GRAND RIVER WATERSHED
Water Management Plan

Grand River Watershed Water Management Plan

Environmental Flow Requirements in the Grand River Watershed

Report from the E-flows Working Group

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Acronyms and Abbreviations

7Q20	Seven day flow with a 20 year return period
AMP	Adaptive Management Plan
CO	Conservation Ontario
D_{50}	Median grain size
D_{90}	Grain size of 90th percentile, (90% of grain sizes are smaller)
e-flows	Environmental flow (needs)
EFR	Environmental flow requirements
GRCA	Grand River Conservation Authority
HEC-RAS	Hydrologic Engineering Centers River Analysis System (hydraulic modeling software)
LPRCA	Long Point Region Conservation Authority
m^3/s	Cubic metres per second (a flow rate)
MOECC	Ministry of the Environment and Climate Change
OLWRP	Ontario Low Water Response Program
OWDC	Ontario Water Director's Committee
PTTW	Permit to Take Water
Q_{MA}	Mean Annual Flow
Q_{MM}	Mean monthly flow
SPP	Source Protection Planning
WMP	Water Management Plan
WQSA	Water Quantity Stress Assessment
WSC	Water Survey of Canada

Executive Summary

Environmental flows, or e-flows, describe the quantity, quality and timing of flows required to sustain healthy river ecosystems, as well as the human livelihoods that rely on these ecosystems (Brisbane Declaration, 2007). The Grand River Water Management Plan Update strives to maintain healthy aquatic ecosystems as one of its objectives and the establishment of e-flows thresholds for an environmental flow regime to support this objective was the goal of this report.

The river we have today reflects past choices. More water for environmental conditions means there may be less water for people and this can create conflict. The intent over time is to find an acceptable balance. This is one of the challenges with establishing e-flows. It will always be a negotiation, which requires a cooperative effort to address these conflicts so that water management decisions can connect people to the actual decisions.

The GRCA owns and operates 29 dams in the watershed, including seven that manage river flows and 22 smaller run-of-the-river dams which together, help incorporate flood reduction and low flow augmentation into regular GRCA operations. Knowledge of e-flow needs helps inform operational decisions and where possible operational decisions are refined to compliment e-flow needs or preferences.

This report summarizes the findings of previous work to identify e-flow requirements in the Grand River watershed and the lessons learned from these studies. An Environmental Flows Working Group combined their efforts to establish a variety of high and low flow thresholds for a suite or flow regimes for maintaining healthy aquatic ecosystems in the Grand and Speed Rivers. The e-flows regime includes eight e-flows thresholds in three categories: channel maintenance and formation; nutrient management or biological functions; and low flow considerations. Once the criteria for these flow thresholds were established, flow values were established for each of them in four reaches in the Grand and Speed Rivers. This report details these flow thresholds, their historic occurrences and whether these occurrences have been sufficient to perform their e-flow functions. The tools and techniques highlighted can be applied in water management decisions by agencies and larger water users.

In addition, low flow thresholds on two important tributaries of the Grand – Whitemans Creek and the Eramosa River – were determined for the protection of longitudinal connectivity flows for coldwater fisheries. These case studies highlight areas where dam control is unavailable to help augment e-flows and water managers rely on the landscape and people to manage land use and water takings to meet e-flow thresholds. In general, the environmental low flow needs are less than the reservoir operational flow targets. There is challenge only during dry periods.

The higher environmental maintenance flow needs (e.g., flushing flows) are poorly to moderately met. Further investigation and field verification of the e-flows thresholds are recommended. There is a need for more monitoring of the biological aspects of the river system to help us determine whether we can achieve feasible ecosystem goals and targets. Research is needed to develop practical cost effective approaches to biological monitoring for a range of water courses from headwaters to larger rivers. This is an area where University researchers could assist by sourcing funding and completing research to develop cost effective practical approaches.

. In addition, the feasibility of operating the reservoirs to satisfy e-flow needs more consistently without sacrificing their reliability to meet low flow requirements or endangering recreational users or structures and inhabitants in the floodplain should be explored.

Information, knowledge and approaches in this report has been considered and where appropriate included in other technical reports related to the water management plan. Specific reports include the watershed management plan report, the Drought Contingency Plan and report analyzing flow reliability for regulated reaches in the Grand River watershed.

In some river reaches the river cross section has adjusted to the changed hydrology. In these reaches some elements of environment flows are not met and are not expected to be met in the future. For these types of reaches information contains in this and other documents can be used to design restoration projects aimed at improving ecological function. An example of an effective restoration project is Schneider Flats in the Kitchener area.

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1 Introduction

Environmental flows or 'e-flows', has developed into a field of research to describe "the quantity, quality and timing of water flows required to sustain freshwater ecosystems and the human livelihoods and well-being that depend on these ecosystems" (Brisbane Declaration, 2007).

The river we have today reflects past choices and environmental conditions. E-flow regimes should incorporate both high and low flows to mimic the natural variability of rivers, with the timing, duration and frequency taken into consideration for the flow to be effective. Having flow variability similar to the natural flow regime increases biodiversity and resilience in the system (King, 2002; Poff *et al.*, 1997). More water for environmental conditions means there may be mean less water for people and this can create conflict. The intent over time is to find an acceptable balance. This is one of the challenges with establishing e-flows. It will always be a negotiation, which requires a cooperative effort to address these conflicts so that water management decisions can connect people to the actual decisions.

In some river reaches the river cross section has adjusted to the changed hydrology. In these reaches some elements of environment flows are not met and are not expected to be met in the future. For these types of reaches information contains in this and other documents can be used to design restoration projects aimed at improving ecological function. This report discusses historic events that have led to altered hydrology in the Grand River system, describes the e-flows work that has been completed for the Grand River system, and characterizes some tributaries that experience seasonal low flows, and the e-flows needed during those times to maintain a healthy aquatic ecosystem. This report was completed for the update to the Grand River Water Management Plan and represents the collective knowledge of the E-Flows Working Group. The tools and techniques highlighted can also be applied in water management decisions, not just agencies but also larger water users. As such, it provides recommendations to Water Management Plan partners for further investigation and implementation.

1.1 Historic Events Leading to Altered Hydrology

The Grand River watershed, with a drainage area of 6800 square kilometres, is the largest in southern Ontario. Land use conversion to agricultural and urban uses during European settlement in the 1800's, resulted in extensive deforestation and the loss of over 65 % of the wetlands (Grand River Conservation Authority, 2003). As the land was altered, the ability for the landscape to naturally hold and release water diminished. The resultant higher, more intent flows caused more scour, erosion and slumping of natural channel shape. River flows became uncontrolled, flashy and caused widespread flooding during the spring, yet severe droughts occurred during the summer. The hydrology of the streams showed a greater variability than the natural regime – larger floods, longer droughts – as the landscape produced more runoff and less infiltration. The sediment regime was also altered by the changing land use. More sediment was delivered to streams and rivers, resulting in over-widening of the channel, sedimentation and entrenchment, with many river channels disconnected from their associated floodplains.

Run-of-the river dams, constructed for generating water power throughout the river system, obstructed fish migration, decreased flow rates, and increased water depths upstream, causing increases in water temperature, sediment loads and contaminant deposits. Furthermore, human and livestock waste were dumped into the river without treatment. By the 1930s, river conditions were so severe that floods, drought and pollution affected public health and economic development in watershed communities. Public concerns resulted in the formation of the Grand River Conservation Commission (GRCC) in 1932 to address water management issues in the watershed.

A report entitled Report on Grand River Drainage (Finlayson Report) (Finlayson, 1932) recommended the construction of the Shand Dam on the Grand River near Fergus. The Shand Dam, completed by the GRCC in 1942, was the first dam built in Canada for conservation purposes, incorporating flood reduction and low flow augmentation into its operations. It was the first attempt to partly simulate pre-settlement flows and mimic the natural flow regime by capturing spring floods and slowly releasing stored water over the summer period. The GRCC went on to build several large multi-purpose dams and reservoirs - adaptive measures to restore some of the lost storage on the landscape and to modify the flow regime back to a less altered, more natural state. Today GRCA owns and operates 29 dams in the watershed, including seven that manage river flows and 22 smaller run-of-the-river dams which together, help incorporate flood reduction and low flow augmentation into regular GRCA operations.

A timeline of the important occurrences for the consideration of the e-flow needs of the Grand River and tributaries, changes in land use, flow regulation and operating policies are provided in **Figure 1**.

