	0.20	0.36	0.00	0.36	0.00	**0.36**	0.43	0.30	0.21	0.13
12	0.93	0.90	**0.27**	**10**	0.64	0.26	0.36	0.00	0.36	0.00	**0.36**				
				11	0.87	0.35	0.36	0.00	0.36	0.00	**0.36**				
Annual	**0.90**			**12**	0.93	0.37	0.36	0.00	0.00	0.37	**0.37**				

Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	30% MMF	(30% MAF)	(MMF < 30% MAF)	MMF>30% MAF and 30% MMF < 30% MAF	30% MMF > 30% MAF		Normal	Level 1	Level 2	Level 3
1	1.25	0.90	**0.27**	**1**	1.25	0.37	0.27	0.00	0.00	0.37	**0.37**				
2	1.25	0.90	**0.27**	**2**	1.25	0.38	0.27	0.00	0.00	0.38	**0.38**				
3	1.35	0.90	**0.27**	**3**	1.35	0.41	0.27	0.00	0.00	0.41	**0.41**				
4	1.45	0.90	**0.45**	**3.5**	1.45						**1.79**				
5	0.99	0.90	**0.45**	**4.0**	1.45						**1.79**				
6	0.64	0.90	**0.45**	**4.0**	1.45	0.43	0.27	0.00	0.00	0.43	**0.43**	0.43	0.30	0.21	0.13
7	0.48	0.90	**0.45**	**5**	0.99	0.30	0.27	0.00	0.00	0.30	**0.30**	0.43	0.30	0.21	0.13
8	0.43	0.90	**0.45**	**6**	0.64	0.19	0.27	0.00	0.27	0.00	**0.27**	0.43	0.30	0.21	0.13
9	0.49	0.90	**0.45**	**7**	0.48	0.14	0.27	0.00	0.27	0.00	**0.27**	0.43	0.30	0.21	0.13
10	0.64	0.90	**0.27**	**8**	0.43	0.13	0.27	0.00	0.27	0.00	**0.27**	0.43	0.30	0.21	0.13
11	0.87	0.90	**0.27**	**9**	0.49	0.15	0.27	0.00	0.27	0.00	**0.27**	0.43	0.30	0.21	0.13
12	0.93	0.90	**0.27**	**10**	0.64	0.19	0.27	0.00	0.27	0.00	**0.27**				
				11	0.87	0.26	0.27	0.00	0.27	0.00	**0.27**				
Annual	**0.90**			**12**	0.93	0.28	0.27	0.00	0.00	0.28	**0.28**				

MILL CREEK REACH

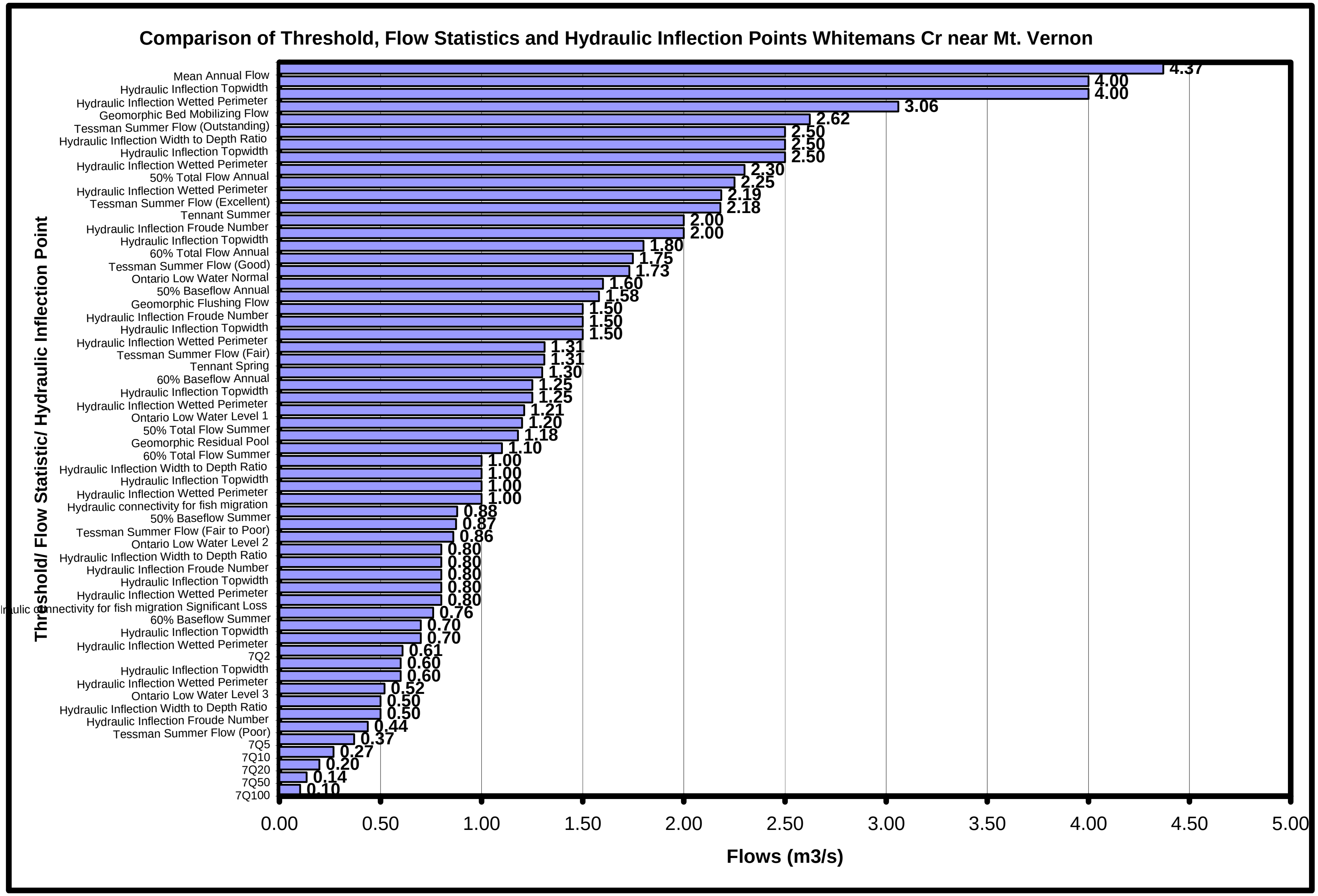
Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	20% MMF	(20% MAF)	(MMF < 20% MAF)	MMF>20% MAF and 20% MMF < 20% MAF	20% MMF > 20% MAF		Normal	Level 1	Level 2	Level 3
1	1.25	0.90	**0.27**	**1**	1.25	0.25	0.18	0.00	0.00	0.25	**0.25**				
2	1.25	0.90	**0.27**	**2**	1.25	0.25	0.18	0.00	0.00	0.25	**0.25**				
3	1.35	0.90	**0.27**	**3**	1.35	0.27	0.18	0.00	0.00	0.27	**0.27**				
4	1.45	0.90	**0.45**	**3.5**	1.45						**1.79**				
5	0.99	0.90	**0.45**	**4.0**	1.45						**1.79**				
6	0.64	0.90	**0.45**	**4.0**	1.45	0.29	0.18	0.00	0.00	0.29	**0.29**	0.43	0.30	0.21	0.13
7	0.48	0.90	**0.45**	**5**	0.99	0.20	0.18	0.00	0.00	0.20	**0.20**	0.43	0.30	0.21	0.13
8	0.43	0.90	**0.45**	**6**	0.64	0.13	0.18	0.00	0.18	0.00	**0.18**	0.43	0.30	0.21	0.13
9	0.49	0.90	**0.45**	**7**	0.48	0.10	0.18	0.00	0.18	0.00	**0.18**	0.43	0.30	0.21	0.13
10	0.64	0.90	**0.27**	**8**	0.43	0.09	0.18	0.00	0.18	0.00	**0.18**	0.43	0.30	0.21	0.13
11	0.87	0.90	**0.27**	**9**	0.49	0.10	0.18	0.00	0.18	0.00	**0.18**	0.43	0.30	0.21	0.13
12	0.93	0.90	**0.27**	**10**	0.64	0.13	0.18	0.00	0.18	0.00	**0.18**				
				11	0.87	0.17	0.18	0.00	0.18	0.00	**0.18**				
Annual	**0.90**			**12**	0.93	0.19	0.18	0.00	0.00	0.19	**0.19**				

Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)				
				Month	MMF	10% MMF	(10% MAF)	(MMF < 10% MAF)	MMF>10% MAF and 10% MMF < 10% MAF	10% MMF > 10% MAF		Normal	Level 1	Level 2	Level 3
1	1.25	0.90	**0.27**	**1**	1.25	0.12	0.09	0.00	0.00	0.12	**0.12**				
2	1.25	0.90	**0.27**	**2**	1.25	0.13	0.09	0.00	0.00	0.13	**0.13**				
3	1.35	0.90	**0.27**	**3**	1.35	0.14	0.09	0.00	0.00	0.14	**0.14**				
4	1.45	0.90	**0.45**	**3.5**	1.45						**1.79**				
5	0.99	0.90	**0.45**	**4.0**	1.45						**1.79**				
6	0.64	0.90	**0.45**	**4.0**	1.45	0.14	0.09	0.00	0.00	0.14	**0.14**	0.43	0.30	0.21	0.13
7	0.48	0.90	**0.45**	**5**	0.99	0.10	0.09	0.00	0.00	0.10	**0.10**	0.43	0.30	0.21	0.13
8	0.43	0.90	**0.45**	**6**	0.64	0.06	0.09	0.00	0.09	0.00	**0.09**	0.43	0.30	0.21	0.13
9	0.49	0.90	**0.45**	**7**	0.48	0.05	0.09	0.00	0.09	0.00	**0.09**	0.43	0.30	0.21	0.13
10	0.64	0.90	**0.27**	**8**	0.43	0.04	0.09	0.00	0.09	0.00	**0.09**	0.43	0.30	0.21	0.13
11	0.87	0.90	**0.27**	**9**	0.49	0.05	0.09	0.00	0.09	0.00	**0.09**	0.43	0.30	0.21	0.13
12	0.93	0.90	**0.27**	**10**	0.64	0.06	0.09	0.00	0.09	0.00	**0.09**				
				11	0.87	0.09	0.09	0.00	0.09	0.00	**0.09**				
Annual	**0.90**			**12**	0.93	0.09	0.09	0.00	0.00	0.09	**0.09**				

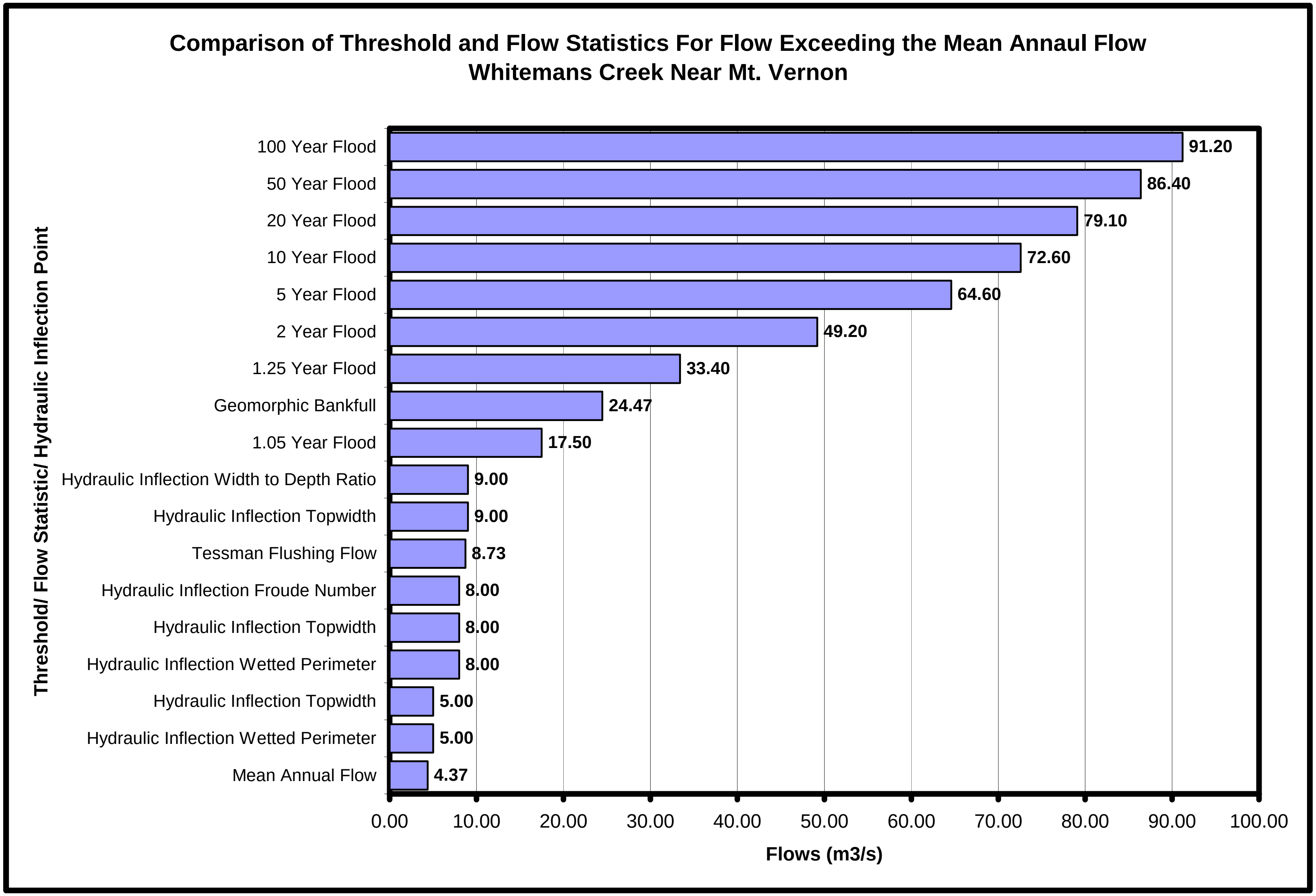
F-5: WHITEMANS CREEK

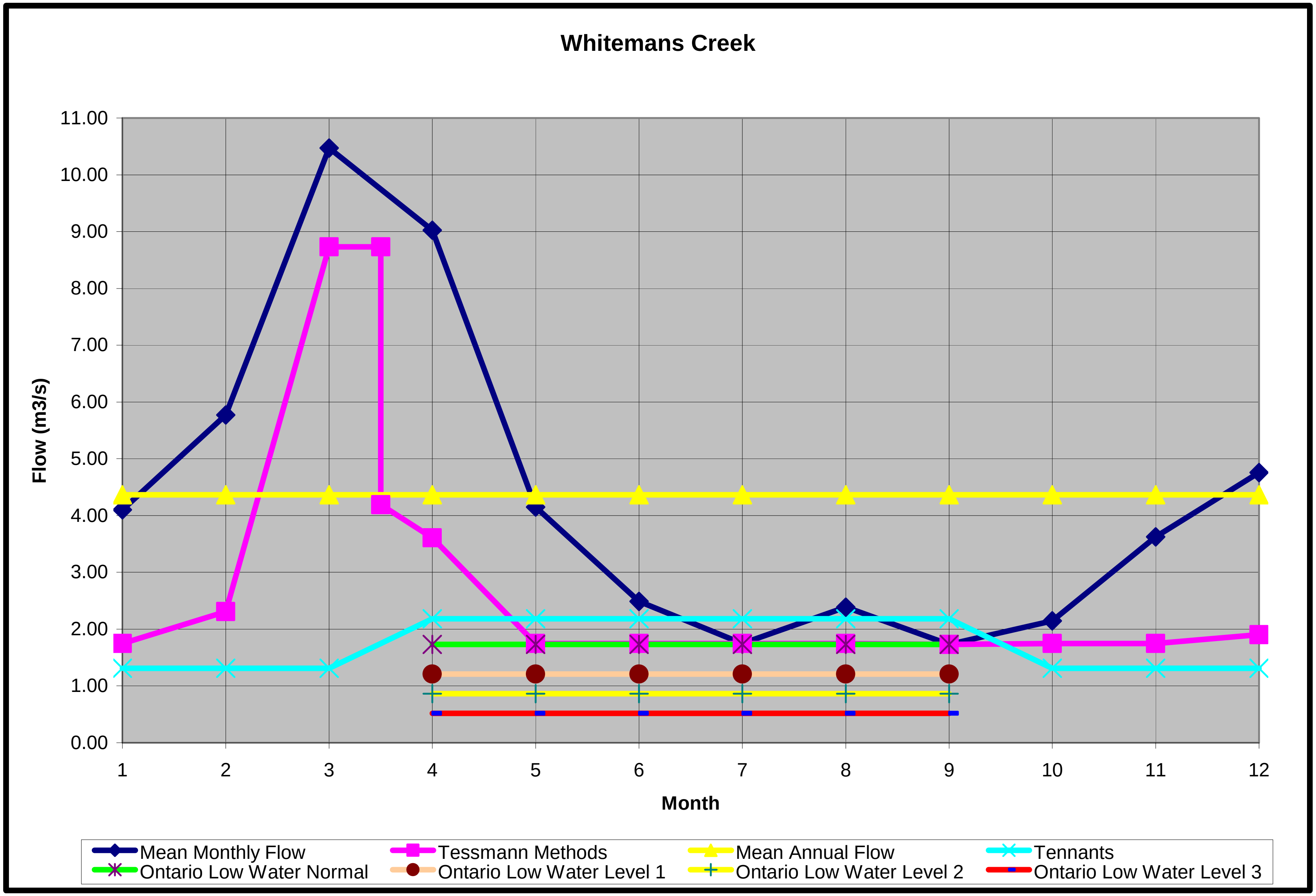
Whitemans Creek Near Mt Vernon		OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
7Q100	0.103	0.07	0.20
7Q50	0.135	0.09	0.29
7Q20	0.198	0.13	0.34
7Q10	0.268	0.17	0.38
7Q5	0.370	0.23	0.46
Tessman Summer Flow (Poor)	0.44		
Hydraulic Inflection Froude Number	0.50		
Hydraulic Inflection Width to Depth Ratio	0.50		
Ontario Low Water Level 3	0.52		
Hydraulic Inflection Wetted Perimeter	0.60		
Hydraulic Inflection Topwidth	0.60		
7Q2	0.609	0.39	0.67
Hydraulic Inflection Wetted Perimeter	0.70		
Hydraulic Inflection Topwidth	0.70		
60% Baseflow Summer	0.76		
Hydraulic connectivity for fish migration Significant Loss	0.80		
Hydraulic Inflection Wetted Perimeter	0.80		
Hydraulic Inflection Topwidth	0.80		
Hydraulic Inflection Froude Number	0.80		
Hydraulic Inflection Width to Depth Ratio	0.80		
Ontario Low Water Level 2	0.86		
Tessman Summer Flow (Fair to Poor)	0.87		
50% Baseflow Summer	0.88		
Hydraulic connectivity for fish migration	1.00		
Hydraulic Inflection Wetted Perimeter	1.00		
Hydraulic Inflection Topwidth	1.00		
Hydraulic Inflection Width to Depth Ratio	1.00		
60% Total Flow Summer	1.10		
Geomorphic Residual Pool	1.18		
50% Total Flow Summer	1.20		
Ontario Low Water Level 1	1.21		
Hydraulic Inflection Wetted Perimeter	1.25		
Hydraulic Inflection Topwidth	1.25		
60% Baseflow Annual	1.30		
Tennant Spring	1.31		
Tessman Summer Flow (Fair)	1.31		
Hydraulic Inflection Wetted Perimeter	1.50		
Hydraulic Inflection Topwidth	1.50		

Whitemans Creek Near Mt Vernon		OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Hydraulic Inflection Froude Number	1.50		
Geomorphic Flushing Flow	1.58		
50% Baseflow Annual	1.60		
Ontario Low Water Normal	1.73		
Tessman Summer Flow (Good)	1.75		
60% Total Flow Annual	1.80		
Hydraulic Inflection Topwidth	2.00		
Hydraulic Inflection Froude Number	2.00		
Tennant Summer	2.18		
Tessman Summer Flow (Excellent)	2.19		
Hydraulic Inflection Wetted Perimeter	2.25		
50% Total Flow Annual	2.30		
Hydraulic Inflection Wetted Perimeter	2.50		
Hydraulic Inflection Topwidth	2.50		
Hydraulic Inflection Width to Depth Ratio	2.50		
Tessman Summer Flow (Outstanding)	2.62	2.63	
Geomorphic Bed Mobilizing Flow	3.06		
Hydraulic Inflection Wetted Perimeter	4.00		
Hydraulic Inflection Topwidth	4.00		
Mean Annual Flow	4.37	4.39	
Hydraulic Inflection Wetted Perimeter	5.00		
Hydraulic Inflection Topwidth	5.00		
Hydraulic Inflection Wetted Perimeter	8.00		
Hydraulic Inflection Topwidth	8.00		
Hydraulic Inflection Froude Number	8.00		
Tessman Flushing Flow	8.73		
Hydraulic Inflection Topwidth	9.00		
Hydraulic Inflection Width to Depth Ratio	9.00		
1.05 Year Flood	17.50		
Geomorphic Bankfull	24.47	102.5	104.4
1.25 Year Flood	33.40	98.9	100.6
2 Year Flood	49.20	73.8	112.0
5 Year Flood	64.60	105.5	159.0
10 Year Flood	72.60	126.9	188.1
20 Year Flood	79.10	147.4	245.0
50 Year Flood	86.40	153.9	249.1
100 Year Flood	91.20	174.1	332.0



Comparison of Threshold, Flow Statistics and Hydraulic Inflection Points Whitemans Cr near Mt. Vernon


Comparison of Threshold and Flow Statistics For Flow Exceeding the Mean Annaul Flow
Whitemans Creek Near Mt. Vernon
Threshold/ Flow Statistic/ Hydraulic Inflection Point
100 Year Flood
91.20
50 Year Flood
86.40
20 Year Flood
79.10
10 Year Flood
72.60
5 Year Flood
64.60
2 Year Flood
49.20
1.25 Year Flood
33.40
Geomorphic Bankfull
24.47
1.05 Year Flood
17.50
Hydraulic Inflection Width to Depth Ratio
9.00
Hydraulic Inflection Topwidth
9.00
Tessman Flushing Flow
8.73
Hydraulic Inflection Froude Number
8.00
Hydraulic Inflection Topwidth
8.00
Hydraulic Inflection Wetted Perimeter
8.00
Hydraulic Inflection Topwidth
5.00
Hydraulic Inflection Wetted Perimeter
5.00
Mean Annual Flow
4.37
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
Flows (m3/s)


Whitemans Creek
Flow (m3/s)
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1
2
3
4
5
6
7
8
9
10
11
12
Month
Mean Monthly Flow
Tessmann Methods
Mean Annual Flow
Tennants
Ontario Low Water Normal
Ontario Low Water Level 1
Ontario Low Water Level 2
Ontario Low Water Level 3

WHITEMANS CREEK

				Tessmann Method 1980								OLWRP Thresholds			
Month	**Mean Monthly Flow (m3/s)**	**Mean Annual Flow (m3/s)**	**TENNANTS Method Results (m3/s)**	**Month**	**MMF**	**40% MMF**	**(40% MAF)**	**(MMF < 40% MAF)**	**MMF>40% MAF and 40% MMF < 40% MAF**	**40% MMF > 40% MAF**	**Tessmann Method Flows (m3/s)**	**Normal**	**Level 1**	**Level 2**	**Level 3**
1	4.10	4.37	**1.31**	**1**	4.10	1.64	1.75	0.00	1.75	0.00	**1.75**				
2	5.77	4.37	**1.31**	**2**	5.77	2.31	1.75	0.00	0.00	2.31	**2.31**				
3	10.47	4.37	**1.31**	**3**	10.47	4.19	1.75	0.00	0.00	4.19	**8.73**				
4	9.03	4.37	**2.18**	**3.5**	10.47						**8.73**				
5	4.15	4.37	**2.18**	**3.5**	10.47						**4.19**				
6	2.49	4.37	**2.18**	**4.0**	9.03	3.61	1.75	0.00	0.00	3.61	**3.61**	1.73	1.21	0.86	0.52
7	1.75	4.37	**2.18**	**5**	4.15	1.66	1.75	0.00	1.75	0.00	**1.75**	1.73	1.21	0.86	0.52
8	2.38	4.37	**2.18**	**6**	2.49	1.00	1.75	0.00	1.75	0.00	**1.75**	1.73	1.21	0.86	0.52
9	1.73	4.37	**2.18**	**7**	1.75	0.70	1.75	0.00	1.75	0.00	**1.75**	1.73	1.21	0.86	0.52
10	2.14	4.37	**1.31**	**8**	2.38	0.95	1.75	0.00	1.75	0.00	**1.75**	1.73	1.21	0.86	0.52
11	3.62	4.37	**1.31**	**9**	1.73	0.69	1.75	1.73	0.00	0.00	**1.73**	1.73	1.21	0.86	0.52
12	4.76	4.37	**1.31**	**10**	2.14	0.86	1.75	0.00	1.75	0.00	**1.75**				
				11	3.62	1.45	1.75	0.00	1.75	0.00	**1.75**				
Annual	**4.37**			**12**	4.76	1.90	1.75	0.00	0.00	1.90	**1.90**				

				Tessmann Method 1980								OLWRP Thresholds			
Month	**Mean Monthly Flow (m3/s)**	**Mean Annual Flow (m3/s)**	**TENNANTS Method Results (m3/s)**	**Month**	**MMF**	**30% MMF**	**(30% MAF)**	**(MMF < 30% MAF)**	**MMF>30% MAF and 30% MMF < 30% MAF**	**30% MMF > 30% MAF**	**Tessmann Method Flows (m3/s)**	**Normal**	**Level 1**	**Level 2**	**Level 3**
1	4.10	4.37	**1.31**	**1**	4.10	1.23	1.31	0.00	1.31	0.00	**1.31**				
2	5.77	4.37	**1.31**	**2**	5.77	1.73	1.31	0.00	0.00	1.73	**1.73**				
3	10.47	4.37	**1.31**	**3**	10.47	3.14	1.31	0.00	0.00	3.14	**8.73**				
4	9.03	4.37	**2.18**	**3.5**	10.47						**8.73**				
5	4.15	4.37	**2.18**	**3.5**	10.47						**4.19**				
6	2.49	4.37	**2.18**	**4.0**	9.03	2.71	1.31	0.00	0.00	2.71	**2.71**	1.73	1.21	0.86	0.52
7	1.75	4.37	**2.18**	**5**	4.15	1.25	1.31	0.00	1.31	0.00	**1.31**	1.73	1.21	0.86	0.52
8	2.38	4.37	**2.18**	**6**	2.49	0.75	1.31	0.00	1.31	0.00	**1.31**	1.73	1.21	0.86	0.52
9	1.73	4.37	**2.18**	**7**	1.75	0.52	1.31	0.00	1.31	0.00	**1.31**	1.73	1.21	0.86	0.52
10	2.14	4.37	**1.31**	**8**	2.38	0.72	1.31	0.00	1.31	0.00	**1.31**	1.73	1.21	0.86	0.52
11	3.62	4.37	**1.31**	**9**	1.73	0.52	1.31	0.00	1.31	0.00	**1.31**	1.73	1.21	0.86	0.52
12	4.76	4.37	**1.31**	**10**	2.14	0.64	1.31	0.00	1.31	0.00	**1.31**				
				11	3.62	1.09	1.31	0.00	1.31	0.00	**1.31**				
Annual	**4.37**			**12**	4.76	1.43	1.31	0.00	0.00	1.43	**1.43**				

WHITEMANS CREEK

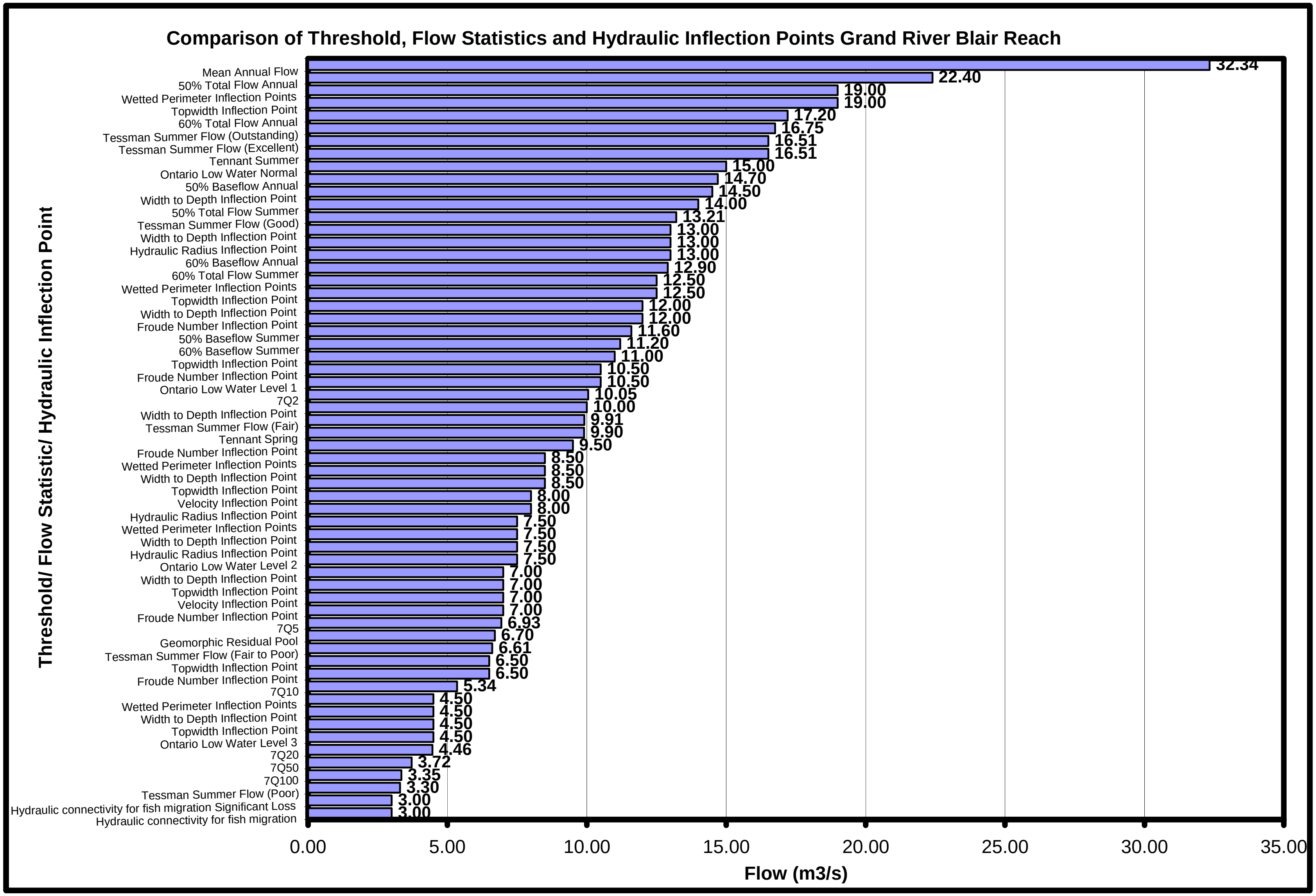
Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	20% MMF	(20% MAF)	(MMF < 20% MAF)	MMF>20% MAF and 20% MMF < 20% MAF	20% MMF > 20% MAF		Normal	Level 1	Level 2	Level 3
1	4.10	4.37	**1.31**	**1**	4.10	0.82	0.87	0.00	0.87	0.00	**0.87**				
2	5.77	4.37	**1.31**	**2**	5.77	1.15	0.87	0.00	0.00	1.15	**1.15**				
3	10.47	4.37	**1.31**	**3**	10.47	2.09	0.87	0.00	0.00	2.09	**8.73**				
4	9.03	4.37	**2.18**	**3.5**	10.47						**8.73**				
5	4.15	4.37	**2.18**	**3.5**	10.47						**4.19**				
6	2.49	4.37	**2.18**	**4.0**	9.03	1.81	0.87	0.00	0.00	1.81	**1.81**	1.73	1.21	0.86	0.52
7	1.75	4.37	**2.18**	**5**	4.15	0.83	0.87	0.00	0.87	0.00	**0.87**	1.73	1.21	0.86	0.52
8	2.38	4.37	**2.18**	**6**	2.49	0.50	0.87	0.00	0.87	0.00	**0.87**	1.73	1.21	0.86	0.52
9	1.73	4.37	**2.18**	**7**	1.75	0.35	0.87	0.00	0.87	0.00	**0.87**	1.73	1.21	0.86	0.52
10	2.14	4.37	**1.31**	**8**	2.38	0.48	0.87	0.00	0.87	0.00	**0.87**	1.73	1.21	0.86	0.52
11	3.62	4.37	**1.31**	**9**	1.73	0.35	0.87	0.00	0.87	0.00	**0.87**	1.73	1.21	0.86	0.52
12	4.76	4.37	**1.31**	**10**	2.14	0.43	0.87	0.00	0.87	0.00	**0.87**				
				11	3.62	0.72	0.87	0.00	0.87	0.00	**0.87**				
Annual	**4.37**			**12**	4.76	0.95	0.87	0.00	0.00	0.95	**0.95**				