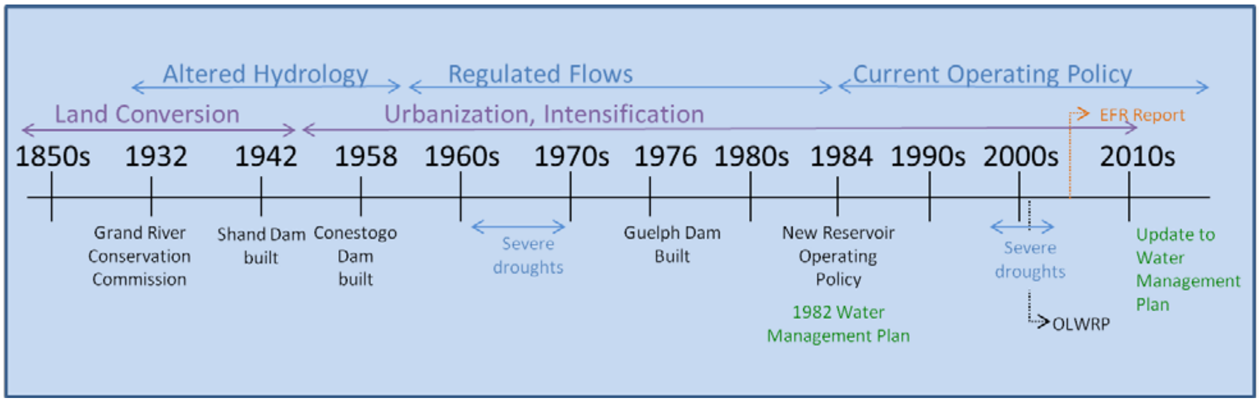

Figure 1. Chronology of Factors Affecting River Flows

Prior to construction of the large multi-purpose dams, the altered hydrology and sediment regime caused by land use conversion resulted in entrenchment and over widening of the river through some reaches, such as the Grand River near Blair reach. After construction of the dams and reservoirs, the downstream river channels readjusted to a more managed flow and sediment regime. Other reaches in the watershed have been considerably impacted by water takings. For instance, the flows in Whitemans Creek have been affected for decades by agricultural surface water takings to irrigate cash crops on the well-drained soils of that subwatershed. A challenge exists because of the finite amount of water available for irrigation, which is largely consumptive and has been increasing in the watershed. In contrast to agricultural water use, the consumptive portion of municipal water takings have been reduced through water efficiency and conservation efforts.

1.2 The Water Management Plan

The Grand River watershed has a tradition of collaborative, watershed-based, integrated water management spanning more than 75 years. The Grand River Conservation Authority (GRCA) and its predecessors, the GRCC and the Grand Valley Conservation Authority, in partnership with municipalities, federal and provincial agencies, First Nations, and non-government organizations (NGOs), have undertaken several major water management planning initiatives. The latest comprehensive water management plan, the Grand River Basin Water Management Study (Basin Study), was completed in 1982 and is now out-of-date. While many of the plan's 22 recommendations have been implemented over the past 30 years, mounting demographic and land use pressures and climate change effects demand new integrated management approaches and tools to address existing and emerging water issues in the Grand River system. These issues relate to water quality and the health of aquatic ecosystems, water supply and demand, and fluctuating river flows (e.g., flooding and droughts). This situation prompted the GRCA to reach out to federal, provincial and municipal agencies and First Nations to renew a collaborative process for water management in the Grand River watershed.

In 2009, a voluntary, multi-stakeholder, collaborative initiative to update the Grand River Watershed Water Management Plan (WMP) was launched. Plan partners signed a Project Charter, which outlined: 1) the purpose and goals, benefits, scope and deliverables, and timelines for the project, 2) described the governance structure and roles of the partners, and 3) emphasized that the resolution of water issues. They agreed that addressing water issues requires a collaborative approach that recognizes the complexity and inter-relatedness of hydrological and ecological processes and acknowledges that solutions to address the impacts of multiple inputs throughout the river system must be watershed based. Four main goals of the WMP were stated in the Project Charter, including:

1. Ensure sustainable water supplies for communities, economies and ecosystems;
2. Improve water quality to improve river health and reduce the river's impact on Lake Erie;
3. Reduce flood damage potential; and
4. Increase resiliency to deal with climate change.

The Water Management Plan (WMP) for the Grand River has twenty-three broad water objectives that reflect the human uses, ecological needs and societal values associated with water. One objective is "a flow regime that supports healthy river processes" in rivers where flows are regulated.

The GRCA currently maintains a watershed-wide monitoring system and operates seven multi-purpose water control structures to reduce flood damage and risk potential and to maintain summer flows for water supply and water quality. In addition to these primary-operating objectives, e-flow needs are considered and, where practical and where information is available, operations of these reservoirs are adapted to include consideration of e-flows. While dam and reservoir operations have helped to offset the impacts of land use conversion on the hydrology of the river system where flows are regulated, it is unlikely that channel form can ever return to a natural state. For example, floodplain inundation may not be achievable given the now-entrenched nature of the channel. However, improvements to the existing river conditions to improve ecological health are possible. Additional hydraulic analyses and scientific research about how management decisions affect flow patterns, species composition, and habitat is needed for identifying and designing effective measures to restore river habitats and flow regimes, as well as supporting a wider array of life cycle requirements for aquatic species. For instance, slight modifications to the operating procedures for the dams may improve e-flows in downstream reaches. This approach may be the most effective means of recapturing some of the lost channel and floodplain functions in the river system. However, until further data is acquired, the nature and extent of opportunities to restore river reaches and to what level is indefinite.

Run-of-the-river dams and remnants and other human-made structures built in the channel continue to affect sediment transport, nutrient cycling, thermal regimes and block fish passage (King, 2002). The Grand River Fisheries Management Plan provides guidance regarding existing run-of-the-river dams from a fishery management perspective (Ontario Ministry of Natural Resources and Forestry and the Grand River Conservation Authority 1998/2005). Some existing run-of-the-river dams are a benefit for fisheries management by limiting the movement of introduced species that may be detrimental to native species. Other run-of-the-river dams are a barrier to sediment movement and impede the river's ability to process nutrients; improvement to downstream aquatic health can be gained through decommissioning of these structures. An inventory of run-of-the-river in the Grand River watershed is needed to: 1) summarize the functions of existing dams, along with a qualitative assessment of their impacts from a sediment transport, nutrient processing and fisheries perspective, and 2) provide context and identify opportunities to improve or enhance the resiliency of the river to pass sediment, process nutrients and allow fish migration in the Grand River watershed.

Altering flow regimes and sedimentation processes to improve aquatic ecosystem health is not a straightforward endeavour. Water quality is also a significant factor affecting ecological health. Understanding the impact of water quality on aquatic health, where river ecology is constrained by water quality rather than by flows, and the interplay between flows and waters quality, is another important aspect of research, which is needed to improve e-flows.

The e-flows framework should be grounded in day-to-day decision-making. From a management perspective, other water management concerns must be considered and choices made when water management objectives diverge or when priorities are set. For instance, the use of water for agricultural irrigation may interfere with the flows required to support a healthy aquatic ecosystem. The Water Management Plan provides an opportunity for water managers to consider options, solutions and next steps in the context of the range of water uses, needs and values as articulated in the broad water objectives.

2 Background on E-flows Research in the Grand River Watershed

2.1 Previous Technical Studies

A list of the previous technical studies directly related to environmental flows is outlined below:

- Evaluation of Ecological Flow Requirements Assessment Techniques in Selected Reach of the Grand River (Grand River Conservation Authority, 2005)
- E-Flows for Blue Springs Creek: report for the City of Guelph Adaptive Management Plan (AMP) for the Arkell Spring Grounds
- Reports on environmental flows for Source Protection Planning (SPP) Tier 3 Water Budgets for the Region of Waterloo
- Reports on environmental flows for Source Protection Planning Tier 3 Water Budgets for the City of Guelph
- Whitemans Creek Level 3 Ontario Low Water Response Program (OLWRP) Pilot 2007
- Level 3 recommendations reports for Ontario Water Director's Committee 2012 for Whitemans Creek and Eramosa River subwatersheds

These studies are summarized below and sources are provided as reference for more detailed information.