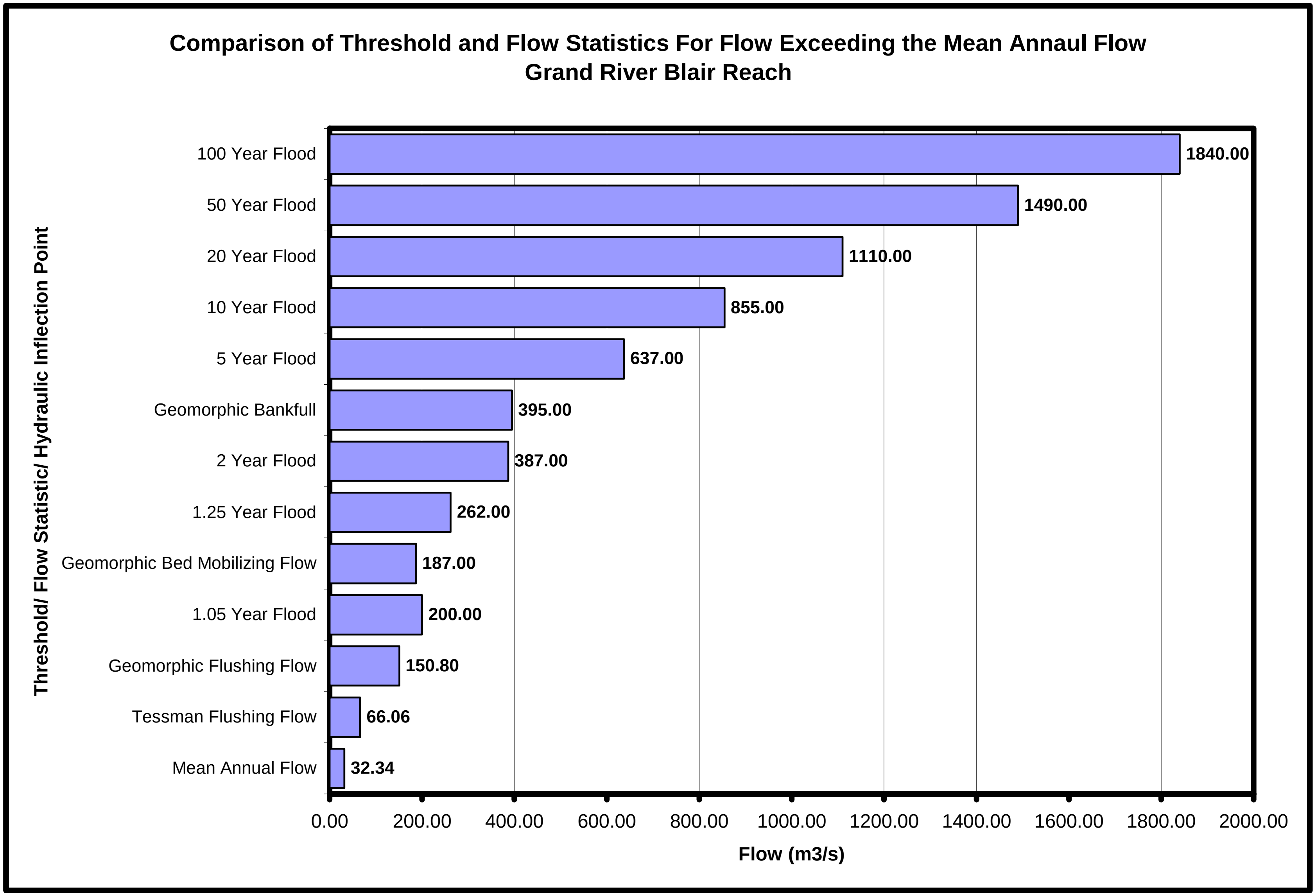
Month	Mean Monthly Flow (m3/s)	Mean Annual Flow (m3/s)	TENNANTS Method Results (m3/s)	Tessmann Method 1980							Tessmann Method Flows (m3/s)	OLWRP Thresholds			
				Month	MMF	10% MMF	(10% MAF)	(MMF < 10% MAF)	MMF>10% MAF and 10% MMF < 10% MAF	10% MMF > 10% MAF		Normal	Level 1	Level 2	Level 3
1	4.10	4.37	**1.31**	**1**	4.10	0.41	0.44	0.00	0.44	0.00	**0.44**				
2	5.77	4.37	**1.31**	**2**	5.77	0.58	0.44	0.00	0.00	0.58	**0.58**				
3	10.47	4.37	**1.31**	**3**	10.47	1.05	0.44	0.00	0.00	1.05	**8.73**				
4	9.03	4.37	**2.18**	**3.5**	10.47						**8.73**				
5	4.15	4.37	**2.18**	**3.5**	10.47						**4.19**				
6	2.49	4.37	**2.18**	**4.0**	9.03	0.90	0.44	0.00	0.00	0.90	**0.90**	1.73	1.21	0.86	0.52
7	1.75	4.37	**2.18**	**5**	4.15	0.42	0.44	0.00	0.44	0.00	**0.44**	1.73	1.21	0.86	0.52
8	2.38	4.37	**2.18**	**6**	2.49	0.25	0.44	0.00	0.44	0.00	**0.44**	1.73	1.21	0.86	0.52
9	1.73	4.37	**2.18**	**7**	1.75	0.17	0.44	0.00	0.44	0.00	**0.44**	1.73	1.21	0.86	0.52
10	2.14	4.37	**1.31**	**8**	2.38	0.24	0.44	0.00	0.44	0.00	**0.44**	1.73	1.21	0.86	0.52
11	3.62	4.37	**1.31**	**9**	1.73	0.17	0.44	0.00	0.44	0.00	**0.44**	1.73	1.21	0.86	0.52
12	4.76	4.37	**1.31**	**10**	2.14	0.21	0.44	0.00	0.44	0.00	**0.44**				
				11	3.62	0.36	0.44	0.00	0.44	0.00	**0.44**				
Annual	**4.37**			**12**	4.76	0.48	0.44	0.00	0.00	0.48	**0.48**				

F-6: GRAND RIVER AT BLAIR REACH

Grand River Blair Reach		OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Hydraulic connectivity for fish migration	3.00		
Hydraulic connectivity for fish migration Significant Loss	3.00		
Tessman Summer Flow (Poor)	3.30		
7Q100	3.350	0.90	1.24
7Q50	3.715	0.97	1.37
7Q20	4.461	1.16	1.62
Ontario Low Water Level 3	4.50		
Topwidth Inflection Point	4.50		
Width to Depth Inflection Point	4.50		
Wetted Perimeter Inflection Points	4.50		
7Q10	5.343	1.36	1.90
Froude Number Inflection Point	6.50		
Topwidth Inflection Point	6.50		
Tessman Summer Flow (Fair to Poor)	6.61		
Geomorphic Residual Pool	6.70		
7Q5	6.930	1.77	2.30
Froude Number Inflection Point	7.00		
Velocity Inflection Point	7.00		
Topwidth Inflection Point	7.00		
Width to Depth Inflection Point	7.00		
Ontario Low Water Level 2	7.50		
Hydraulic Radius Inflection Point	7.50		
Width to Depth Inflection Point	7.50		
Wetted Perimeter Inflection Points	7.50		
Hydraulic Radius Inflection Point	8.00		
Velocity Inflection Point	8.00		
Topwidth Inflection Point	8.50		
Width to Depth Inflection Point	8.50		
Wetted Perimeter Inflection Points	8.50		
Froude Number Inflection Point	9.50		
Tennant Spring	9.90		
Tessman Summer Flow (Fair)	9.91		
Width to Depth Inflection Point	10.00		
7Q2	10.050	2.90	3.32
Ontario Low Water Level 1	10.50		
Froude Number Inflection Point	10.50		

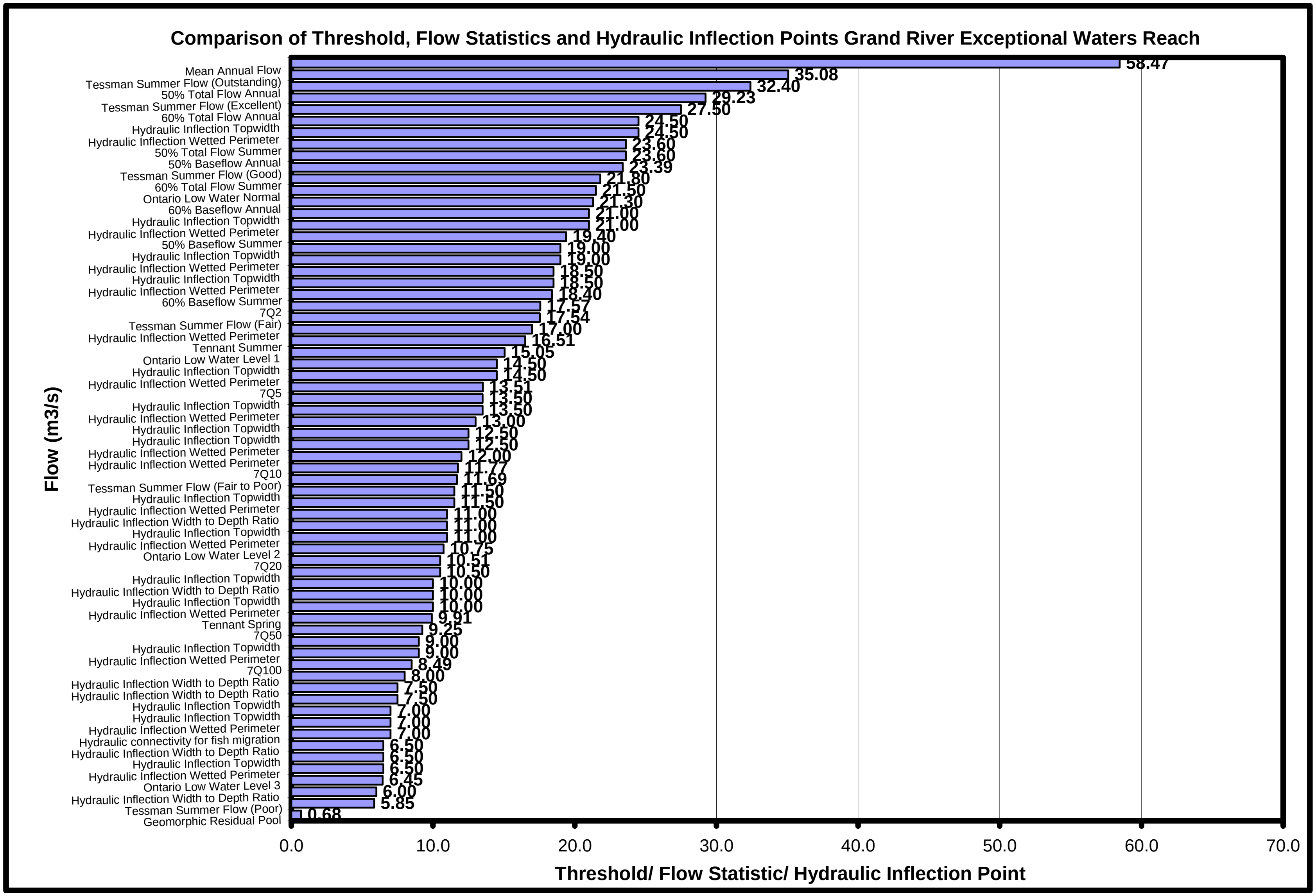
Grand River Blair Reach		OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Topwidth Inflection Point	11.00		
60% Baseflow Summer	11.20		
50% Baseflow Summer	11.6		
Froude Number Inflection Point	12.00		
Width to Depth Inflection Point	12.00		
Topwidth Inflection Point	12.50		
Wetted Perimeter Inflection Points	12.50		
60% Total Flow Summer	12.9		
60% Baseflow Annual	13.00		
Hydraulic Radius Inflection Point	13.00		
Width to Depth Inflection Point	13.00		
Tessman Summer Flow (Good)	13.21		
50% Total Flow Summer	14.0		
Width to Depth Inflection Point	14.50		
50% Baseflow Annual	14.70		
Ontario Low Water Normal	15.00		
Tennant Summer	16.51		
Tessman Summer Flow (Excellent)	16.51		
Tessman Summer Flow (Outstanding)	16.75		
60% Total Flow Annual	17.20		
Topwidth Inflection Point	19.00		
Wetted Perimeter Inflection Points	19.00		
50% Total Flow Annual	22.40		
Mean Annual Flow	32.34		
Tessman Flushing Flow	66.06		
Geomorphic Flushing Flow	150.80		
Geomorphic Bed Mobilizing Flow	187.00		
1.05 Year Flood	200.00		
1.25 Year Flood	262.00	478.3	486.8
2 Year Flood	387.00	309.2	1084.5
Geomorphic Bankfull	395.00		
5 Year Flood	637.00	441.9	1590.6
10 Year Flood	855.00	531.4	1897.6
20 Year Flood	1130.00	617.2	2179.4
50 Year Flood	1490.00	644.5	2535.5
100 Year Flood	1840.00	728.9	2794.4


Comparison of Threshold, Flow Statistics and Hydraulic Inflection Points Grand River Blair Reach
Threshold/ Flow Statistic/ Hydraulic Inflection Point
Mean Annual Flow
32.34
50% Total Flow Annual
22.40
Wetted Perimeter Inflection Points
19.00
Topwidth Inflection Point
19.00
60% Total Flow Annual
17.20
Tessman Summer Flow (Outstanding)
16.75
Tessman Summer Flow (Excellent)
16.51
Tennant Summer
16.51
Ontario Low Water Normal
15.00
50% Baseflow Annual
14.70
Width to Depth Inflection Point
14.50
50% Total Flow Summer
14.00
Tessman Summer Flow (Good)
13.21
Width to Depth Inflection Point
13.00
Hydraulic Radius Inflection Point
13.00
60% Baseflow Annual
13.00
60% Total Flow Summer
12.90
Wetted Perimeter Inflection Points
12.50
Topwidth Inflection Point
12.50
Width to Depth Inflection Point
12.00
Froude Number Inflection Point
12.00
50% Baseflow Summer
11.60
60% Baseflow Summer
11.20
Topwidth Inflection Point
11.00
Froude Number Inflection Point
10.50
Ontario Low Water Level 1
10.50
7Q2
10.05
Width to Depth Inflection Point
10.00
Tessman Summer Flow (Fair)
9.91
Tennant Spring
9.90
Froude Number Inflection Point
9.50
Wetted Perimeter Inflection Points
8.50
Width to Depth Inflection Point
8.50
Topwidth Inflection Point
8.50
Velocity Inflection Point
8.00
Hydraulic Radius Inflection Point
8.00
Wetted Perimeter Inflection Points
7.50
Width to Depth Inflection Point
7.50
Hydraulic Radius Inflection Point
7.50
Ontario Low Water Level 2
7.50
Width to Depth Inflection Point
7.00
Topwidth Inflection Point
7.00
Velocity Inflection Point
7.00
Froude Number Inflection Point
7.00
7Q5
6.93
Geomorphic Residual Pool
6.70
Tessman Summer Flow (Fair to Poor)
6.61
Topwidth Inflection Point
6.50
Froude Number Inflection Point
6.50
7Q10
5.34
Wetted Perimeter Inflection Points
4.50
Width to Depth Inflection Point
4.50
Topwidth Inflection Point
4.50
Ontario Low Water Level 3
4.50
7Q20
4.46
7Q50
3.72
7Q100
3.35
Tessman Summer Flow (Poor)
3.30
Hydraulic connectivity for fish migration Significant Loss
3.00
Hydraulic connectivity for fish migration
3.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
Flow (m3/s)

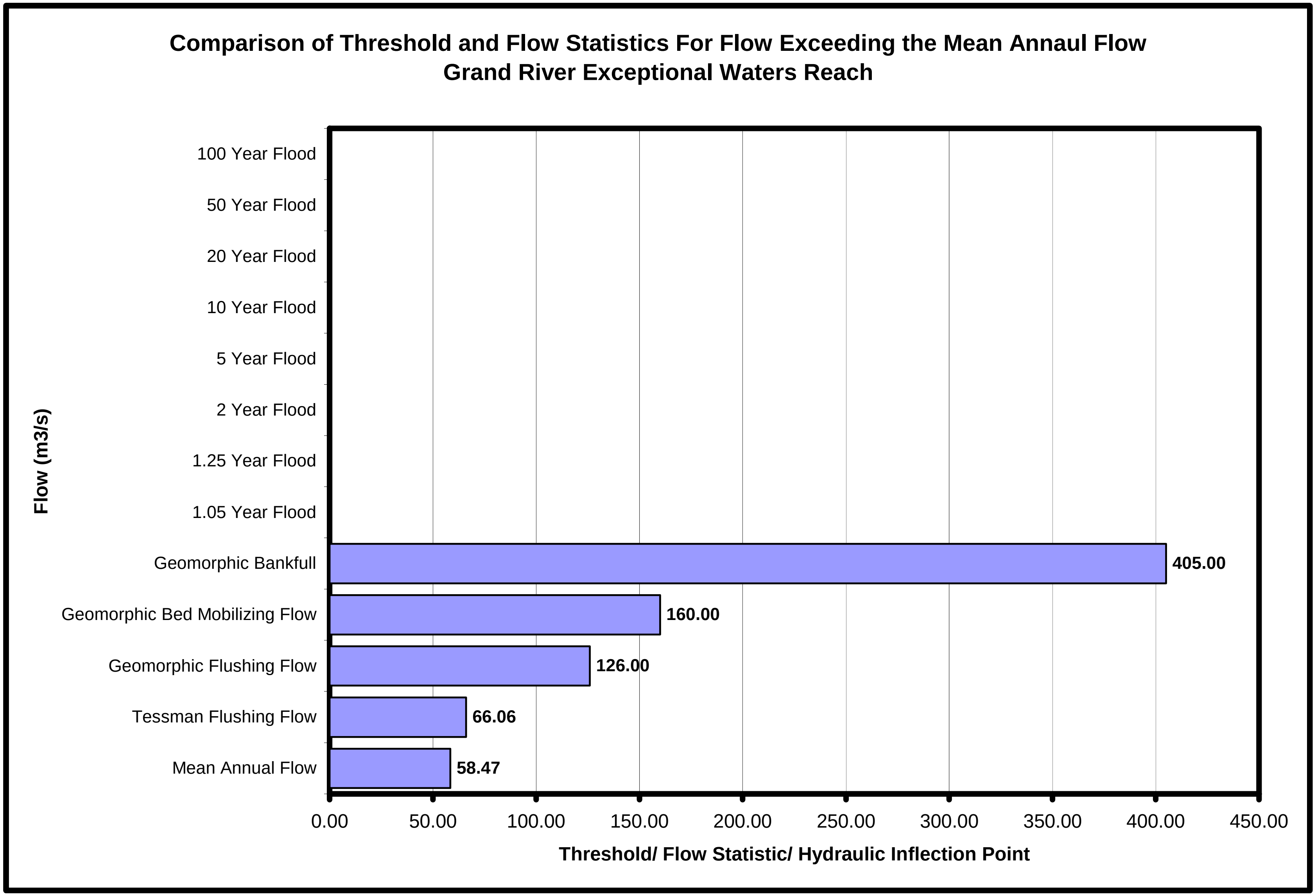

Comparison of Threshold and Flow Statistics For Flow Exceeding the Mean Annaul Flow
Grand River Blair Reach
Threshold/ Flow Statistic/ Hydraulic Inflection Point
100 Year Flood
1840.00
50 Year Flood
1490.00
20 Year Flood
1110.00
10 Year Flood
855.00
5 Year Flood
637.00
Geomorphic Bankfull
395.00
2 Year Flood
387.00
1.25 Year Flood
262.00
Geomorphic Bed Mobilizing Flow
187.00
1.05 Year Flood
200.00
Geomorphic Flushing Flow
150.80
Tessman Flushing Flow
66.06
Mean Annual Flow
32.34
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
1400.00
1600.00
1800.00
2000.00
Flow (m3/s)

F-7: GRAND RIVER EXCEPTIONAL WATERS REACH – Upstream

Grand River Exceptional Waters Reach	Upstream	OFAT ESTIMATES	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Geomorphic Residual Pool	0.68		
Tessman Summer Flow (Poor)	5.85		
Hydraulic Inflection Width to Depth Ratio	6.00		
Ontario Low Water Level 3	6.45		
Hydraulic Inflection Wetted Perimeter	6.50		
Hydraulic Inflection Topwidth	6.50		
Hydraulic Inflection Width to Depth Ratio	6.50		
Hydraulic connectivity for fish migration	7.00		
Hydraulic Inflection Wetted Perimeter	7.00		
Hydraulic Inflection Topwidth	7.00		
Hydraulic Inflection Topwidth	7.50		
Hydraulic Inflection Width to Depth Ratio	7.50		
Hydraulic Inflection Width to Depth Ratio	8.00		
7Q100	8.49	1.63	2.31
Hydraulic Inflection Wetted Perimeter	9.00		
Hydraulic Inflection Topwidth	9.00		
7Q50	9.25	1.75	2.54
Tennant Spring	9.91		
Hydraulic Inflection Wetted Perimeter	10.00		
Hydraulic Inflection Topwidth	10.00		
Hydraulic Inflection Width to Depth Ratio	10.00		
Hydraulic Inflection Topwidth	10.50		
7Q20	10.51	2.10	2.99
Ontario Low Water Level 2	10.75		
Hydraulic Inflection Wetted Perimeter	11.00		
Hydraulic Inflection Topwidth	11.00		
Hydraulic Inflection Width to Depth Ratio	11.00		
Hydraulic Inflection Wetted Perimeter	11.50		
Hydraulic Inflection Topwidth	11.50		
Tessman Summer Flow (Fair to Poor)	11.69		
7Q10	11.77	2.46	3.52
Hydraulic Inflection Wetted Perimeter	12.00		
Hydraulic Inflection Wetted Perimeter	12.50		
Hydraulic Inflection Topwidth	12.50		
Hydraulic Inflection Topwidth	13.00		
Hydraulic Inflection Wetted Perimeter	13.50		
Hydraulic Inflection Topwidth	13.50		
7Q5	13.51	3.21	4.27
Hydraulic Inflection Wetted Perimeter	14.50		
Hydraulic Inflection Topwidth	14.50		
Ontario Low Water Level 1	15.05		
Tennant Summer	16.51		
Hydraulic Inflection Wetted Perimeter	17.00		
Tessman Summer Flow (Fair)	17.54		
7Q2	17.57	5.24	6.22
60% Baseflow Summer	18.40		
Hydraulic Inflection Wetted Perimeter	18.50		
Hydraulic Inflection Topwidth	18.50		
Hydraulic Inflection Wetted Perimeter	19.00		
Hydraulic Inflection Topwidth	19.00		
50% Baseflow Summer	19.40		
Hydraulic Inflection Wetted Perimeter	21.00		
Hydraulic Inflection Topwidth	21.00		
60% Baseflow Annual	21.30		
Ontario Low Water Normal	21.50		
60% Total Flow Summer	21.80		
Tessman Summer Flow (Good)	23.39		
50% Baseflow Annual	23.60		
50% Total Flow Summer	23.60		
Hydraulic Inflection Wetted Perimeter	24.50		
Hydraulic Inflection Topwidth	24.50		
60% Total Flow Annual	27.50		
Tessman Summer Flow (Excellent)	29.23		
50% Total Flow Annual	32.40		
Tessman Summer Flow (Outstanding)	35.08		
Mean Annual Flow	58.47	52.29	
Tessman Flushing Flow	66.06	104.58	
Geomorphic Flushing Flow	126.00		
Geomorphic Bed Mobilizing Flow	160.00		
1.05 Year Flood	293		
Geomorphic Bankfull	405.00		
1.25 Year Flood	417	793	807

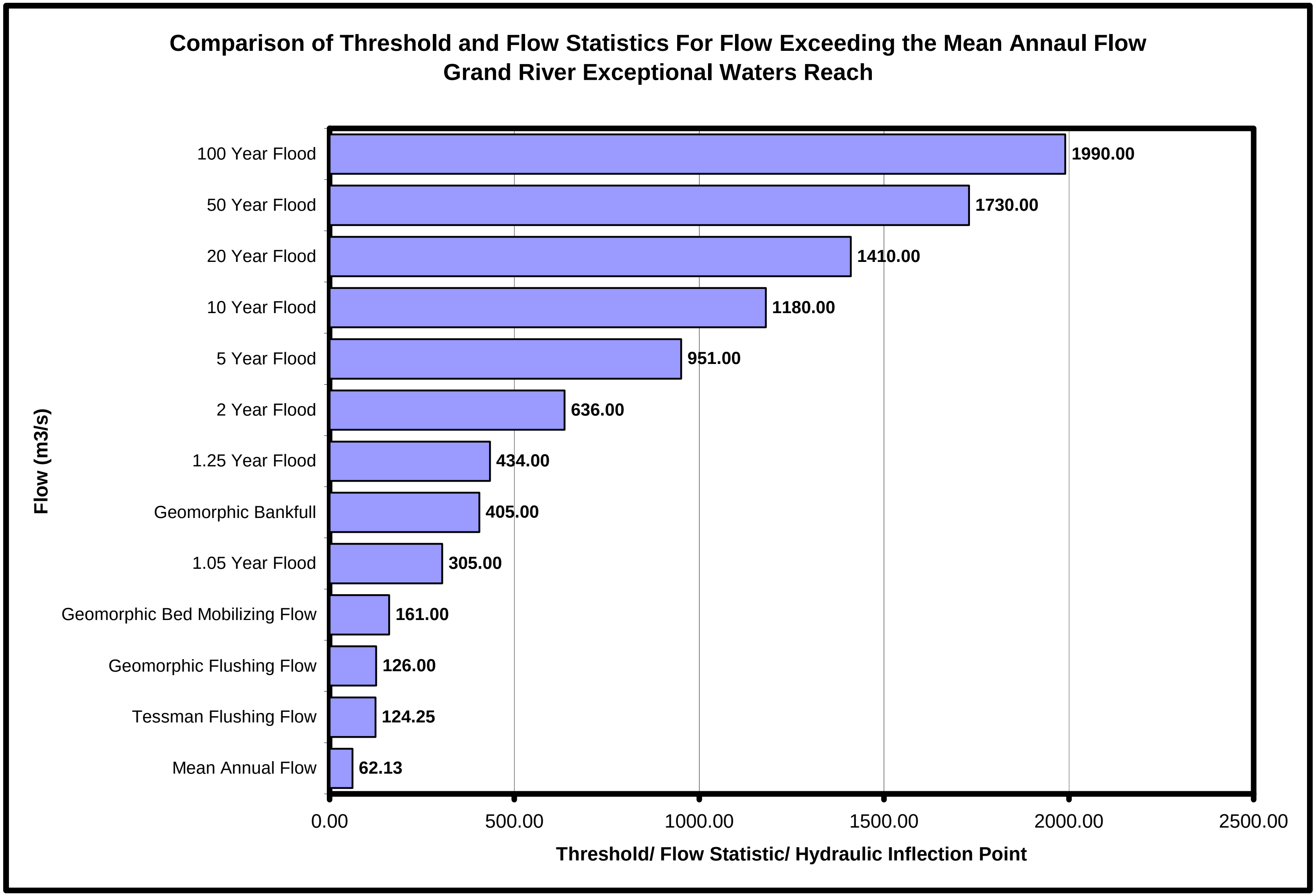


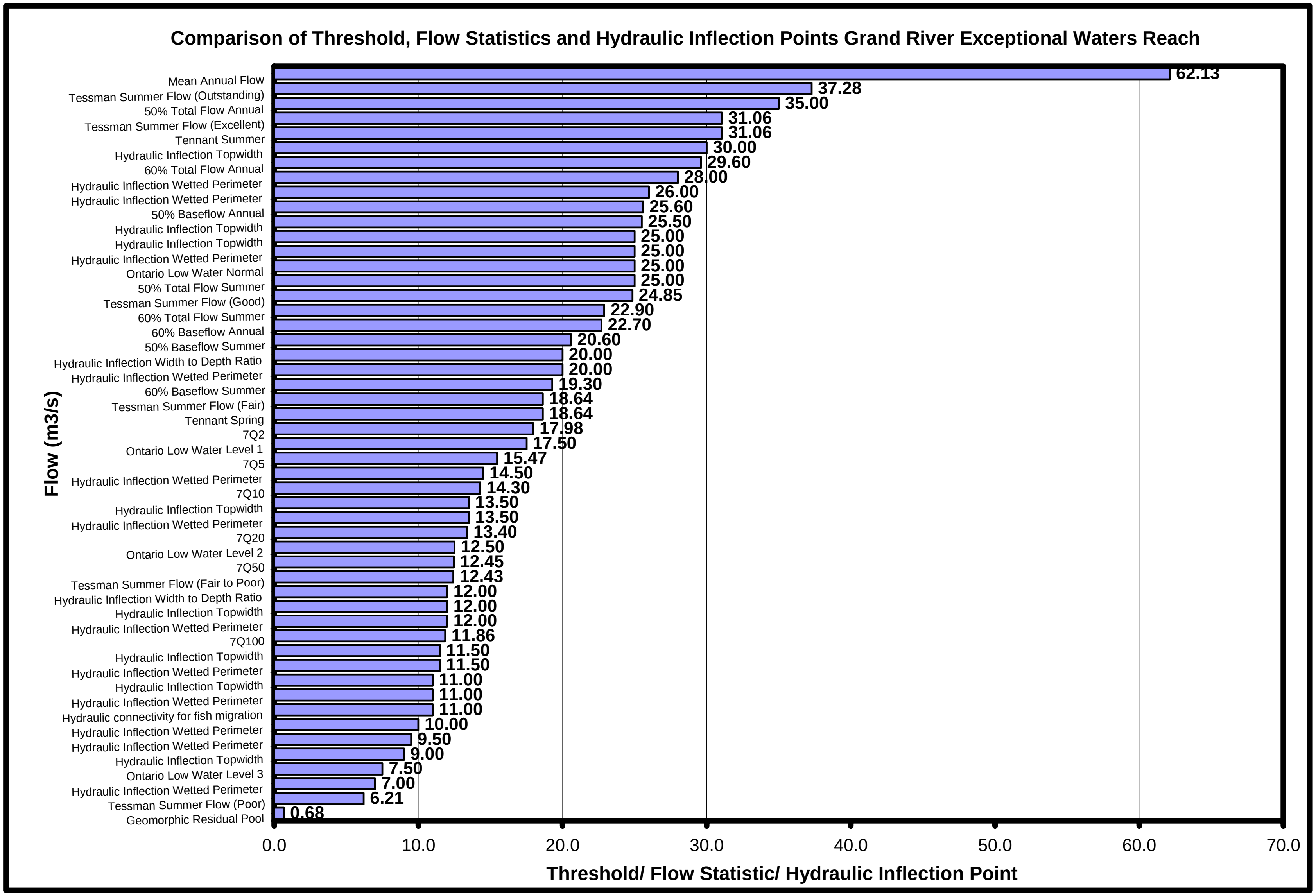
Comparison of Threshold, Flow Statistics and Hydraulic Inflection Points Grand River Exceptional Waters Reach


Comparison of Threshold and Flow Statistics For Flow Exceeding the Mean Annaul Flow
Grand River Exceptional Waters Reach
Flow (m3/s)
100 Year Flood
50 Year Flood
20 Year Flood
10 Year Flood
5 Year Flood
2 Year Flood
1.25 Year Flood
1.05 Year Flood
Geomorphic Bankfull
Geomorphic Bed Mobilizing Flow
Geomorphic Flushing Flow
Tessman Flushing Flow
Mean Annual Flow
405.00
160.00
126.00
66.06
58.47
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
Threshold/ Flow Statistic/ Hydraulic Inflection Point

F-8: GRAND RIVER EXCEPTIONAL WATERS REACH – Downstream

Grand River Exceptional Waters Reach	Downstream	OFAT Estimates	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Geomorphic Residual Pool	0.68		
Tessman Summer Flow (Poor)	6.21		
Hydraulic Inflection Wetted Perimeter	7.00		
Ontario Low Water Level 3	7.50		
Hydraulic Inflection Topwidth	9.00		
Hydraulic Inflection Wetted Perimeter	9.50		
Hydraulic Inflection Wetted Perimeter	10.00		
Hydraulic connectivity for fish migration	11.00		
Hydraulic Inflection Wetted Perimeter	11.00		
Hydraulic Inflection Topwidth	11.00		
Hydraulic Inflection Wetted Perimeter	11.50		
Hydraulic Inflection Topwidth	11.50		
7Q100	11.86	1.78	2.64
Hydraulic Inflection Wetted Perimeter	12.00		
Hydraulic Inflection Topwidth	12.00		
Hydraulic Inflection Width to Depth Ratio	12.00		
Tessman Summer Flow (Fair to Poor)	12.43		
7Q50	12.45	1.91	3.13
Ontario Low Water Level 2	12.50		
7Q20	13.40	2.29	3.69
Hydraulic Inflection Wetted Perimeter	13.50		
Hydraulic Inflection Topwidth	13.50		
7Q10	14.30	2.68	4.51
Hydraulic Inflection Wetted Perimeter	14.50		
7Q5	15.47	3.50	6.63
Ontario Low Water Level 1	17.50		
7Q2	17.98	5.72	9.36
Tennant Spring	18.64		
Tessman Summer Flow (Fair)	18.64		
60% Baseflow Summer	19.30		
Hydraulic Inflection Wetted Perimeter	20.00		
Hydraulic Inflection Width to Depth Ratio	20.00		
50% Baseflow Summer	20.60		
60% Baseflow Annual	22.70		
60% Total Flow Summer	22.90		
Tessman Summer Flow (Good)	24.85		
50% Total Flow Summer	25.00		
Ontario Low Water Normal	25.00		
Hydraulic Inflection Wetted Perimeter	25.00		
Hydraulic Inflection Topwidth	25.00		
Hydraulic Inflection Topwidth	25.50		
50% Baseflow Annual	25.60		
Hydraulic Inflection Wetted Perimeter	26.00		
Hydraulic Inflection Wetted Perimeter	28.00		
60% Total Flow Annual	29.60		
Hydraulic Inflection Topwidth	30.00		
Tennant Summer	31.06		
Tessman Summer Flow (Excellent)	31.06		
50% Total Flow Annual	35.00		
Tessman Summer Flow (Outstanding)	37.28		
Mean Annual Flow	62.13	57.17	
Tessman Flushing Flow	124.25	114.34	
Geomorphic Flushing Flow	126.00		
Geomorphic Bed Mobilizing Flow	161.00		
1.05 Year Flood	305.00		
Geomorphic Bankfull	405.00		
1.25 Year Flood	434.00	853.83	869.01
2 Year Flood	636.00	523.43	1922.59
5 Year Flood	951.00	747.97	2820.50
10 Year Flood	1180.00	899.55	3368.86
20 Year Flood	1410.00	1044.86	3868.82
50 Year Flood	1730.00	1091.06	4497.58
100 Year Flood	1990.00	1233.91	4952.14


Comparison of Threshold and Flow Statistics For Flow Exceeding the Mean Annaul Flow
Grand River Exceptional Waters Reach
Flow (m3/s)
100 Year Flood
1990.00
50 Year Flood
1730.00
20 Year Flood
1410.00
10 Year Flood
1180.00
5 Year Flood
951.00
2 Year Flood
636.00
1.25 Year Flood
434.00
Geomorphic Bankfull
405.00
1.05 Year Flood
305.00
Geomorphic Bed Mobilizing Flow
161.00
Geomorphic Flushing Flow
126.00
Tessman Flushing Flow
124.25
Mean Annual Flow
62.13
0.00
500.00
1000.00
1500.00
2000.00
2500.00
Threshold/ Flow Statistic/ Hydraulic Inflection Point


Comparison of Threshold, Flow Statistics and Hydraulic Inflection Points Grand River Exceptional Waters Reach
Flow (m3/s)
Mean Annual Flow
Tessman Summer Flow (Outstanding)
50% Total Flow Annual
Tessman Summer Flow (Excellent)
Tennant Summer
Hydraulic Inflection Topwidth
60% Total Flow Annual
Hydraulic Inflection Wetted Perimeter
Hydraulic Inflection Wetted Perimeter
50% Baseflow Annual
Hydraulic Inflection Topwidth
Hydraulic Inflection Topwidth
Hydraulic Inflection Wetted Perimeter
Ontario Low Water Normal
50% Total Flow Summer
Tessman Summer Flow (Good)
60% Total Flow Summer
60% Baseflow Annual
50% Baseflow Summer
Hydraulic Inflection Width to Depth Ratio
Hydraulic Inflection Wetted Perimeter
60% Baseflow Summer
Tessman Summer Flow (Fair)
Tennant Spring
7Q2
Ontario Low Water Level 1
7Q5
Hydraulic Inflection Wetted Perimeter
7Q10
Hydraulic Inflection Topwidth
Hydraulic Inflection Wetted Perimeter
7Q20
Ontario Low Water Level 2
7Q50
Tessman Summer Flow (Fair to Poor)
Hydraulic Inflection Width to Depth Ratio
Hydraulic Inflection Topwidth
Hydraulic Inflection Wetted Perimeter
7Q100
Hydraulic Inflection Topwidth
Hydraulic Inflection Wetted Perimeter
Hydraulic Inflection Topwidth
Hydraulic Inflection Wetted Perimeter
Hydraulic connectivity for fish migration
Hydraulic Inflection Wetted Perimeter
Hydraulic Inflection Wetted Perimeter
Hydraulic Inflection Topwidth
Ontario Low Water Level 3
Hydraulic Inflection Wetted Perimeter
Tessman Summer Flow (Poor)
Geomorphic Residual Pool
62.13
37.28
35.00
31.06
31.06
30.00
29.60
28.00
26.00
25.60
25.50
25.00
25.00
25.00
25.00
24.85
22.90
22.70
20.60
20.00
20.00
19.30
18.64
18.64
17.98
17.50
15.47
14.50
14.30
13.50
13.50
13.40
12.50
12.45
12.43
12.00
12.00
12.00
11.86
11.50
11.50
11.00
11.00
11.00
10.00
9.50
9.00
7.50
7.00
6.21
0.68
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Threshold/ Flow Statistic/ Hydraulic Inflection Point