2.2 Assessment of Ecological Flow Requirements Techniques: 2005 Study

2.2.1 Introduction

The Grand River Conservation Authority (GRCA) participated in a study commissioned by Conservation Ontario (CO) for the Ontario Ministry of the Environment and Climate Change (MOECC) on ecological flow requirements (EFR), completed in 2005. The study assessed currently available EFR techniques on eight reaches in the Grand River watershed (Figure 2). This was the first e-flows study in the watershed to cover a wide variety of techniques for assessment. It generated a wealth of hydrological, geomorphic, hydraulic and biological information. This report created a framework, illustrating how flow, hydraulic, geomorphic and biotic life cycle requirements could be arranged to analyze characteristics of a river reach and quantify specific e-flow thresholds for consideration.

The project was a collaborative effort among Trout Unlimited Canada, Parish Geomorphic Ltd, academics, and the GRCA. A synthesis report with the other studies (in Long Point Region and Cataraqui Region Conservation Authorities) was also completed by a consultant on behalf of Conservation Ontario (CO), to give a summary of the recommendations and key findings (Conservation Ontario, 2006).

The following sections provide a summary of the investigations completed for the GRCA report.

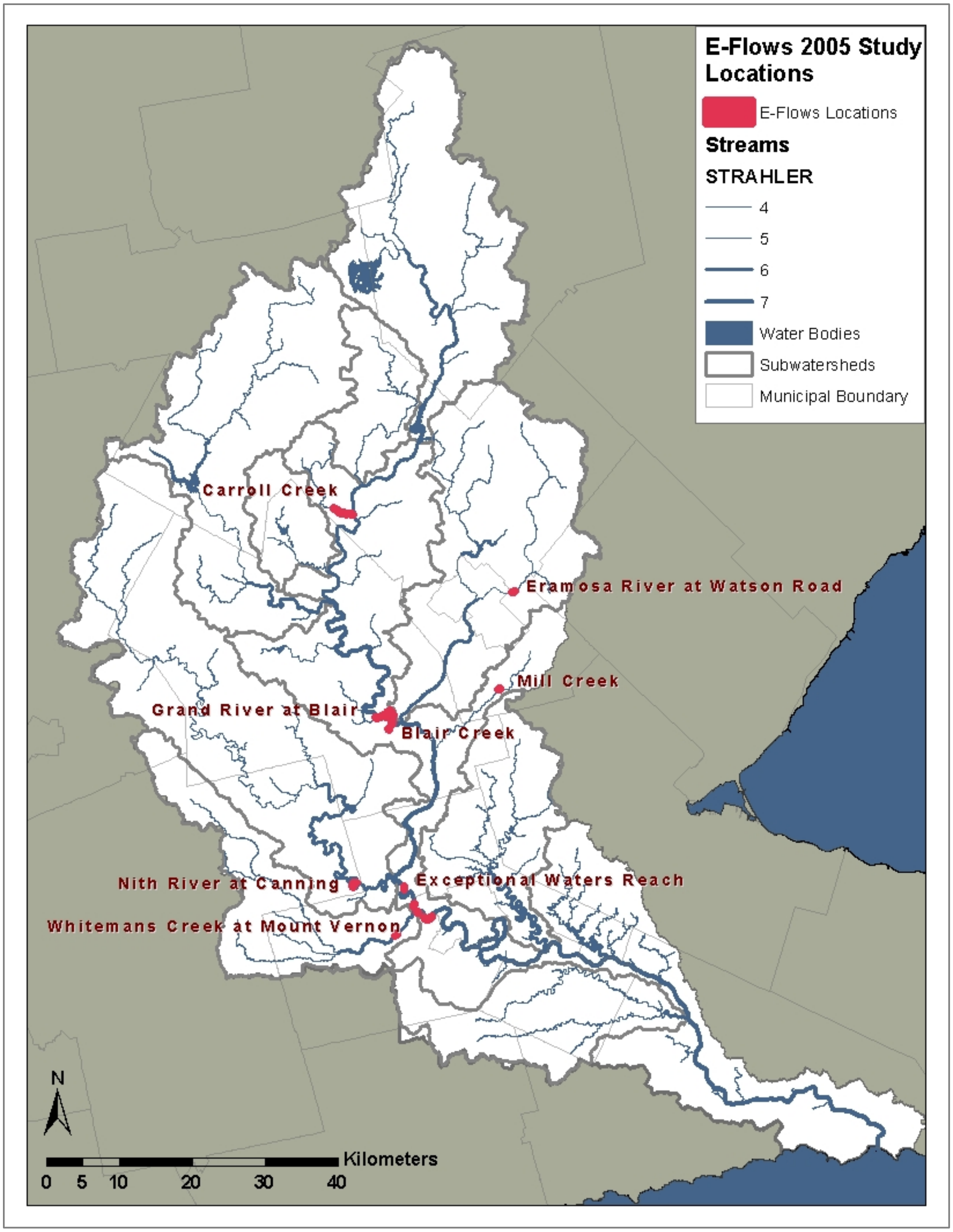

Figure 2. Location of pilot reaches for the 2005 EFR study

2.2.2 Geomorphic Field Investigation and Analysis

Geomorphic field investigations were completed based on protocols outlined in a report by Parish Geomorphic Ltd. (Parish Geomorphic Ltd., 2005a). The geomorphic investigations estimated geomorphic thresholds needed to support stream processes. These thresholds were related to stream flow for further flow and hydraulic analysis and for comparative purposes. These thresholds were developed to help understand what flows are required to maintain geomorphic and sediment transport processes that would help support healthy ecological processes.

The eight study sites selected were located along a stretch of reach near flow gauge stations. These sites included: large river sites on the Grand River at Blair, the Exceptional Waters reach, and the Nith River at Canning, an intermediate sized site on the Eramosa River at Watson Road, and small study sites on Blair Creek, Whitemans Creek, Mill Creek and Carroll Creek (Figure 2). Reach lengths were at least 20 bankfull channel widths to capture dominant channel characteristics. The field survey included 10 hydraulic cross sections spaced along the study reach, selected to capture hydraulic controlling features along the reach such as riffles and runs, as well as the diversity of the bed configurations at the site. Riffle crests, when not perpendicular to the channel banks, were surveyed along the top of the crest to better capture the hydraulic control.

A longitudinal profile was measured along the reach - along the thalweg of the channel - to capture the channel invert using an automatic level and stadia rod, capturing both the channel planform (channel gradient) and water surface profile. Points were surveyed to capture main breaks in the slope and the deepest point in the pools, with a focus on the hydraulic controls. This longitudinal profile was later used to verify the hydraulic modeling and to estimate connectivity flow thresholds from a geomorphic perspective. The long profile is very insightful to illustrate how a study reach is functioning hydraulically.

Substrate information collected included pebble counts, degree of embeddedness, hydraulic roughness and subpavement composition. Pebble counts were completed, and field observations were taken of substrate material, using a modified Wolman sampling technique at each cross section. This information was later used in the analysis that generated selected geomorphic thresholds such as flushing and bed mobilizing flows.

Width-to-depth ratios for each cross section were calculated, as the calculation allows for confirmation or refinement of field estimates. In addition, analysis of the minimum ratio gives an indication of bankfull or channel forming stage, and plotting the ratio to find inflection points in the curve can identify the thalweg, or low flow channel, if present.

The geomorphic information was further analyzed when incorporated into a hydraulic model. Hydraulic modeling of reaches allows a more thorough analysis of hydraulic inflection points and thresholds such as bankfull flows (detailed in further sections).

Geomorphic analysis was completed using the hydraulic and pebble count information to develop thresholds including bankfull flow, bed mobilizing flow, flushing flows and residual pool flows.

2.2.3 Geomorphic Thresholds

One of the primary geomorphic thresholds initially calculated was bankfull stage, which was used to determine when out-of-channel flooding begins to occur. Bankfull flow stage can be defined as the point at which the flow resistance reaches a minimum, which in turn allows the channel to operate at highest efficiency for transporting flow and sediment (see Figure 3). Bankfull stage can be calculated by determining the minimum width-to-depth ratio, or through other field indications such as change in slope, bank vegetation and other bankfull characteristics. Hydraulic modelling provides the best estimate of bankfull flow thresholds.