F-9: CARROLL CREEK REACH

Carroll Creek Reach		OFAT Estimate	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Hydraulic Inflection Topwidth	0.1		
Hydraulic Inflection Wetted Perimeter	0.1		
Hydraulic Inflection Wetted Perimeter	0.11		
Geomorphic Residual Pool	0.13		
Geomorphic Flushing Flow	0.15		
Hydraulic Inflection Wetted Perimeter	0.15		
Hydraulic Inflection Wetted Perimeter	0.2		
Hydraulic Inflection Topwidth	0.25		
Hydraulic Inflection Wetted Perimeter	0.25		
Hydraulic Inflection Topwidth	0.3		
Hydraulic Inflection Wetted Perimeter	0.3		
Hydraulic Inflection Wetted Perimeter	0.35		
Hydraulic Inflection Topwidth	0.4		
Hydraulic Inflection Wetted Perimeter	0.4		
Hydraulic Inflection Topwidth	0.45		
Hydraulic Inflection Wetted Perimeter	0.45		
Hydraulic Inflection Topwidth	0.5		
Hydraulic Inflection Wetted Perimeter	0.5		
Hydraulic Inflection Topwidth	0.55		
Hydraulic Inflection Wetted Perimeter	0.55		
Hydraulic Inflection Topwidth	0.6		
Hydraulic Inflection Wetted Perimeter	0.6		
Hydraulic Inflection Topwidth	0.65		
Hydraulic Inflection Wetted Perimeter	0.65		
Hydraulic Inflection Topwidth	0.7		
Hydraulic Inflection Wetted Perimeter	0.7		
Hydraulic Inflection Wetted Perimeter	0.75		
Hydraulic Inflection Topwidth	0.8		
Hydraulic Inflection Wetted Perimeter	0.8		
Hydraulic Inflection Wetted Perimeter	0.85		
Hydraulic Inflection Topwidth	0.9		
Hydraulic Inflection Wetted Perimeter	0.9		
Hydraulic Inflection Topwidth	0.95		
Hydraulic Inflection Wetted Perimeter	0.95		
Hydraulic Inflection Wetted Perimeter	1		
Hydraulic Inflection Topwidth	1.1		
Hydraulic Inflection Wetted Perimeter	1.1		
Hydraulic Inflection Topwidth	1.3		
Hydraulic Inflection Wetted Perimeter	1.3		
Hydraulic Inflection Topwidth	1.4		
Hydraulic Inflection Wetted Perimeter	1.4		
Hydraulic Inflection Topwidth	1.5		
Hydraulic Inflection Wetted Perimeter	1.6		
Hydraulic Inflection Topwidth	1.7		
Hydraulic Inflection Wetted Perimeter	1.7		
Hydraulic Inflection Topwidth	1.8		
Hydraulic Inflection Wetted Perimeter	1.8		
Hydraulic Inflection Topwidth	1.9		
Hydraulic Inflection Wetted Perimeter	1.9		

Carroll Creek Reach		OFAT Estimate	
Thresholds, Statistics, Hydraulic Inflections	**Flow**	**Min**	**Max**
Hydraulic Inflection Topwidth	2		
Hydraulic Inflection Wetted Perimeter	2		
Hydraulic Inflection Wetted Perimeter	2.3		
Hydraulic Inflection Topwidth	2.4		
Hydraulic Inflection Topwidth	2.6		
Hydraulic Inflection Wetted Perimeter	2.6		
Hydraulic Inflection Topwidth	2.7		
Hydraulic Inflection Wetted Perimeter	2.7		
Hydraulic Inflection Wetted Perimeter	4		
Geomorphic Bankfull	5.12		
1.05 Year Flood			
1.25 Year Flood		15.82	16.10
10 Year Flood		24.01	43.33
100 Year Flood		32.94	60.56
2 Year Flood		13.34	26.10
20 Year Flood		27.89	48.93
5 Year Flood		19.97	37.02
50 Year Flood		29.13	55.76
50% Baseflow Annual			
50% Baseflow Summer			
50% Total Flow Annual			
50% Total Flow Summer			
60% Baseflow Annual			
60% Baseflow Summer			
60% Total Flow Annual			
60% Total Flow Summer			
7Q10		0.03	0.05
7Q100		0.02	0.03
7Q2		0.06	0.10
7Q20		0.03	0.04
7Q5		0.04	0.06
7Q50		0.03	0.03
Geomorphic Bed Mobilizing Flow			
Hydraulic connectivity for fish migration			
Hydraulic connectivity for fish migration Significant Loss			
Mean Annual Flow		0.47	
Ontario Low Water Level 1			
Ontario Low Water Level 2			
Ontario Low Water Level 3			
Ontario Low Water Normal			
Tennant Spring			
Tennant Summer			
Tessman Flushing Flow			
Tessman Summer Flow (Excellent)		0.23	
Tessman Summer Flow (Fair to Poor)		0.05	
Tessman Summer Flow (Fair)		0.14	
Tessman Summer Flow (Good)		0.19	
Tessman Summer Flow (Outstanding)		0.28	
Tessman Summer Flow (Poor)		0.05	
Hydraulic Inflection Topwidth	4		

APPENDIX G: INDICATORS OF HYDROLOGICAL ALTERATION: DESCRIPTION AND RESULTS

Included in this appendix:

List of Figures for Plotted Results: Each plotted for both IHA and RVA results

1. IHA Monthly Mean Daily Flows of Water Year (12 months, 12 plots)
2. RVA Monthly Mean Daily Flows of Water Year (12 months, 12 plots)
3. Minimum Flows (4 plots): 3-day, 7-day, 30-day, 90-day
4. Maximum Flows (5 plots): 1-day, 3-day, 7-day, 30-day, 90-day
5. Standard Baseflows
6. Hydrologic Alteration (2 plots): Normal and Greatest Alteration
7. Mean daily flows

Description of the *Indicators of Hydrologic Alteration* Software

The *Indicators of Hydrologic Alteration* (IHA) software is available from the US Nature Conservancy. The software summarizes 33 relevant parameters to analyze the degree of alteration to the hydrologic regime associated with a taking strategy. This software is an excellent tool to analyze changes to the flow regime.

The IHA software presents a range of statistics for the 33 parameters considered by the software. The IHA parameters are arranged into 5 groups on the scorecards. The groups include the following:

- **Magnitude of monthly water conditions**
- **Magnitude and duration of annual extreme water conditions**
- **Timing of annual extreme water conditions**
- **Frequency and duration of high and low pulses**
- **Rate and frequency of water condition changes**

The goal of the IHA software is to characterize the temporal variation of the hydrologic conditions using attributes that are biologically relevant, yet sensitive to human influences. Sixteen of the parameters measure the central tendancy of the magnitude or rate of change. Another sixteen of the parameters focus on magnitude, timing, duration, and the frequency of extremes.

A range of statistics is generated for the parameters in each of these groups to help describe alterations to the hydrologic regime. A full description of the parameters in each group and how they may influence the ecosystem is presented in **Table G.1**. This table is referenced from the IHA software manual. It is important to realize IHA results will quantify statistically the change in the 33 hydrologic parameters it assesses. It doesn't quantify impacts related to habitat associated with the changes in flow regime.

The program creates output for two methods, the Indicators of Hydrologic Alteration (IHA) and the Range of Variability (RVA). The software assesses if an impact or perturbation significantly differs from the natural state using these two methods. The statistical analysis can be conducted based on either a parametric or non-parametric statistical approach. The authors recommend a non-parametric approach in most cases.

The IHA non-parametric (percentile) analysis calculates the median (50th percentile) and one standard deviation on either side of the mean for each of the 33 parameters. The IHA software (The Nature Conservancy, 2001) and supporting technical papers (Richter *et al*., 1996; Richter *et al*., 1997; Richter *et al*., 1998) use one standard deviation of change in any of the 33 parameters as a guideline for the limits of hydrologic change. The non-parametric RVA analysis differs from the IHA analysis in that the flow regime is partitioned limits about the mean being based on the 33rd and 67th percentiles of the various parameters (a 17% departure from the mean).

Hydrologic data often has a strongly skewed frequency distribution, therefore if statistics such as one standard deviation about the mean fall outside the range of the data, the software uses the 25th and 75th percentiles. The software also reports the maximum and minimum values of each parameter to quantify the range of the data.

The degree of hydrologic alteration is calculated based on the following equation:

(Expected Frequency – Observed Frequency) / Expected Frequency

The above equation creates a dimensionless measure of hydrologic alteration. This plots is organized from left to right summarizing monthly flow statistics, minimum daily statistics, maximum daily statistics, baseflow statistics, dates of minimum and maximum flows, frequency and duration of high and low flow pulses and statistics regarding the rate of rise, rate of fall and reversals.

Table G.1 Summary of parameters used in the IHA software

IHA Statistics Group	Hydrologic Parameters	Ecosystem Influences
Group 1 Parameters		
Magnitude of monthly water conditions	Mean value for each calendar month	• Habitat availability for aquatic organisms • Soil moisture availability for plants • Availability of water for terrestrial animals • Availability of food/cover for fur-bearing mammals • Reliability of water supplies for terrestrial animals • Access by predators to nesting sites • Influences water temperature, oxygen levels, photosynthesis in water column
Group 2 Parameters		
Magnitude and duration of annual extreme water conditions	Annual 1-day minima	• Balance of competitive, ruderal, and stress- tolerant organisms
	Annual minima, 3-day means	• Creation of sites for plant colonization
	Annual minima, 7-day means	• Structuring of aquatic ecosystems by abiotic vs. biotic factors
	Annual minima, 30-day means	• Structuring of river channel morphology and physical habitat conditions
	Annual minima, 90-day means	• Soil moisture stress in plants
	Annual 1-day maxima	• Dehydration in animals
	Annual maxima, 3-day means	• Anaerobic stress in plants
	Annual maxima, 7-day means	• Volume of nutrient exchanges between rivers and floodplains
	Annual maxima, 30-day means	• Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments
	Annual maxima, 90-day means	• Distribution of plant communities in lakes, ponds, floodplains
	Number of zero-flow days (zero flow)	• Duration of high flows for waste disposal, aeration of spawning beds in channel sediments
	7-day minimum flow/mean for year (base flow)	

IHA Statistics Group	Hydrologic Parameters	Ecosystem Influences
Group 3 Parameters		
Timing of annual extreme water conditions	Julian date of each annual 1-day maximum	• Compatibility with life cycles of organisms • Predictability/avoidability of stress for organisms
	Julian date of each annual 1-day minimum	• Access to special habitats during reproduction or to avoid predation • Spawning cues for migratory fish • Evolution of life history strategies, behavioral mechanisms
Group 4 Parameters		
Frequency and duration of high and low pulses	Number of low pulses within each year	• Frequency and magnitude of soil moisture stress for plants • Frequency and duration of anaerobic stress for plants
	Mean duration of low pulses within each year	• Availability of floodplain habitats for aquatic organisms • Nutrient and organic matter exchanges between river and floodplain
	Number of high pulses within each year	• Soil mineral availability • Access for waterbirds to feeding, resting, reproduction sites
	Mean duration of high pulses within each year	• Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
Group 5 Parameters		
Rate and frequency of water condition changes	Means of all positive differences between consecutive daily values	• Drought stress on plants (falling levels)
	Means of all positive differences between consecutive daily values	• Entrapment of organisms on islands, floodplains (rising levels)
	Number of hydrological reversals	• Desiccation stress on low-mobility streamedge (varial zone) organisms

The IHA software allows analysis of single flow series or comparison of an impacted and unimpacted flow series. Daily streamflow data from the pilot reaches were modeled on a water year basis (Oct 1 - Sept 30) and organized for analysis by the IHA software. Data was organized and formatted in an MS-Excel spreadsheet and exported in comma-separated format (CSV). This approach allows both the pre-impact and post-impact flow series to be included in one file to serve as input to the IHA software. It is suggested that a longer period of record be used, of at least 20 years, so the results are more meaningful and reliable.

The IHA software produces a range of standard plots and statistical summaries referred to as Scorecards. The range of variability divides the flow regime into three equal categories, an upper, middle and a lower.

IHA Scorecard

A discussion of the output parameters in this table can be found in the IHA manual. Two columns in the Scorecard focus on the difference between pre and post impact conditions. Column 6 reports the percentage change in the mean between pre and post impact conditions. Column 8 reports the percentage change in the coefficient of variation between the pre and post development conditions; this is a measure of the change in the range of data about the mean. If the change in the mean of a parameter between pre and post impact conditions is less than one standard deviation it is assumed the change is within the normal range of variability.

RVA Scorecard

The RVA Scorecard table presents statistics related to the pre- and post-impact conditions which include the mean, the standard deviation, and high and low extreme values of each parameter. The target RVA low and high ranges are included and are based on the 33rd and 67th percentile about the pre-impact mean. The degree of hydrologic alternation is seen in the final column of the table, based on the change in the frequency of values falling in the middle category.

Results in the RVA Scorecard are very useful in providing the existing condition and post condition mean, standard deviation and expected range limits. This information is needed to quantify the expected changes in habitat associated with the proposed taking strategy.

The second page in the RVA Scorecard compares the expected and observed frequency distributions in the three RVA categories. The final page of the RVA scorecard is the warning messages generated by the software.

IHA Percentile Summary

The IHA percentile summary table presents the pre- and post-impact summary information. This table is useful in that it reports the difference in flow percentiles and allows the user to examine the range different parameters that are affected.

IHA Annual Summary

The software also produces an annual summary that includes the pre-impact and post-impact values for the entire period analyzed. To facilitate analyzing results this table was imported into an Excel spreadsheet and formulas added to calculate many of the statistics in the Scorecard tables. This seemed to be an effective means to organize information and facilitate integration with hydraulic habitat analysis.

IHA Results

The IHA analysis provided a context to identify and quantify the impacts to the flow regime. This tool is an effective means of diagnosing impacts to the flow regime, the results from IHA combined with species life cycle information can be used to infer potential impacts associated with flow alterations. This software does not quantify the impacts to habitat, however results from IHA combined with hydraulic model results can be used to quantify impacts to habitat.

The software also provides the user with a graphing interface to plot out the results. The results of the pre-impact and post-impact conditions are plotted on the same graph, with the category or standard deviation limits also shown for comparison.

The amount of output and statistics produced by the IHA software can be intimidating and requires careful interpretation, however, the software is well thought out and designed. A structured interpretation of results allows the user to focus on selected program outputs, this seems to be an effective approach.

IHA PLOTTED RESULTS

Blair Creek

Blair Mean Daily Flows
Standard IHA Average Daily Flows

RVA Average Mean Daily Flow

Standard IHA Minimum Flows

RVA Minimum Flows

Standard IHA Maximum Flows

RVA Maximum Streamflow

Standard IHA Baseflow

RVA Baseflow

Hydrologic Alteration: Normal

Hydrologic Alteration: Greatest Alteration

Monthly Alteration

Mean Daily Flows

APPENDIX H: OFAT RESULTS

Order of Tables:

1. Summary Comparison of Bankfull Discharges
2. Flood Flow Estimates
3. Low Flow Estimates
4. Instream Flow Needs estimates based on the Tennant Method

H-1: NITH RIVER AT CANNING

Nith River at Canning **Bank Full Estimates**	**Bank Full Discharge (m^3/s)**	**Ratio Compared to Observed Estimates** **Parish 2003**	 **Parish 2004**
OFAT Models			
(Annable 1994)	229.580	**2.55**	**3.73**
(Dury 1973)	229.580	**2.55**	**3.73**
(Leopold *et al.* 1964)	225.544	**2.51**	**3.67**
Field Calculated Bankfull			
Annable 1996			
Parish 2003	90.00	**1.0**	**1.46**
Parish 2004	61.5	**0.68**	**1.0**

Nith River at Canning	**Estimated Flood Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**Q1.05**	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Index Flood Dimensionless Flood Frequency Method (MNR 2000)			151.115	221.25	265.55	307.41	361.55	402.554		
Index Flood Method (Moin & Shaw 1985) Q1.25		221.364	241.663	322.862	382.8	438.14	516.43	571.775	627.12	696.47
Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)		217.5	241.663	318.27	378.69	455.05	547.85	636.299	708.8	801.6
Index Flood Regional Flood Frequency Method (MNR 2000)			151.115	215.94	259.7	301.65	314.991	356.233	397.54	
Isoline Method (MNR 2000)			422.628	609.89	723.42	826.63	955.02	1048.07		
Multiple Regression Method (MNR 2000)						582.53		772.213		
Primary Multiple Regression Method (Moin & Shaw 1985)			251.229	341.5	398.68	451.94	516.89	568.075		
Secondary Multiple Regression Method (Moin & Shaw 1985) Q2			209.097	289.19	341.72	391.34	470.41	521.619		
Actual Data	**Q1.05**	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Extreme Valve	85.8	141	210	297	351	400	460	502	543	593
Log Pearson	87.9	142	213	298	346	386	432	461	488	519
Three Parameter Log Normal	**91.2**	**142**	**209**	**295**	**350**	**401**	**465**	**513**	**560**	**622**
Walkby	85.2	139	209	302	357	402	448	476	498	522