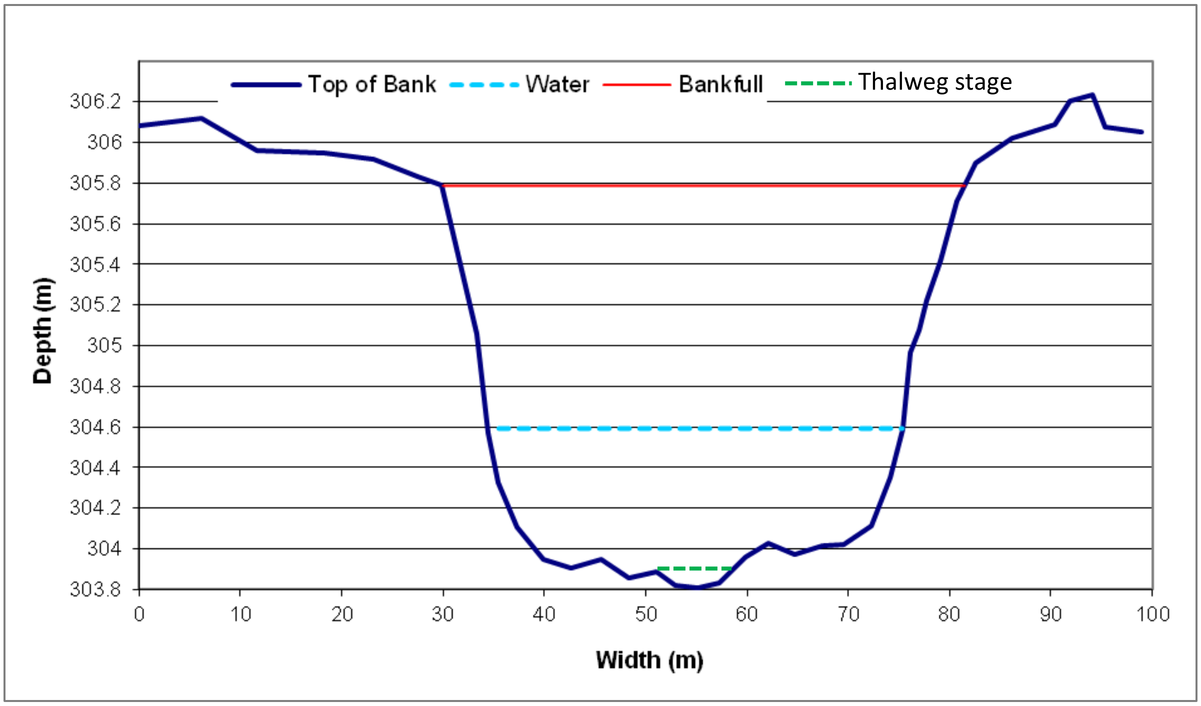

Figure 3. Example cross section showing bankfull and thalweg stage

The bed mobilizing flow is the flow threshold that moves the median grain size (D_{50}) bed material. This flow was analyzed to determine flow requirements for promoting the resorting and redistribution of bed material, which becomes a surrogate for estimating turnover and refreshing of aquatic habitat. The bed mobilizing flow also helps to restore assimilative capacity of the reach to improve water quality for the next low flow season.

The flushing flow is the flow threshold that allows for re-entrainment of finer sediments, which become embedded in the coarser sediment matrix of riffles. This flow requires sufficient energy to re-entrain these sediments. The removal of fine sediments reduces embeddedness, which can cause impairment to aquatic habitat and spawning areas.

The residual pool flow threshold was estimated to determine the low flow at which pools become disconnected from one another as flow drops below the riffle crests. Low flow values for residual pool flows were determined based on the geomorphology of the river and subsequent hydraulic inflection point analysis, as described in a 1999 report(Prairie Provinces Water Board, 1999). By plotting width-to-depth ratios versus flow, hydraulic inflection points (changes in slope or curvature of the line) show abrupt changes in the width-to-depth ratio as the flow decreases, meaning much less hydraulic habitat is available with a small change in flow.

Geomorphic fieldwork was completed by Parish Geomorphic Ltd, who provided reports on field collection and analysis for each study site. A supporting report was also provided to the GRCA regarding protocols for geomorphic field evaluations of these four ecological flow thresholds (Parish Geomorphic Ltd., 2004; Parish Geomorphic Ltd., 2005a; Parish Geomorphic Ltd., 2005b; Parish Geomorphic Ltd., 2005c).

2.2.4 Flow Analysis

Data from the Water Survey of Canada daily stream flow archive were used to complete a flow analysis. Study sites were selected to correspond to locations where long term gauge records existed. The flow analysis produced several tables and charts to analyze and characterize the historic flow regime. A list of information was compiled to support interpretation of flow information, along with hydraulic, geomorphic and empirical environmental flow approaches. In all, 15 figures and tables were compiled to present flow information (**Table 1**).

Table 1. Flow analysis completed in the 2005 e-flows study

Table or Figure	Description
1. Mean Monthly Flow Table	Provides supporting information for empirical methods and summarizes low flow events
2. 7-Day low flows summary table (also 15-day and 30-day)	Summarizes 7-day flows monthly, annually and seasonally, along with occurrence of annual minimum by season
3. Annual 7-Day low flows	For the 2, 5, 10, 20, 50 and 100 year return periods for comparison with typical designs, such as 7Q20 for assimilative capacity purposes
4. 7, 15, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330 and 360 day running low flows (charts and tables)	Used to assess the persistence of low flows Used to identify short duration and longer duration droughts and wetter periods in the gauge history
5. Ranked running low flow	Used to assess duration or persistence of running flows to characterize the flow regime
6. Chart of daily flow percentiles by day of year for the period of record	Used to illustrate variability of flows over the year, used to characterize the flow regime, from a timing and duration of flow perspective
7. Flow duration curve for period of record by month and composite for the period of record	Used to characterize the persistence of flow by month, used for later comparison with other information and methods
8. Annual instantaneous flows	Used to assess the frequency and magnitude of out of bank flow threshold
9. Annual maximum annual daily mean flows	Used to assess the frequency and magnitude of out of bank flow threshold
10. Daily flows compared with out of bank flow threshold	Used to assess the frequency and magnitude of the out of bank flow threshold
11. Flood frequency flow statistics for the 2,5,10,20,50,100,200 and 500 return period flows	Used to assess the frequency of flood and frequency of out of bank flows
12. Baseflows (June through September) and annual	Calculated using a program called BFLOW, a baseflow separation technique. Separates out baseflow from streamflow using a 3-phase filter over streamflow records. A description of the baseflow separation technique is described (Bellamy, 2003).

2.2.5 Empirical Thresholds

The 2005 study looked at several simple empirical thresholds that had been developed and were available at that time. These included the Tennant Method, the Tessmann method, and the modified

Tennant Method. These empirical thresholds were simple existing techniques available at the time, and were typically used to complete desktop historical flow-based analysis. However, these methods are not suitable for use in the Grand River watershed, as the thresholds were developed in Montana for mountain stream ecology and not transferable to the Grand River watershed. Statistics from these methods were calculated for comparative purposes.

The Tennant method (Tennant, 1976) is a streamflow-based, desktop method used to estimate environmental flow requirements. It assumes aquatic habitat conditions are similar for streams carrying the same proportion of mean annual flow. Environmental 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 2** 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 2. Habitat conditions for the Tennant instream flow method

*Aquatic-Habitat Condition for Small Streams	Percentage of Q_{MA}, Apr – Sep %	Percentage of Q_{MA}, Oct – Mar %
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 3**, from the Prairie Provinces Water Board 1999 Study, summarizes the criteria for application of the Tessmann method.

Table 3.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 described above assumes a Tennant April to September good condition and an October to March outstanding condition. For the 2005 study, the Tessmann method was further modified by using the Tennant criteria for other conditions to produce optimum, outstanding, excellent, good, fair, poor and degraded conditions.

2.2.6 Ontario Low Water Response Thresholds

The OLWRP flow levels are a 3-tiered 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 normals. The reason for calculating the low water response thresholds (**Table 4**) was to assess how the low water response criteria compared against the environmental flow needs calculated by various other methods.

Table 4. Summary of OLWRP levels and thresholds

Condition	Indicator	
	Precipitation (3- or 18-month)	Streamflows
Level 1	<80% of average	**Spring:** – monthly flow < 100% of lowest average summer month flow **Other times:** – monthly flow < **70%** of lowest average summer month flow
Level 2	<60% of average 2 consecutive weeks with < 7.6mm of rain/week	**Spring:**– monthly flow < 70% of lowest average summer month flow **Other times:** – monthly flow < **50%** of lowest average summer month flow
Level 3	<40% of average	**Spring:**– monthly flow < 50% of lowest average summer month flow **Other times:** – monthly flow < **30%** of lowest average summer month flow

The daily average or median flows are summarized using a 7-day running average, which is compared to the level thresholds to better represent the overall trend of low flows.