Nith River at Canning	**Estimated Low Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Graphical Index Method (MOEE 1995) 7Q				1.164	0.712	0.546	0.467	0.388	0.362	
Isoline Method (MOEE 1995) 7Q	2.427	1.609	1.322	0.877	0.555	0.436	0.353	0.283	0.251	0.230
Isoline Method (MOEE 1995) 7Q Monthly							0.629			
Regression Method (MOEE 1995) 7Q				2.439			1.347	1.132		
Statistical Index Method (MOEE 1995) 7Q				1.164						
Actual Data	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Two Parameter Log Normal Method of Moments				2.090	1.698	1.523	1.393	1.259	1.177	
Two Parameter Log Normal Maximum Likelihood				2.090	1.698	1.523	1.393	1.259	1.177	
Three Parameter Log Normal Method of Moments				2.109	1.695	1.501	1.352	1.194	1.095	
Type III External Distribution Method of Moments				2.103	1.676	1.494	1.370	1.260	1.203	
Type III External Distribution Method of Smallest Observed Drought				2.070	1.680	1.533	1.441	1.367	1.332	
Type III External Distribution Method of Maximum Likelihood				2.048	1.667	1.531	1.450	1.389	1.362	
Pearson Type III External Distribution Method of Moments				2.098	1.693	1.510	1.374	1.235	1.151	
Pearson Type III External Distribution Method of Maximum Likelihood				2.033	1.666	1.532	1.446	1.373	1.337	
Pearson Type III External Distribution Method of Moments (indirect)				2.079	1.695	1.529	1.406	1.281	1.206	

Nith River at Canning Montana Method (Tennant 1976)				
Condition	**OFAT**		**GRCA 2004**	
	Apr to Sep (m^3/s)	**Oct to Mar (m^3/s)**	**Apr to Sep (m^3/s)**	**Oct to Mar (m^3/s)**
Severe Degradation	1.132	1.132	1.13	1.13
Poor or Minimum	1.132	1.132	1.13	1.13
Fair to Degrading	3.396	1.132	3.40	1.13
Good	4.528	2.264	4.54	2.27
Excellent	5.660	3.396	5.67	3.40
Outstanding	6.792	4.528	6.80	4.54
Optimal Range Min	6.792	6.792	6.80	6.80
Optimal Range Max	11.319	11.319	11.34	11.34
Flushing to Maximum	22.639	22.639	22.68	22.68

H-2: ERAMOSA RIVER

Eramosa River Above Guelph		**Ratio Compared to Observed Estimates**	
Bank Full Estimates	**Bank Full Discharge (m^3/s)**	**Parish**	**Annable**
OFAT Models			
(Annable 1994)	68.5	**4.4**	**3.9**
(Dury 1973)	68.5	**4.4**	**3.9**
(Leopold *et al.* 1964)	67.3	**4.3**	**3.8**
Field Calculated Bankfull			
Annable 1996	17.8	**1.1**	**1.0**
Parish 2003	15.5	**1.0**	**0.9**

Eramosa River Above Guelph	**Estimated Flood Flow (m^3/s)**										
Ontario Flow Assessment Tool (OFAT) Estimates	**Q1**	**Q1.05**	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Index Flood Dimensionless Flood Frequency Method (MNR 2000)				50.4	73.8	88.5	102.5	120.6	134.2		
Index Flood Method (Moin & Shaw 1985) Q1.25			66.1	72.1	96.4	114.3	130.8	154.2	170.7	187.2	207.9
Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)			64.9	72.1	95.0	113.0	135.8	163.5	189.9	211.6	239.3
Index Flood Regional Flood Frequency Method (MNR 2000)				50.4	72.0	86.6	100.6	105.0	118.8	132.6	
Isoline Method (MNR 2000)				42.3	63.0	75.7	87.3	102.0	112.4		
Multiple Regression Method (MNR 2000)							142.0		193.2		
Primary Multiple Regression Method (Moin & Shaw 1985)				62.6	93.8	115.0	135.7	151.5	171.4		
Secondary Multiple Regression Method (Moin & Shaw 1985) Q2				58.6	98.3	120.5	142.1	167.9	190.0		
Actual Data	**Q1**	**Q1.05**	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Extreme Valve	0.9	8.2	15.0	23.8	34.9	41.9	48.3	56.3	62.0	67.5	74.4
Log Pearson	4.0	9.3	15.2	23.3	34.6	42.1	49.2	58.6	65.7	72.9	82.5
Three Parameter Log Normal	**1.9**	**7.2**	**15.2**	**25.9**	**36.6**	**41.3**	**44.5**	**47.2**	**48.6**	**49.5**	**50.2**
Walkby	8.3	9.5	13.7	23.5	36.8	43.3	47.9	51.9	53.8	55.2	56.4

Eramosa River Above Guelph	**Estimated Low Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Graphical Index Method (MOEE 1995) 7Q				0.312	0.191	0.146	0.125	0.104	0.097	
Isoline Method (MOEE 1995) 7Q	1.147	0.890	0.790	0.621	0.480	0.424	0.383	0.351	0.333	0.320
Isoline Method (MOEE 1995) 7Q Monthly							0.440			
Regression Method (MOEE 1995) 7Q				0.358			0.179	0.153		
Statistical Index Method (MOEE 1995) 7Q				0.312						
Actual Data	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Two Parameter Log Normal Method of Moments				0.457	0.330	0.278	0.242	0.207	0.186	
Two Parameter Log Normal Maximum Likelihood				0.457	0.330	0.278	0.242	0.207	0.186	
Three Parameter Log Normal Method of Moments				0.482	0.324	0.247	0.186	0.120	0.077	
Type III External Distribution Method of Moments				0.481	0.324	0.248	0.188	0.123	0.081	
Type III External Distribution Method of Smallest Observed Drought				0.482	0.319	0.244	0.190	0.139	0.111	
Type III External Distribution Method of Maximum Likelihood				**0.488**	**0.320**	**0.239**	**0.178**	**0.118**	**0.084**	
Pearson Type III External Distribution Method of Moments				0.479	0.323	0.249	0.192	0.130	0.092	
Pearson Type III External Distribution Method of Maximum Likelihood				0.481	0.325	0.251	0.192	0.129	0.089	
Pearson Type III External Distribution Method of Moments (indirect)				0.489	0.318	0.240	0.184	0.131	0.102	

Eramosa River above Guelph Montana Method (Tennant 1976)

Condition	**OFAT**		**GRCA 2004**	
	Apr to Sep (m^3/s)	**Oct to Mar (m^3/s)**	**Apr to Sep (m^3/s)**	**Oct to Mar (m^3/s)**
Severe Degradation	0.259	0.259	0.25	0.25
Poor or Minimum	0.259	0.259	0.25	0.25
Fair to Degrading	0.777	0.259	0.74	0.25
Good	1.036	0.518	0.99	0.50
Excellent	1.294	0.777	1.24	0.74
Outstanding	1.553	1.036	1.49	0.99
Optimal Range Min	1.553	1.553	1.49	1.49
Optimal Range Max	2.589	2.589	2.48	2.48
Flushing to Maximum	5.178	5.178	4.96	4.96

H-3: BLAIR CREEK REACH

Blair Creek		**Ratio Compared to Observed Estimates**	
Bank Full Estimates	**Bank Full Discharge (m^3/s)**	**Parish**	**Annable**
OFAT Models			
(Annable 1994)	6.5	**3.7**	
(Dury 1973)	6.5	**3.7**	
(Leopold *et al.* 1964)	6.4	**3.6**	
Field Calculated Bankfull			
Annable 1996			
Parish 2003	1.77	**1.0**	

Blair Creek	**Estimated Flood Flow (m^3/s)**								
Ontario Flow Assessment Tool (OFAT) Estimates	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Index Flood Dimensionless Flood Frequency Method (MNR 2000)		6.0	8.7	10.5	12.1	14.3	15.9		
Index Flood Method (Moin & Shaw 1985) Q1.25	6.3	6.9	9.2	10.9	12.5	14.7	16.3	17.9	19.9
Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)	6.2	6.9	9.1	10.8	13.0	15.6	18.1	20.2	22.8
Index Flood Regional Flood Frequency Method (MNR 2000)		6.0	9.0	10.3	11.9	12.4	14.1	15.7	
Isoline Method (MNR 2000)		6.4	10.5	13.3	15.9	19.4	22.0		
Multiple Regression Method (MNR 2000)					11.1		15.0		
Primary Multiple Regression Method (Moin & Shaw 1985)		5.6	9.0	11.5	14.0	18.4	21.3		
Secondary Multiple Regression Method (Moin & Shaw 1985) Q2		5.0	8.5	10.8	13.2	16.8	19.6		
Actual Data									
Extreme Valve									
Log Pearson									
Three Parameter Log Normal									
Walkby									

Blair Creek	**Estimated Low Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Graphical Index Method (MOEE 1995) 7Q				0.06	0.04	0.03	0.03	0.02	0.02	
Isoline Method (MOEE 1995) 7Q	0.05	0.04	0.03	0.02	0.014	0.01	0.01	0.01	0.01	0.01
Isoline Method (MOEE 1995) 7Q Monthly										
Regression Method (MOEE 1995) 7Q				0.081			0.012	0.004		
Statistical Index Method (MOEE 1995) 7Q				0.1						
Actual Data	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Two Parameter Log Normal Method of Moments										
Two Parameter Log Normal Maximum Likelihood										
Three Parameter Log Normal Method of Moments										
Type III External Distribution Method of Moments										
Type III External Distribution Method of Smallest Observed Drought										
Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments										
Pearson Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments (indirect)										

Blair Creek Montana Method (Tennant 1976)				
Condition	**OFAT**		**GRCA 2004**	
	Apr to Sep (m^3/s)	**Oct to Mar (m^3/s)**	**Apr to Sep (m^3/s)**	**Oct to Mar (m^3/s)**
Severe Degradation	0.015	0.015	0.024	0.024
Poor or Minimum	0.015	0.015	0.024	0.024
Fair to Degrading	0.045	0.015	0.072	0.024
Good	0.059	0.030	0.096	0.048
Excellent	0.074	0.045	0.12	0.072
Outstanding	0.089	0.059	0.144	0.096
Optimal Range Min	0.089	0.089	0.144	0.144
Optimal Range Max	0.149	0.149	0.24	0.24
Flushing to Maximum	0.297	0.297	0.48	0.48

H-4: MILL CREEK REACH

Mill Creek		**Ratio Compared to Observed Estimates**	
Bank Full Estimates	**Bank Full Discharge (m^3/s)**	**Parish**	**Annable**
OFAT Models			
(Annable 1994)	27.7	**6.6**	
(Dury 1973)	27.7	**6.6**	
(Leopold *et al.* 1964)	27.2	**6.5**	
Field Calculated Bankfull			
Annable 1996			**1.0**
Parish 2003	4.2	**1.0**	

Mill Creek	**Estimated Flood Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**Q1.05**	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Index Flood Dimensionless Flood Frequency Method (MNR 2000)			22.2	32.433	38.9	45.1	53.0	59.0		
Index Flood Method (Moin & Shaw 1985) Q1.25	26.7	29.2	39.0	46.2	52.9	62.4	69.1	75.8	84.1	
Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)		26.3	29.2	38.4	45.7	55.0	66.2	76.9	85.6	96.8
Index Flood Regional Flood Frequency Method (MNR 2000)			22.2	31.7	38.1	44.2	46.2	52.2	58.3	
Isoline Method (MNR 2000)			17.8	27.1	33.0	38.3	45.1	49.9		
Multiple Regression Method (MNR 2000)			35.4					46.9		
Primary Multiple Regression Method (Moin & Shaw 1985)			15.4	23.8	29.9	36.0	41.6	47.7		
Secondary Multiple Regression Method (Moin & Shaw 1985) Q2										
Actual Data	**Q1.05**	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Extreme Valve	2.36	3.78	5.43	7.3	8.35	9.23	10.2	10.9	11.4	12.1
Log Pearson	2.68	3.82	5.3	7.16	8.32	9.40	10.7	11.7	12.7	14.0
Three Parameter Log Normal	**2.63**	**3.76**	**5.29**	**7.26**	**8.49**	**9.62**	**11.0**	**12**	**13.0**	**14.2**
Walkby	2.72	3.41	4.94	7.06	8.25	9.23	10.3	11.1	11.7	12.5

Mill Creek	**Estimated Low Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Graphical Index Method (MOEE 1995) 7Q				0.137	0.084	0.064	0.055	0.046	0.043	0.190
Isoline Method (MOEE 1995) 7Q	0.343	0.255	0.222	0.167	0.121	0.104	0.091	0.081	0.075	0.071
Isoline Method (MOEE 1995) 7Q Monthly							0.107			
Regression Method (MOEE 1995) 7Q				0.305			0.155	0.135		
Statistical Index Method (MOEE 1995) 7Q				0.137						
Actual Data	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Two Parameter Log Normal Method of Moments				0.267	0.201	0.174	0.154	0.134	0.122	
Two Parameter Log Normal Maximum Likelihood				0.267	0.201	0.174	0.154	0.134	0.122	
Three Parameter Log Normal Method of Moments										
Type III External Distribution Method of Moments				0.288	0.204	0.157	0.118	0.074	0.047	
Type III External Distribution Method of Smallest Observed Drought				0.276	0.199	0.164	0.139	0.116	0.104	
Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments				0.291	0.204	0.153	0.108	0.055	0.017	
Pearson Type III External Distribution Method of Maximum Likelihood				0.256	0.184	0.158	0.142	0.130	0.123	
Pearson Type III External Distribution Method of Moments (indirect)				0.284	0.197	0.156	0.125	0.095	0.077	

Mill Creek Montana Method (Tennant 1976)				
Condition	**OFAT**		**GRCA 2004**	
	Apr to Sep (m^3/s)	**Oct to Mar (m^3/s)**	**Apr to Sep (m^3/s)**	**Oct to Mar (m^3/s)**
Severe Degradation	0.088	0.088	0.09	0.09
Poor or Minimum	0.088	0.088	0.09	0.09
Fair to Degrading	0.264	0.088	0.27	0.09
Good	0.352	0.176	0.36	0.18
Excellent	0.440	0.264	0.45	0.27
Outstanding	0.528	0.352	0.54	0.36
Optimal Range Min	0.528	0.528	0.54	0.54
Optimal Range Max	0.879	0.879	0.9	0.9
Flushing to Maximum	1.759	1.759	1.8	1.8

H-5: WHITEMANS CREEK AT MOUNT VERNON

Whitemans Creek at Mt. Vernon		**Ratio Compared to Observed Estimates**	
Bank Full Estimates	**Bank Full Discharge (m^3/s)**	**Parish**	**Annable**
OFAT Models			
(Annable 1994)	104.384	**4.26**	
(Dury 1973)	104.384	**4.26**	
(Leopold *et al.* 1964)	102.549	**4.19**	
Field Calculated Bankfull			
Annable 1996			**1.0**
Parish 2003	24.5	**1.0**	

Whitemans Creek at Mount Vernon	**Estimated Flood Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**Q1.05**	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Index Flood Dimensionless Flood Frequency Method (MNR 2000)			73.8	108.1	129.8	150.2	176.7	196.7		
Index Flood Method (Moin & Shaw 1985) Q1.25		100.6	109.9	146.8	174.0	199.2	234.8	260.0	285.1	316.7
Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)		98.9	109.9	144.7	172.2	206.9	249.1	289.3	322.3	364.5
Index Flood Regional Flood Frequency Method (MNR 2000)			73.8	105.5	126.9	147.4	153.9	174.1	194.3	
Isoline Method (MNR 2000)			112.0	159.0	188.1	213.8	245.1	267.6		
Multiple Regression Method (MNR 2000)						245.0		332.0		
Primary Multiple Regression Method (Moin & Shaw 1985)			98.8	141.7	170.1	197.3	215.9	241.3		
Secondary Multiple Regression Method (Moin & Shaw 1985) Q2			92.5	138.1	166.5	193.7	226.2	253.5		
Actual Data	**Q1.05**	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Extreme Valve	8.15	15	23.8	34.9	41.9	48.3	56.3	62	67.5	74.4
Log Pearson	9.3	15.2	23.3	34.6	42.1	49.2	58.6	65.7	72.9	82.5
Three Parameter Log Normal	**7.21**	**15.2**	**25.9**	**36.6**	**41.3**	**44.5**	**47.2**	**48.6**	**49.5**	**50.2**
Walkby	9.48	13.7	23.5	36.8	43.3	47.9	51.9	53.8	55.2	56.4

Whitemans Creek at Mt. Vernon	**Estimated Low Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Graphical Index Method (MOEE 1995) 7Q				0.485	0.296	0.227	0.194	0.162	0.151	
Isoline Method (MOEE 1995) 7Q	1.153	0.766	0.624	0.398	0.233	0.172	0.134	0.104	0.094	0.086
Isoline Method (MOEE 1995) 7Q Monthly							0.222			
Regression Method (MOEE 1995) 7Q				0.543			0.274	0.226		
Statistical Index Method (MOEE 1995) 7Q				0.485						
Actual Data	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Two Parameter Log Normal Method of Moments				0.575	0.394	0.323	0.274	0.228	0.202	
Two Parameter Log Normal Maximum Likelihood				0.575	0.394	0.323	0.274	0.228	0.202	
Three Parameter Log Normal Method of Moments				0.621	0.379	0.261	0.167	0.066	0.003	
Type III External Distribution Method of Moments				0.621	0.377	0.256	0.173	0.095	0.052	
Type III External Distribution Method of Smallest Observed Drought				0.609	0.370	0.268	0.198	0.135	0.103	
Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments				0.617	0.378	0.265	0.176	0.082	0.027	
Pearson Type III External Distribution Method of Maximum Likelihood				0.592	0.371	0.278	0.211	0.147	0.110	
Pearson Type III External Distribution Method of Moments (indirect)				0.599	0.364	0.268	0.203	0.145	0.144	