2.2.7 Hydraulic Modeling

Hydraulic modeling was completed using the cross sections from the geomorphic surveys. Table 5 shows the eight hydraulic parameters that were calculated for interpretation and analysis.

Table 5. Hydraulic analysis completed for the 2005 e-flows study

Analysis	Description
1. Flow versus Depth - Maximum water depth	Used to assess depth for fish passage and connectivity of pools.
2. Flow versus area - Wetted cross sectional area	Used to identify when large changes in cross sectional area occurred which cause more confinement of aquatic life in the stream or river.
3. Flow versus wetted perimeter - Cross-sectional bottom in contact with the water	Used to identify when large changes in the wetted areas of the stream or riverbed changed, indicating changes in available habitat.
4. Flow vs. top width - Span across	Used to define when the stream became much narrower, again

Analysis	Description
the cross section water surface	inferring changes in habitat.
5. Flow vs. Hydraulic Radius (not available for all reaches)	The **hydraulic radius** is a measure of a channel flow efficiency. Inflections in hydraulic radius help identify transition to floodplain or thalweg flow conditions.
6. Flow vs. Froude Number	Describes open channel flow condition turbulent or non-turbulent flow. Used to define when the stream flow condition changed from non-turbulent conditions to a faster flowing turbulent condition.
7. Flow vs. Channel Velocity Average cross sectional velocity	Used to confirm geomorphic thresholds and to assess fish passage from a velocity perspective.
8. Flow vs. Width-to-Depth Ratio Channel width by maximum depth	Used to infer when large changes in cross width and depth were occurring. The combination of these parameters was useful to infer large changes in hydraulic condition and habitat.

A range of flows were simulated with hydraulic modeling to produce flow relationships for each parameter, and charts were created to illustrate these relationships. The charts were interpreted and inspected for inflection points in the flow versus hydraulic parameter relationship. Inflection points were interpreted to identify key flow thresholds that resulted in changes to hydraulic parameters. For example, a large change in wetted perimeter versus top width inferred a flow where the water flow became more confined to the low flow portion (thalweg) of the stream cross section. This could infer the flow at which the shallow fringes of the stream start to dry up. Loss of this habitat can affect the ecology of the stream.

Inflection points for the various hydraulic parameters in each reach were noted for comparison against other thresholds. This hydraulic information was also used by biologists and geomorphologists to better relate flow to biological and geomorphic thresholds. Further details on the hydraulic modeling results are given in GRCA (2005, Appendix D).

The Indicators of Hydrologic Alteration (IHA) software (Richter *et al.*, 1996) was applied in the 2005 study. This software is a useful diagnostic tool that analyzes daily flow time series data. In all, 33 hydrologic parameters were analyzed to provide insights into changes in magnitude, duration, frequency, timing and rate of change of flow parameters. The software also allows users to assess the flow regime using the Range of Variability Approach (RVA) - software that is capable of analyzing both altered (regulated) and unaltered (natural) time series to summarize changes in the flow regime. RVA software is very effective at illustrating the influence of flow regulation in the regulated reaches of the river. Examples of the range of flow statistics, hydraulic thresholds and empirical indices can be found in Appendix B for unregulated streams.

2.2.8 Ecological Considerations

Biological monitoring data is limited within the Grand River watershed, thus surrogate methods were used to estimate the impacts to the aquatic ecology. One approach was to estimate the ability for fish to migrate up and down the channel, using water depth as the variable. When flow depths drop, riffle crests (high points in the bed of the river) are the first to be exposed. When the flow depth starts to restrict fish migration, the *longitudinal connectivity* is lost. The critical flow depth to limit longitudinal connectivity and start to isolate adult trout fish, is 0.20m (Imhof, 2004). Limited mobility increases stress to the fish as they cannot cross riffle crests to migrate up and down the Creek, or find refuge and food. Stress also induces crowding, which is not normal behaviour for these territorial species (Halyk, 2012). Crowding increases predation of larger fish on smaller fish, as habitat and thermal refuge areas become scarce.

The estimate of longitudinal connectivity converts a flow depth of 20cm over riffle crests into a flow rate. Water depth was collected during hydraulic surveys of riffle crests, which were used to calibrate the hydraulic model (HEC-RAS). Then flow rates were tested to compute a water surface elevation of 20cm depth from hydraulic modeling. In some areas, these were verified in-situ.

2.2.8.1 Life Cycle Requirements for Warm and Cold water Fishery

Another approach was to infer the hydrological needs of certain fish species based on their life cycle preferences. These preferences are based on the age of the fish (life stage) and their known habits during that particular life stage (e.g. migration and spawning). This was a qualitative assessment as detailed data is not available. The following excerpt describes the rationale and the preference charts produced.

Excerpt from GRCA (2005):

> On an annual basis, the characteristics of the flow regime will act as a qualifier of habitat availability and suitability within the channel. 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. Life state variables are also used: overwinter refuge; feeding; and migration. When considering the connections between habitat and biotic use, four factors 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. |
>
> 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 4a), including brook trout and brown trout; and warmwater fish species (Figure 4b), 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.

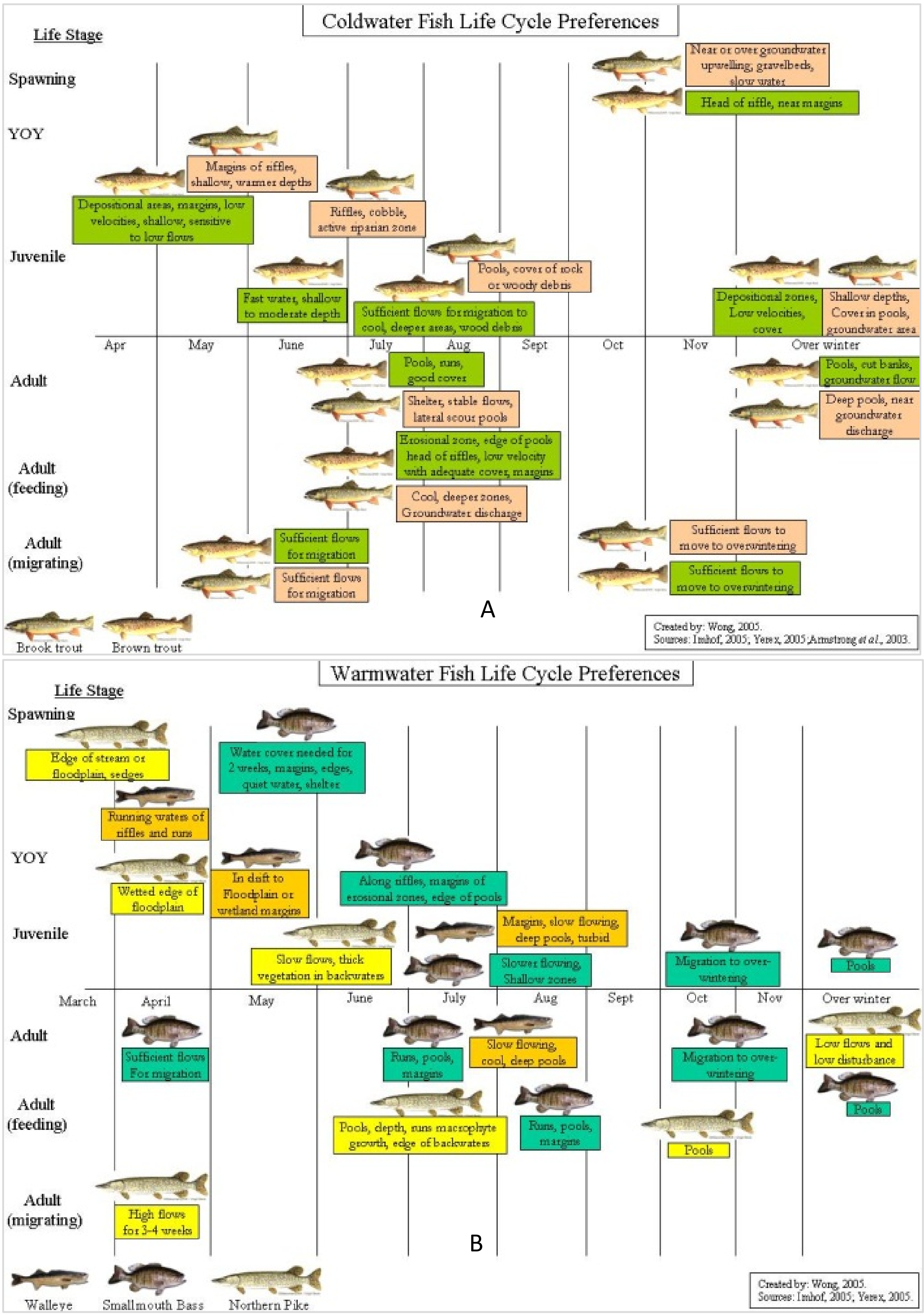

Figure 4. Life cycle preferences of (a) coldwater and (b) warmwater fish species

2.2.9 Summary of 2005 EFR Study

The study was a comprehensive assessment of various techniques readily available in 2005. It was the first study of e-flows in the watershed and produced a wealth of knowledge on the ecological needs of the selected reaches. The report produced a number of recommendations and suggestions for future work, which are described in Section 3.1.

2.3 Speed River Study for Water Quality and Waste Assimilation

Geomorphic flow thresholds were estimated for the Speed River below Guelph in a 2007 study completed by Parish Geomorphic Ltd. This study was completed to compliment the reservoir yield analysis as part of the City of Guelph's Water Supply Master Plan. The field survey followed the approaches developed in the 2005 GRCA study. The long profile identified two distinct reach characteristics along the Speed River corridor, classified as backwater or recovery reaches. Geomorphic flow thresholds were estimated for both recovery and backwater reaches.

Classifying reaches along the long length of river (using the long profile information) was an effective means for understanding how certain reaches function to process nutrients or move sediments. One of the biggest challenges facing many watercourses in the Grand River, including the Speed River, is an overabundance of nutrients. Classifying reaches over a long distance of river, as was done on the lower Speed River, allows water managers to identifying barriers and opportunities for increased nutrient processing. For instance, backwater reaches are areas where barriers to waste assimilation exist. Recovery reaches, described as reaches with groundwater discharge or high slope, are better able to assimilate wastes due to these characteristics. Reach classification compliments the Grand River Simulation Model by allowing the model to better represent the physical characteristics influencing river water quality through model refinement. The classification also increases confidence in modeling results for assessing restoration, which affect the river's ability to move sediment and process nutrients.

The Speed River long profile has been completed from Edinburgh Road 32 to Niska Road down to the mouth at the Grand River (**Figure 5**).

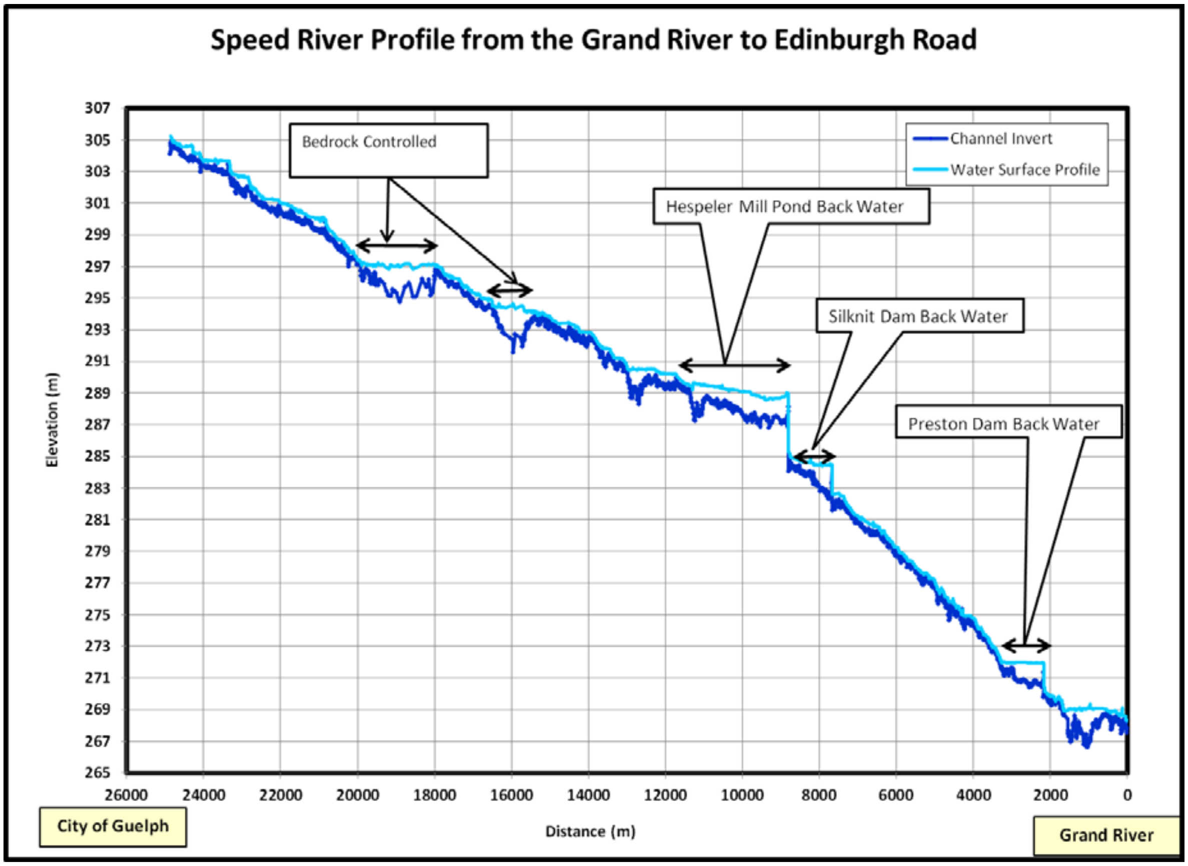

Figure 5. Speed River Profile Road 32from the Grand River to Edinburgh Road

The long profile helps identify riffle (recovery) and backwater reaches which are illustrated in **Figure 6** for the reach from Niska Road down to Road 32. Backwater reaches may be the result of run-of-the-river dams or natural backwater reaches due to bedrock control; a natural backwater reach is what exists downstream of Guelph Dam. Backwater reaches may limit the river's ability to process nutrients, which may impair water quality. Long profile charts such as **Figure 5** provide useful information upon which to build a conceptual understanding of how the river is functioning and where barriers and opportunities may exist to improve the resiliency of a given reach of river.