Whitemans Creek at Mt. Vernon Montana Method (Tennant 1976)				
Condition	**OFAT**		**GRCA 2004**	
	Apr to Sep (m^3/s)	**Oct to Mar (m^3/s)**	**Apr to Sep (m^3/s)**	**Oct to Mar (m^3/s)**
Severe Degradation	0.439	0.439	0.44	0.44
Poor or Minimum	0.439	0.439	0.44	0.44
Fair to Degrading	1.317	0.439	1.31	0.44
Good	1.756	0.878	1.75	0.87
Excellent	2.195	1.317	2.19	1.31
Outstanding	2.634	1.756	2.62	1.75
Optimal Range Min	2.634	2.634	2.62	2.62
Optimal Range Max	4.391	4.391	4.37	4.37
Flushing to Maximum	8.781	8.781	8.74	8.74

H-6 GRAND RIVER AT BLAIR

Grand River at Blair **Bank Full Estimates**	**Bank Full Discharge (m^3/s)**	**Ratio Compared to Observed Estimates**	
		Parish	**Annable**
OFAT Models			
(Annable 1994)	504.908	**1.28**	
(Dury 1973)	504.908	**1.28**	
(Leopold *et al.* 1964)	496.033	**1.26**	
Field Calculated Bankfull			
Annable 1996			**1.0**
Parish 2004	395.00	**1.0**	

Grand River at Blair	**Estimated Flood Flow (m^3/s)**								
Ontario Flow Assessment Tool (OFAT) Estimates	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Index Flood Dimensionless Flood Frequency Method (MNR 2000)		309.21	452.72	543.36	629.02	739.79	823.70		
Index Flood Method (Moin & Shaw 1985) Q1.25	486.84	531.48	710.06	841.87	963.58	1135.78	1257.49	1379.20	1531.73
Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)	478.33	531.48	699.96	832.83	1000.78	1204.87	1399.39	1558.84	1762.93
Index Flood Regional Flood Frequency Method (MNR 2000)		309.21	441.86	531.40	617.24	644.53	728.92	813.45	
Isoline Method (MNR 2000)		1084.53	1590.56	1897.59	2179.44	2535.55	2794.42		
Multiple Regression Method (MNR 2000)					1560.35		2092.38		
Primary Multiple Regression Method (Moin & Shaw 1985)		676.08	904.61	1041.37	1166.89	1232.24	1342.95		
Secondary Multiple Regression Method (Moin & Shaw 1985) Q2		465.82	700.02	820.32	932.98	1067.25	1175.31		
Actual Data	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Extreme Valve	493	761	1100	1310	1500	1730	1900	2050	2250
Log Pearson	491	763	1100	1300	1480	1680	1810	1930	2080
Three Parameter Log Normal	**495**	**755**	**1090**	**1310**	**1510**	**1780**	**1950**	**2150**	**2380**
Walkby	475	782	1070	1260	1460	1760	2020	2310	2750

Grand River at Blair	**Estimated Low Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Graphical Index Method (MOEE 1995) 7Q				2.897	1.771	1.358	1.162	0.966	0.900	
Isoline Method (MOEE 1995) 7Q	7.545	5.399	4.610	3.323	2.302	1.900	1.616	1.369	1.243	1.148
Isoline Method (MOEE 1995) 7Q Monthly							2.882			
Regression Method (MOEE 1995) 7Q				4.485			2.836	2.541		
Statistical Index Method (MOEE 1995) 7Q				2.897						
Actual Data	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Two Parameter Log Normal Method of Moments				11.961	10.068	9.201	8.541	7.855	7.429	
Two Parameter Log Normal Maximum Likelihood				11.961	10.068	9.201	8.541	7.855	7.429	
Three Parameter Log Normal Method of Moments										
Type III External Distribution Method of Moments				12.589	10.374	8.943	7.596	5.891	4.639	
Type III External Distribution Method of Smallest Observed Drought										
Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments				12.736	10.411	8.855	7.373	5.479	4.075	
Pearson Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments (indirect)				12.860	10.349	8.736	7.342	5.795	4.822	

Grand River at Blair Montana Method (Tennant 1976)

Condition	**OFAT**		**GRCA 2004**	
	Apr to Sep (m^3/s)	**Oct to Mar (m^3/s)**	**Apr to Sep (m^3/s)**	**Oct to Mar (m^3/s)**
Severe Degradation	2.912	2.912	3.234	3.234
Poor or Minimum	2.912	2.912	3.234	3.234
Fair to Degrading	8.736	2.912	9.702	3.234
Good	11.648	5.824	12.936	6.468
Excellent	14.560	8.736	16.17	9.702
Outstanding	17.472	11.648	19.404	12.936
Optimal Range Min	17.472	17.472	19.404	19.404
Optimal Range Max	29.120	29.120	32.34	32.34
Flushing to Maximum	58.239	58.239	64.68	64.68

H-7: GRAND RIVER EXCEPTIONAL WATERS REACH – Upstream

Grand River Exceptional Waters Upstream		**Ratio Compared to Observed Estimates**	
Bank Full Estimates	**Bank Full Discharge (m^3/s)**	**Parish**	**Annable**
OFAT Models			
(Annable 1994)	837.026		
(Dury 1973)	837.026		
(Leopold *et al.* 1964)	822.312		
Field Calculated Bankfull			
Annable 1996			**1.0**
Parish 2003		**1.0**	

Grand River Exceptional Waters Upstream	**Estimated Flood Flow (m^3/s)**								
Ontario Flow Assessment Tool (OFAT) Estimates	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Index Flood Dimensionless Flood Frequency Method (MNR 2000)		489.421	716.58	860.04	995.62	1171	1303.8		
Index Flood Method (Moin & Shaw 1985) Q1.25	807.07	881.08	1177.1	1395.6	1597.4	1882.9	2084.6	2286.4	2539.3
Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)	792.97	881.08	1160.4	1380.7	1659.1	1997.4	2319.9	2584.2	2922.5
Index Flood Regional Flood Frequency Method (MNR 2000)		489.421	699.38	841.11	976.98	1020.2	1153.7	1287.5	
Isoline Method (MNR 2000)		1798.26	2645.2	3161.9	3634.1	4229.3	4659.8		
Multiple Regression Method (MNR 2000)					2836.6		3856.5		
Primary Multiple Regression Method (Moin & Shaw 1985)		1156.74	1530.5	1747.7	1945.4	2019.5	2189.3		
Secondary Multiple Regression Method (Moin & Shaw 1985) Q2		783.947	1200.3	1395.6	1576.8	1810.2	1983.5		
Actual Data	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Extreme Valve									
Log Pearson									
Three Parameter Log Normal									
Walkby									

Grand River Exceptional Waters Upstream	**Estimated Low Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Graphical Index Method (MOEE 1995) 7Q				5.242	3.205	2.458	2.103	1.747	5.242	
Isoline Method (MOEE 1995) 7Q	14.470	10.242	8.700	6.216	4.265	3.515	2.989	2.537	2.309	2.141
Isoline Method (MOEE 1995) 7Q Monthly							5.602			
Regression Method (MOEE 1995) 7Q				16.420			11.357	10.539		
Statistical Index Method (MOEE 1995) 7Q				5.242						
Actual Data	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Two Parameter Log Normal Method of Moments										
Two Parameter Log Normal Maximum Likelihood										
Three Parameter Log Normal Method of Moments										
Type III External Distribution Method of Moments										
Type III External Distribution Method of Smallest Observed Drought										
Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments										
Pearson Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments (indirect)										

Grand River Exceptional Waters – Upstream Montana Method (Tennant 1976)

Condition	**OFAT**		**GRCA 2004**	
	Apr to Sep (m^3/s)	**Oct to Mar (m^3/s)**	**Apr to Sep (m^3/s)**	**Oct to Mar(m^3/s)**
Severe Degradation	5.229	5.229	5.847	5.847
Poor or Minimum	5.229	5.229	5.847	5.847
Fair to Degrading	15.687	5.229	17.541	5.847
Good	20.917	10.458	23.388	11.694
Excellent	26.146	15.687	29.235	17.541
Outstanding	31.375	20.917	35.082	23.388
Optimal Range Min	31.375	31.375	35.082	35.082
Optimal Range Max	52.291	52.291	58.47	58.47
Flushing to Maximum	104.583	104.583	116.94	116.94

H-8: GRAND RIVER EXCEPTIONAL WATERS REACH – Downstream

Grand River Exceptional Waters Downstream		**Ratio Compared to Observed Estimates**	
Bank Full Estimates	**Bank Full Discharge (m^3/s)**	**Parish**	**Annable**
OFAT Models			
(Annable 1994)	901.2659		
(Dury 1973)	901.2659		
(Leopold *et al.* 1964)	885.4226		
Field Calculated Bankfull			
Annable 1996			**1.0**
Parish 2003		**1.0**	

Grand River Exceptional Waters Downstream	**Estimated Flood Flow (m^3/s)**								
Ontario Flow Assessment Tool (OFAT) Estimates	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Index Flood Dimensionless Flood Frequency Method (MNR 2000)		523.4	766.4	919.8	1064.8	1252.3	1394.4		
Index Flood Method (Moin & Shaw 1985) Q1.25	869.0	948.7	1267.5	1502.7	1720.0	2027.4	2244.6	2461.9	2734.2
Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)	853.8	948.7	1249.4	1486.6	1786.4	2150.7	2497.9	2782.5	3146.8
Index Flood Regional Flood Frequency Method (MNR 2000)		523.4	748.0	899.6	1044.9	1091.1	1233.9	1377.0	
Isoline Method (MNR 2000)		1922.6	2820.5	3368.9	3868.8	4497.6	4952.1		
Multiple Regression Method (MNR 2000)					3167.0		4323.2		
Primary Multiple Regression Method (Moin & Shaw 1985)		1270.2	1677.8	1913.3	2127.3	2194.5	2377.0		
Secondary Multiple Regression Method (Moin & Shaw 1985) Q2		843.9	1301.4	1512.0	1707.2	1948.5	2133.6		
Actual Data	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Extreme Valve	438	667	964	1160	1330	1560	1720	1880	2090
Log Pearson	434	632	951	1180	1410	1730	1990	2260	2640
Three Parameter Log Normal	**436**	**648**	**957**	**1170**	**1380**	**1660**	**1880**	**2100**	**2390**
Walkby	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Grand River Exceptional Waters Downstream	**Estimated Low Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Graphical Index Method (MOEE 1995) 7Q				5.72	3.50	2.68	2.29	1.91	1.78	
Isoline Method (MOEE 1995) 7Q	15.69	11.05	9.36	6.63	4.51	3.69	3.13	2.64	2.40	2.23
Isoline Method (MOEE 1995) 7Q Monthly							5.05			
Regression Method (MOEE 1995) 7Q				20.28			14.18	13.22		
Statistical Index Method (MOEE 1995) 7Q				5.72						
Actual Data	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Two Parameter Log Normal Method of Moments				17.982	15.469	14.298	13.399	12.454	11.861	
Two Parameter Log Normal Maximum Likelihood				17.982	15.469	14.298	13.399	12.454	11.861	
Three Parameter Log Normal Method of Moments										
Type III External Distribution Method of Moments				18.803	15.931	14.152	12.531	10.551	9.149	
Type III External Distribution Method of Smallest Observed Drought										
Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments				18.944	15.966	14.062	12.294	10.082	8.469	
Pearson Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments (indirect)				19.431	16.335	14.113	12.071	9.721	8.182	

Grand River Exceptional Waters Downstream Montana Method (Tennant 1976)

Condition	**OFAT**		**GRCA 2004**	
	Apr to Sep (m^3/s)	**Oct to Mar (m^3/s)**	**Apr to Sep (m^3/s)**	**Oct to Mar (m^3/s)**
Severe Degradation	5.717	5.717	6.213	6.213
Poor or Minimum	5.717	5.717	6.213	6.213
Fair to Degrading	17.151	5.717	18.639	6.213
Good	22.868	11.434	24.852	12.426
Excellent	28.585	17.151	31.065	18.639
Outstanding	34.302	22.868	37.278	24.852
Optimal Range Min	34.302	34.302	37.278	37.278
Optimal Range Max	57.170	57.170	62.13	62.13
Flushing to Maximum	114.340	114.340	124.26	124.26

H-9: CARROLL CREEK

Carroll Creek		**Ratio Compared to Observed Estimates**	
Bank Full Estimates	**Bank Full Discharge (m^3/s)**	**Parish**	**Annable**
OFAT Models			
(Annable 1994)	16.701		
(Dury 1973)	16.701		
(Leopold *et al.* 1964)	16.407		
Field Calculated Bankfull			
Annable 1996			**1.0**
Parish 2003		**1.0**	

Carroll Creek	**Estimated Flood Flow (m^3/s)**								
Ontario Flow Assessment Tool (OFAT) Estimates	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Index Flood Dimensionless Flood Frequency Method (MNR 2000)		14.0	20.5	24.6	28.4	33.4	37.2		
Index Flood Method (Moin & Shaw 1985) Q1.25	16.1	17.6	23.5	27.8	31.9	37.6	41.6	45.6	50.7
Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)	15.8	17.6	23.2	27.5	33.1	39.9	46.3	51.6	58.3
Index Flood Regional Flood Frequency Method (MNR 2000)		14.0	20.0	24.0	27.9	29.1	32.9	36.8	
Isoline Method (MNR 2000)		26.1	37.0	43.3	48.9	55.8	60.6		
Multiple Regression Method (MNR 2000)					35.6		47.197		
Primary Multiple Regression Method (Moin & Shaw 1985)		19.4	29.6	36.7	43.7	52.6	59.9		
Secondary Multiple Regression Method (Moin & Shaw 1985) Q2		13.3	22.6	28.4	34.2	42.0	48.4		
Actual Data	**Q1.25**	**Q2**	**Q5**	**Q10**	**Q20**	**Q50**	**Q100**	**Q200**	**Q500**
Extreme Valve									
Log Pearson									
Three Parameter Log Normal									
Walkby									

Carroll Creek	**Estimated Low Flow (m^3/s)**									
Ontario Flow Assessment Tool (OFAT) Estimates	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Graphical Index Method (MOEE 1995) 7Q				0.096	0.059	0.045	0.038	0.032	0.030	
Isoline Method (MOEE 1995) 7Q	0.118	0.086	0.075	0.056	0.040	0.034	0.029	0.025	0.022	0.020
Isoline Method (MOEE 1995) 7Q Monthly							0.048			
Regression Method (MOEE 1995) 7Q				0.047			-0.014	-0.021		
Statistical Index Method (MOEE 1995) 7Q				0.096						
Actual Data	**1.01**	**1.11**	**1.25**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Two Parameter Log Normal Method of Moments										
Two Parameter Log Normal Maximum Likelihood										
Three Parameter Log Normal Method of Moments										
Type III External Distribution Method of Moments										
Type III External Distribution Method of Smallest Observed Drought										
Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments										
Pearson Type III External Distribution Method of Maximum Likelihood										
Pearson Type III External Distribution Method of Moments (indirect)										

Carroll Creek Montana Method (Tennant 1976)

Condition	**OFAT**		**GRCA 2004**	
	Apr to Sep (m^3/s)	**Oct to Mar (m^3/s)**	**Apr to Sep (m^3/s)**	**Oct to Mar (m^3/s)**
Severe Degradation	0.046	0.046		
Poor or Minimum	0.046	0.046		
Fair to Degrading	0.139	0.046		
Good	0.186	0.093		
Excellent	0.232	0.139		
Outstanding	0.279	0.186		
Optimal Range Min	0.279	0.279		
Optimal Range Max	0.465	0.465		
Flushing to Maximum	0.930	0.930		

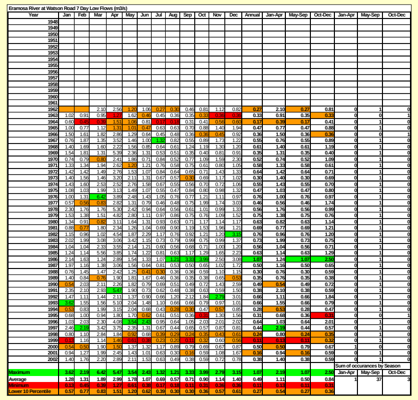
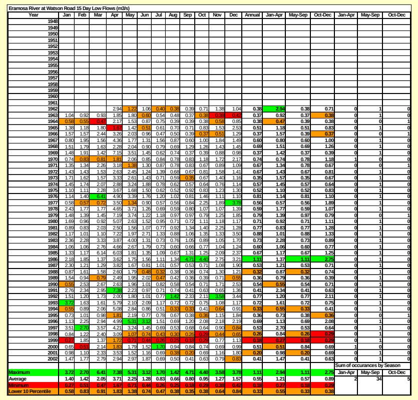
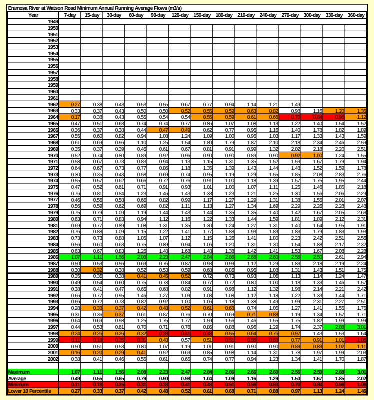
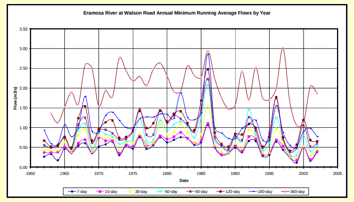
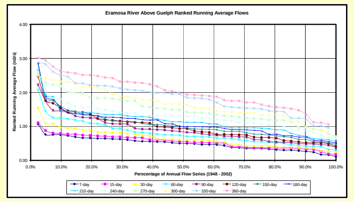
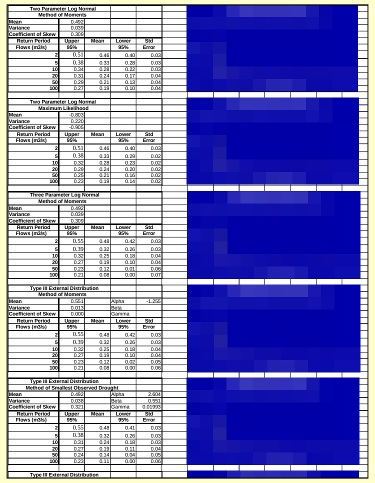
Poster #1 Eramosa River Above Guelph Daily Flow Summary 1962 to 2002

Note: Daily Flow Data Courtesy of Water Survey of Canada Through the Federal Provincial Cost Share Agreement

Figure A.#.1 Eramosa Study Reach Poster 1.

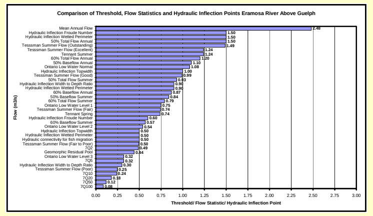
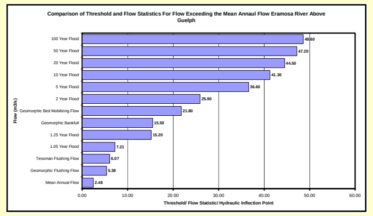
Poster #2 Eramosa River Above Guelph Flow Illustration and Analysis

Moving Average Flow Analysis

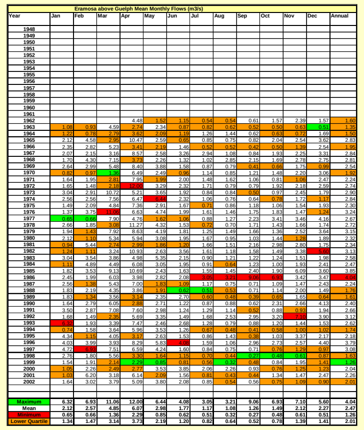







Low Flow Stastics Eramosa River at watson Road 1948 to 2002 Statistical Method	Annual Return Period 7-day Flow (m3/s) 2	5	10	20	50	100
Two Parameter Log Normal Method of Moments	0.457	0.330	0.278	0.242	0.207	0.186
Two Parameter Log Normal Maximum Likelihood	0.457	0.330	0.278	0.242	0.207	0.186
Three Parameter Log Normal Method of Moments	0.482	0.324	0.247	0.186	0.120	0.077
Type III External Distribution Method of Moments	0.481	0.324	0.248	0.188	0.123	0.081
Type III External Distribution Method of Smallest Observed Drought	0.482	0.319	0.244	0.190	0.139	0.111
Type III External Distribution Method of Maximum Likelihood	**0.488**	**0.320**	**0.239**	**0.178**	**0.118**	**0.084**
Pearson Type III External Distribution Method of Moments	0.479	0.323	0.249	0.192	0.130	0.092
Pearson Type III External Distribution Method of Maximum Likelihood	0.481	0.325	0.251	0.192	0.129	0.089
Pearson Type III External Distribution Method of Monments (indirect)	0.489	0.318	0.240	0.184	0.131	0.102
Maximum	0.489	0.330	0.278	0.242	0.207	0.186
Average	0.477	0.324	0.253	0.199	0.145	0.112
Minimum	0.457	0.318	0.239	0.178	0.118	0.077

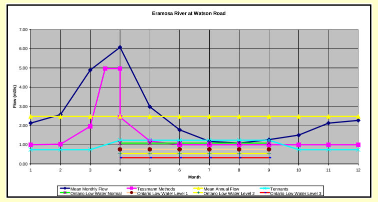
Comparison of Thresholds and Statistics

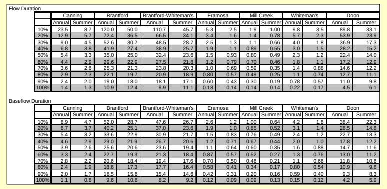



Monthly Flow Analysis

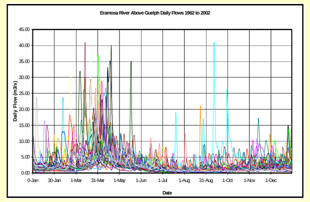
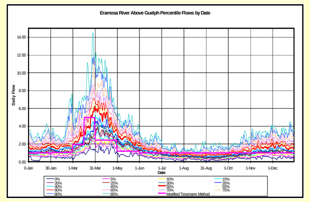
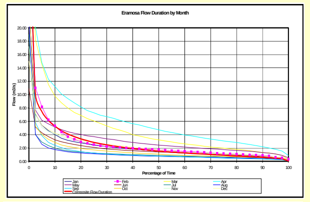
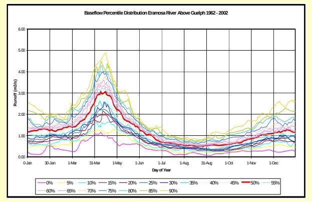
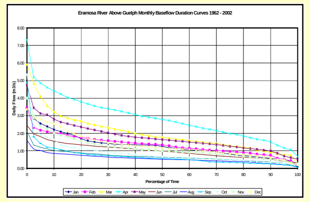
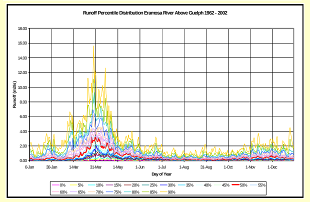
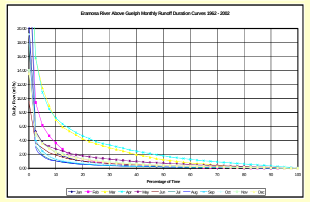


Simple IFN Techniques

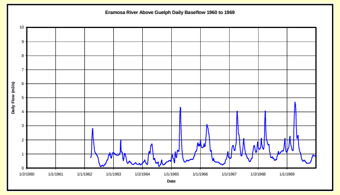
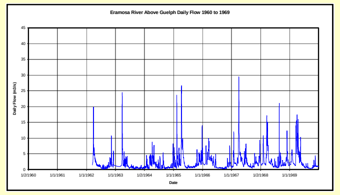
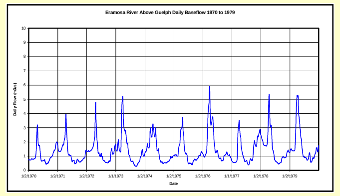
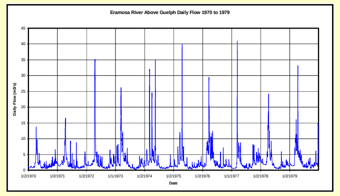
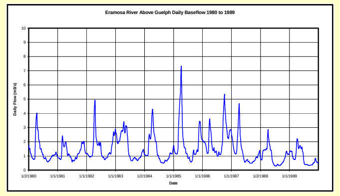
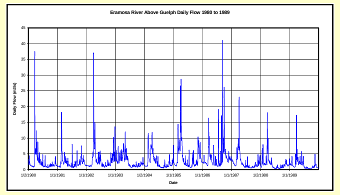
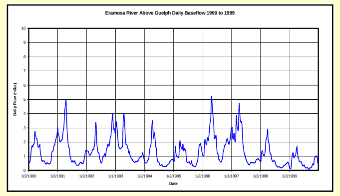
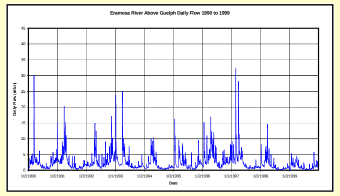
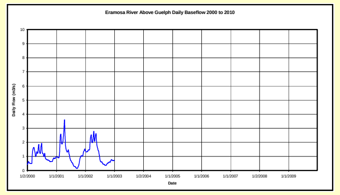
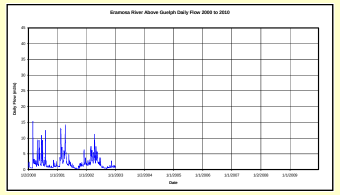




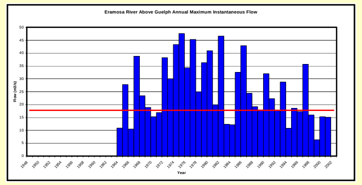
Percentile Flow Illustration

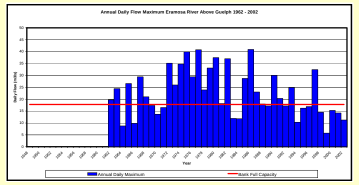
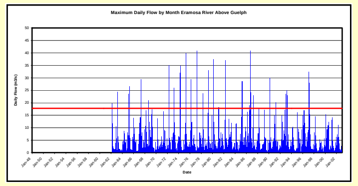
Decadal Flow Illustration

High Flow Analysis



Return Period Period (yr)	Extreme Value (m3/s)	Log Pearson (m3/s)	Three P Log Normal (m3/s)	Walkby (m3/s)
1.003	0.91	3.95	**1.85**	8.29
1.05	8.15	9.3	**7.21**	9.48
1.25	15	15.2	**15.2**	13.7
2	23.8	23.3	**25.9**	23.5
5	34.9	34.6	**36.6**	36.8
10	41.9	42.1	**41.3**	43.3
20	48.3	49.2	**44.5**	47.9
50	56.3	58.6	**47.2**	51.9
100	62	65.7	**48.6**	53.8
200	67.5	72.9	**49.5**	55.2
500	74.4	82.5	**50.2**	56.4

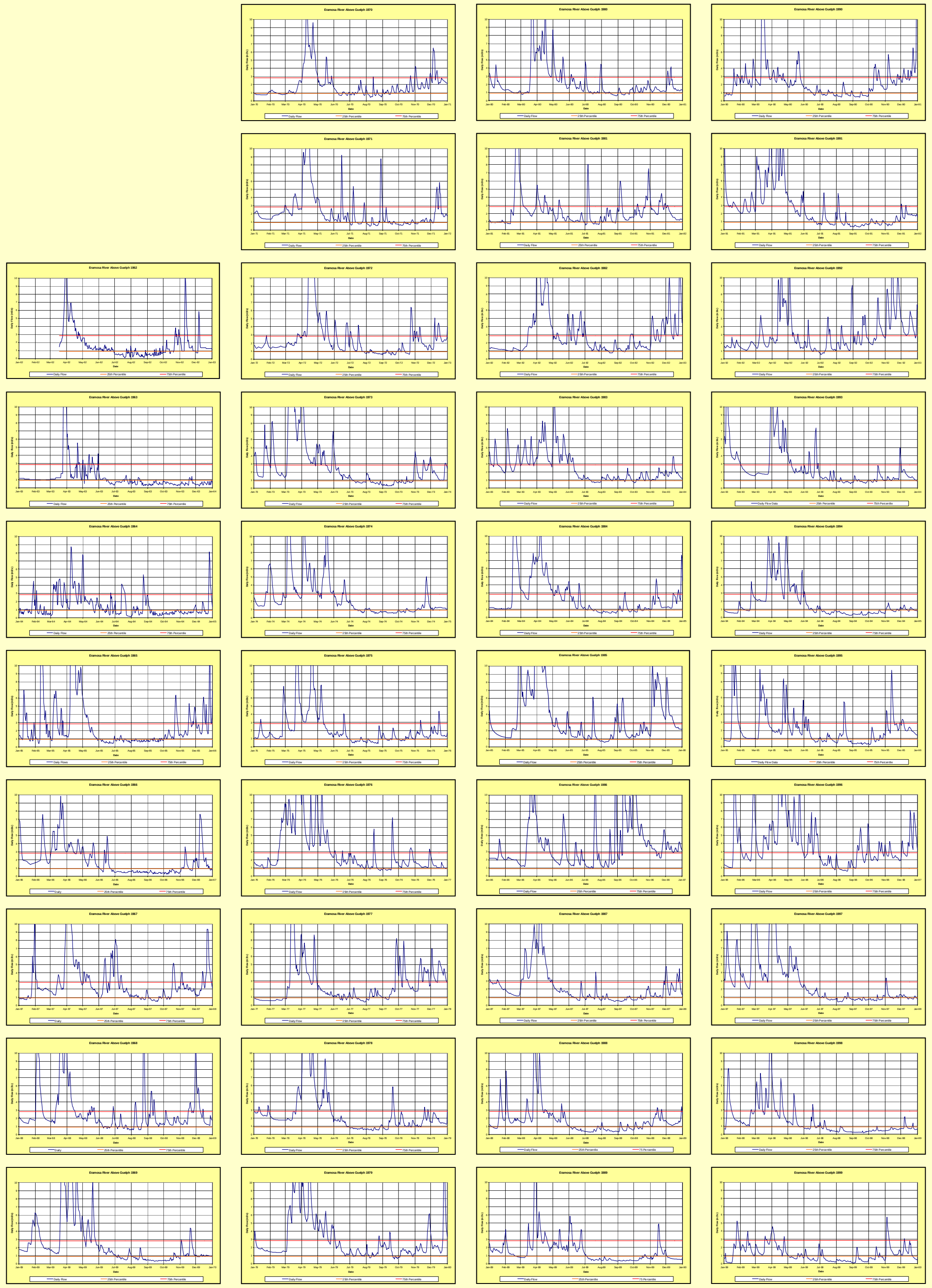



Note: Daily Flow Data Courtesy of Water Survey of Canada Through the Federal Provincial Cost Share Agreement

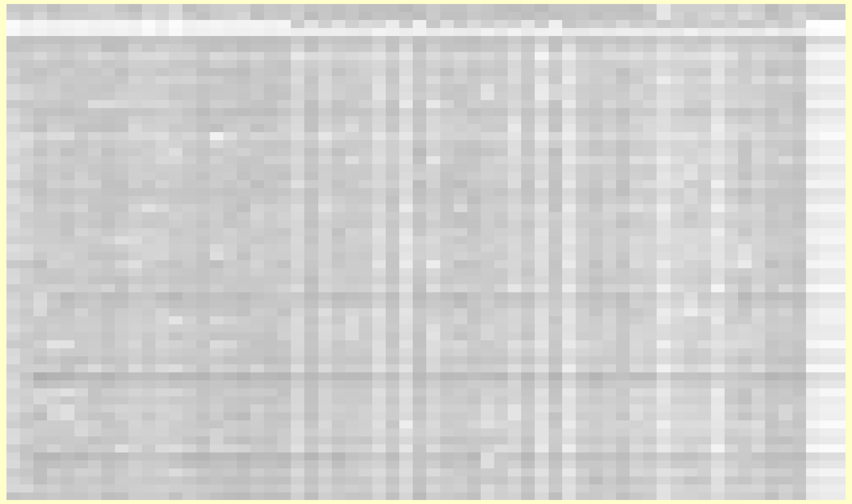
Figure A.#.2. Eramosa Study Reach Poster #2

Poster #3 Eramosa River Above Guelph Range of Variability Analysis and Hydraulic Analysis Results

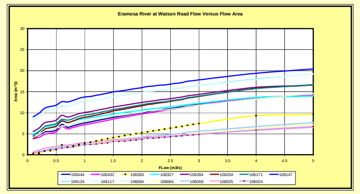
Flow Summaries 25th and 75th Percentiles 1962 to 2002



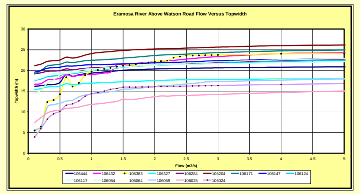
Rank of Variability Analysis Results



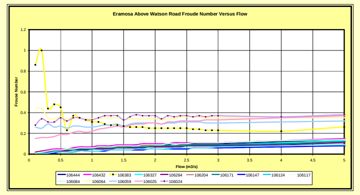
Results of Hydraulic Analysis



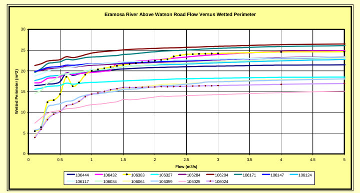
Eramosa River at Watson Road Flow Versus Flow Area



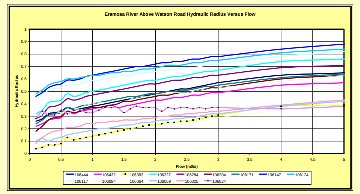
Eramosa River Above Watson Road Flow Versus Topwidth



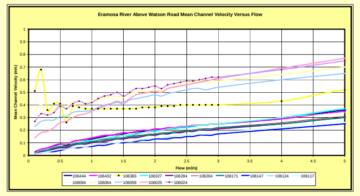
Eramosa Above Watson Road Froude Number Versus Flow



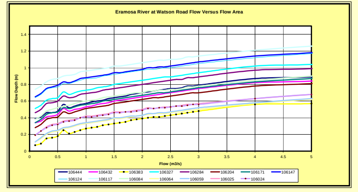
Eramosa River Above Watson Road Flow Versus Wetted Perimeter



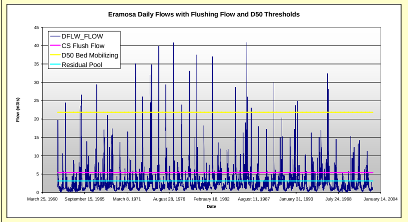
Eramosa River Above Watson Road Hydraulic Radius Versus Flow



Eramosa River Above Watson Road Mean Channel Velocity Versus Flow



Eramosa River at Watson Road Flow Versus Flow Area



Eramosa Daily Flows with Flushing Flow and D50 Thresholds

Flushing Flow - based on threshold to move coarse sand through the system without mobilizing coarser materials

D50 Bed Mobilizing Flow - based on the threshold to move the D50

Residual Pool Flow - based on the flow required to fill the residual pools (see graphs)

Note: Daily Flow Data Courtesy of Water Survey of Canada Through the Federal Provincial Cost Share Agreement

Figure A.#.3 Eramosa Study Reach Poster #3