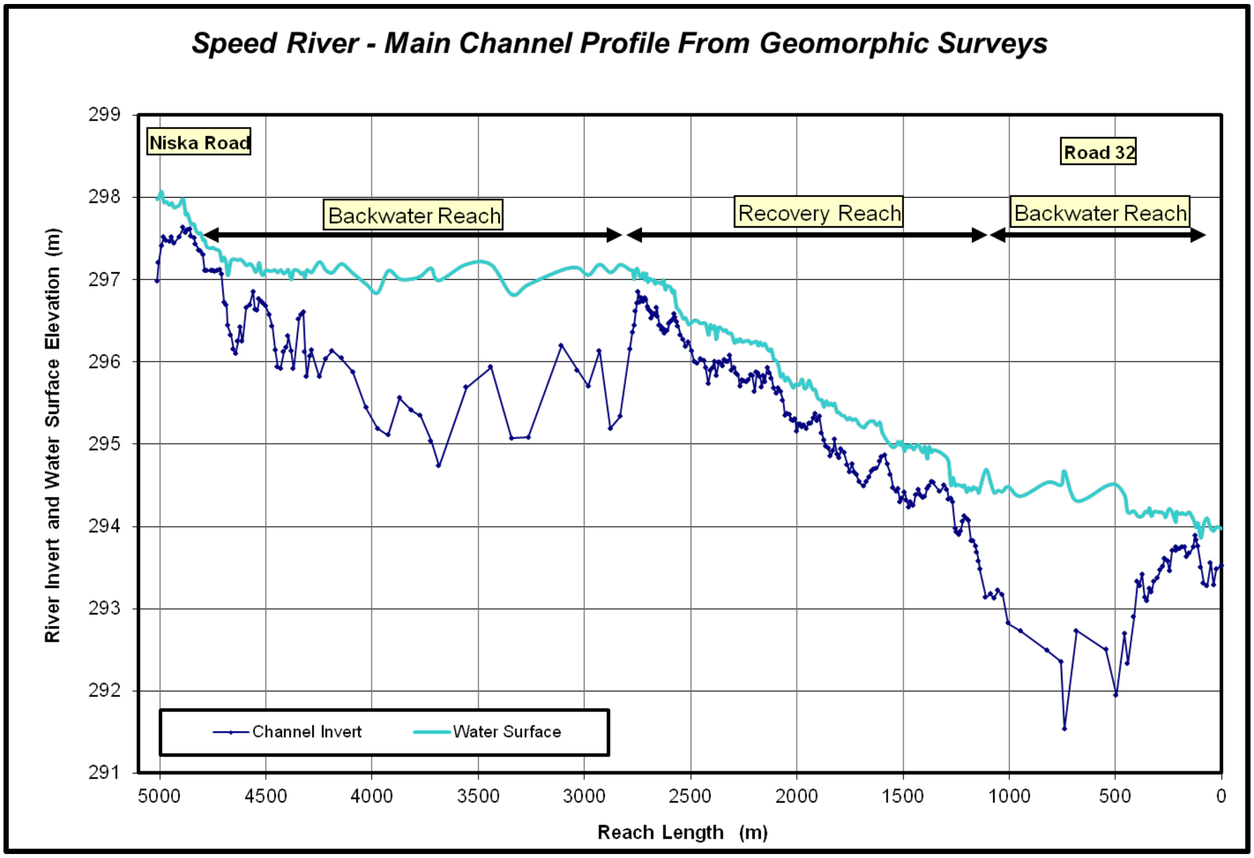

Figure 6. Speed River profile from Niska Road down to Wellington Road 32

2.4 E-Flows for Low Water Response, 2007, 2012

E-flows were studied again several years later under the umbrella of the Ontario Low Water Response Plan (OLWRP), to try to incorporate ecological considerations into the 3-tiered levels. These studies focused on two areas of concern for low water conditions on tributaries of the Grand River, Whitemans Creek and the Eramosa River.

Whitemans Creek has often been used as a test case to determine whether the OLWRP thresholds are suitable for protecting the ecology. In 2007, the subwatershed was studied in a pilot project for assessing a Level 3 declaration, which included having e-flows thresholds revisited. Data was summarized on the three streamflow thresholds, showing that a Level 2 occurs once every 3 years in the Whitemans Creek area. From an ecological perspective, the longitudinal connectivity is below the 20cm threshold at this point, but no further analysis was completed on e-flows needs.

In 2012, another drought year was experienced across the watershed and the Ontario Water Director's Committee (OWDC) requested an update to recommendations for declaring a Level 3 in areas experiencing Level 3 conditions. The report included addressing the ecological needs of Whitemans Creek and the Eramosa River, with field reconnaissance to verify the longitudinal connectivity thresholds and the ecological response to drought conditions in-situ. Field reconnaissance was completed by staff at the MNR to look at the behaviours of the trout in Whitemans Creek. In addition, measurements of water depth were taken at certain riffle crests to determine whether the modeled results coincided with actual water levels seen in the Creek.

The information is summarized further in this document for assessing the low flow e-flow threshold for Whitemans Creek (Section 6.1). The e-flows recommendations from this report were to ensure a longitudinal connectivity flow be maintained to support coldwater fish preferences.

Both the Whitemans Creek and Eramosa River reports aid the establishment of low e-flow thresholds for incorporation into the 2009 update to Grand River Water Management Plan. The Eramosa River information is summarized in Section 6.2.

2.5 E-Flows for Source Water Protection Planning, 2009-11

Drinking water Source Protection Planning (SPP) under the *Clean Water Act, 2006* required water budgeting for surface and groundwater resources. The water budgets accounted for a 'reserve estimate' for surface water resources to be considered for ecological needs. E-flows studies were completed on several creeks and rivers to determine this reserve estimate (**Figure 7**).

- Tier 3 Sites included:
    - Alder Creek (Wong, 2009b), Strasburg Creek (Wong, 2009a), Laurel Creek (geomorphic report only) in RMOW
    - Blue Springs Creek (Wong, 2007) and Lutteral Creek (Parish Geomorphic Ltd., 2009) for the City of Guelph (**Figure 7**)
- Other sites for SPP included:
    - McKenzie Creek (Parish Geomorphic Ltd., 2007)
    - Grand at Glen Morris

The technical analysis followed a similar process as the 2005 Study for geomorphic and flow data. In addition, water use information and subwatershed characterization, such as future development and ecological considerations, were detailed. Reports were supplemented with information extracted from subwatershed studies reports where available. A suite of flow thresholds were calculated for the study areas to give a broad range of information on e-flow needs.

The recommendations and conclusions of the analysis include ways to sustain e-flow needs in the subwatersheds to utilize as the 'reserve estimate', especially as future development or other pressures may affect the subwatershed and creek system. For instance, in Alder Creek, maintaining baseflows to the creek are an important connection that needs to be maintained to support the ecological habitat for aquatic species.

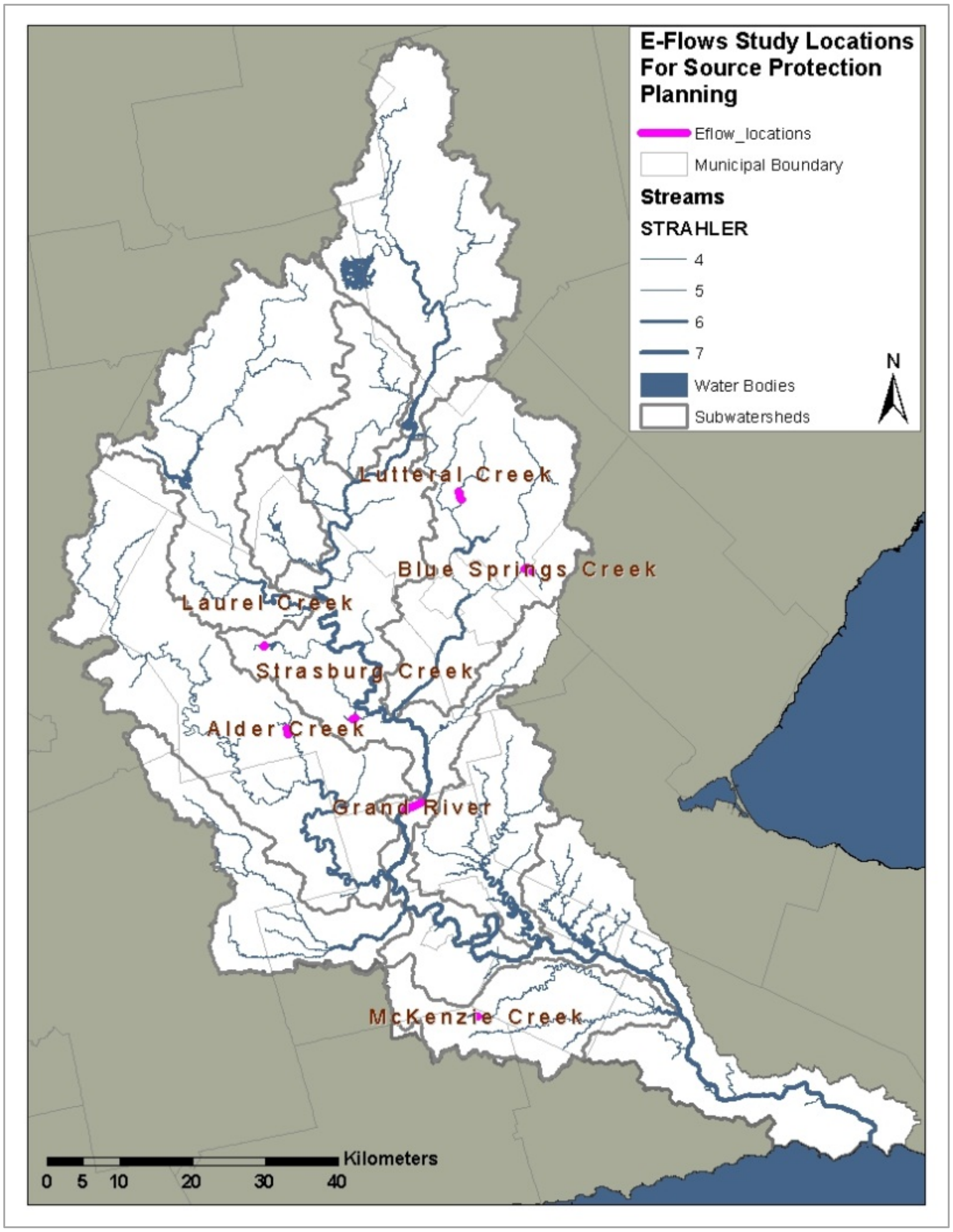

Figure 7. Location of e-flows studies completed for Source Protection Planning Tier 3 Water Budgets

2.6 Literature Review on E-flows Frameworks, 2012

A literature review of the current state of practice for e-flows studies was completed in 2012 (Wong, 2012a). The focus of current e-flows studies is to have a framework for a suite of methods to understand the natural flow regime and the needs of the native aquatic ecology.

The review looked at 10 recent frameworks developed for e-flows research (i.e., most were published since 2010). Five main common themes were found amongst the frameworks that included common elements to study, advice to gather from experts, stepwise tasks and a suite of technical options to consider (Wong, 2012a).

All frameworks suggest a hierarchal approach to achieve a thorough assessment of the e-flows needs. The approach should 1) have an explicit or implicit step-wise methodology to complete a suite of tasks to do scientific assessments, 2) discuss implications of the science-based thresholds, and 3) set appropriate actions for implementation. The framework should also be holistic, to encompass several aspects of the lotic flowing water ecosystems, including several aquatic ecosystem species, humans and the natural variability of flows. A single indicator species and a single flow threshold will not be sufficient to understand and protect the e-flows of a system.

Collaboration was highly recommended, gathering a suite of experts in the fields of hydrology, hydraulics, geomorphology, stream ecology and biology and water managers, to explain the freshwater ecosystem dynamics and to arrive at consensus on how to protect the system. Inter-disciplinary research is becoming more popular, including the study of eco-hydrology to better study the flow-biota relationships. Where available, incorporating this type of research into e-flows studies is suggested.

Finally, the scale to which the study of e-flows is completed should be regional, or watershed wide, to encompass whole-system approaches that affect the entire basin. Reach-scale studies are unable to capture the complexities of upstream and downstream effects. To help scope the project, it was suggested by several publications that river classifications by geomorphic variables or thermal regimes or fish assemblages may be helpful.

These suggestions and frameworks were developed to help implement e-flows regimes in jurisdictions that need guidance. They are helpful in providing incremental steps towards successfully developing e-flows recommendations from science through to implementation.

3 Summary of Lessons Learned from Previous Studies

3.1 2005 Study

- A single threshold is not sufficient to characterize the e-flow needs of a reach; a suite of approaches is necessary, including hydrologic, hydraulic, geomorphic and biotic analysis.
- There are numerous e-flow techniques existing in the literature. The quality of the study is dependent on the careful selection of approaches and models to suit the watershed conditions, issues, and data available.
- Empirical methods (i.e. Tennant, Tessmann) are not suitable for Ontario and the Grand River because the landform (mountainous vs. glaciofluvial plains) and fish assemblages are not comparable. Further research is needed to adapt these methods to Ontario conditions.
- Characterization of each reach produced a wealth of knowledge towards understanding the existing conditions of the river.
- Geomorphic analysis, coupled with hydraulic modelling of a reach, provided the ability to develop defensible geomorphic and hydraulic thresholds. Calibrating and verifying the hydraulic modelling to the water profile, which was collected as part of the geomorphic field data collection, improves the confidence and reliability of the hydraulic modeling results. The geomorphic thresholds provide good insight into healthy sediment transport processes. Careful inspection of the hydraulic modeling results allows hydraulic inflection points to be identified and related to flows. These hydraulic inflection points help identify where specific habitat has been affected, for example when the flow becomes confined to the thalweg and thus the fringes of a stream have dried up.
- Geomorphic and hydraulic analysis (i.e. longitudinal connectivity flow) specific to that reach are considered to be most useful in giving field-verified assessment of ecologically-based thresholds.
- The relationships of ecological integrity with flow, sediment and water quality are very complex. Qualitative approaches for understanding aquatic ecosystem needs can be used as a simple substitute in place of complex habitat modeling, while better data becomes available. Documenting the life cycle preferences for indicator species in a given reach provides useful information to water managers and reservoir operators of ecological considerations at different times of the year. The level of information in the qualitative assessments may be sufficient for many decisions. Further documentation of life cycle preferences for a range of other indicator species would help inform researchers in developing more quantitative means of relating the ecology to the flow, sediment and water quality regimes.
- Geomorphic field protocols were developed to document the field data collection methods needed to collect cross sections and profiles to compliment the construction and calibration of hydraulic models. The protocols included better representation of low flow hydraulics, by collecting cross section information along control points (i.e. riffle crests) that resulted in more reliable hydraulic models during low flow conditions.
- There is convergence of some thresholds (geomorphic, hydraulic, OLWRP levels) to support e-flows management. The 2005 study considered a range of flow statistics, geomorphic thresholds, hydraulic inflection points, hydraulic thresholds, empirical method thresholds and low water response indicators levels. All the information was considered collectively to assess where various thresholds and statistics were converging. The study found that it is important to consider a range of information when trying to understand how a system is functioning from flow, hydraulic and sediment transport perspectives. The study followed the approaches described in recent research at that time.

- Areas that are heavily impacted by agricultural water takings (i.e., Whitemans Creek) cannot rely on historic flow-based thresholds to characterize the e-flow needs. Use of the hydraulic/geomorphic assessments are more suitable in these locations. Identifying the portion of the year affected by agricultural water taking was aided by plotting daily flow percentiles by day of year of their occurrence.
- Biotic relationships with flow are lacking and need further fish or benthic monitoring to properly assess techniques that relate to biological needs. Monitoring should extend over a period of years to decades to fully characterize several life stages and ecological response to perturbation.
- Qualitative assessment of the variable needs of aquatic organisms for flow (i.e. fish life cycle preferences for flow) give a basic assessment of ecological needs in absence of more detailed information
- Reach characterization by similar geomorphic and watershed characteristics may help transferability of e-flows techniques that are suitable when scoping new projects

3.2 Other Studies 2007-2012

- E-flows research and literature has grown extensively since the state of knowledge reported in the 2005 study. Inter-disciplinary studies (i.e. eco-hydrology) are more comprehensive in understanding the e-flow needs and should be included, if possible, in future studies (Wong, 2012a).
- Incremental steps, by continuously building on previous knowledge, are key towards developing a full e-flows understanding (Wong, 2012a).
- Biological monitoring data is still limited in the area and generally only collected for specific studies (i.e. Guelph's AMP). These studies are often limited in scope, or less than necessary, for long-term impact assessment.
- Suggestions for hierarchical, holistic, collaborative, regionally based and adaptive studies from the literature review on e-flows frameworks should be taken into consideration for future e-flows work in the Grand River watershed (Wong, 2012a).
- Level 3 OLWRP and Tier 3 Source Protection planning studies showed that, in areas of high water taking demand from the river, the OLWRP thresholds are not adequate to protecting the stream ecology (i.e. Alder Creek and Whitemans Creek). The flow record, on which the thresholds are based, have already been altered by takings. (Wong, 2012b).
- The longitudinal profile collected as part of the geomorphic assessment which includes both the invert and water elevation profile, is extremely useful. It provides a conceptual picture of how the reach is functioning hydraulically illustrating the hydraulic controls in a reach, and is needed to calibrate and check the hydraulic models developed for the reach.
- Reach classification based on the invert (longitudinal profile) and water elevation profiles was completed for the Speed River reaches. The classification highlighted the functionality of recovery and backwater reaches to assimilate wastes. Backwater reaches were classified as barriers as they impede the river ability to process (assimilate) nutrients and move sediments. Understanding where these barriers exist allows for identification of opportunities for enhancement and restoration.

4 WMP E-Flows Working Group: Key Regulated River Flow Functions and Processes

4.1 Introduction

The 2009 update to the Water Management Plan (WMP) for the Grand River details several broad water objectives addressing aquatic ecosystem health. The purpose of one objective is to establish "**a flow regime that supports healthy river processes**" in key reaches in the watershed. The purpose of this section is to summarize the approaches taken by the Environmental Flows Working Group (E-Flows WG) to develop this flow regime for the Grand and Speed Rivers, where the flows are regulated by reservoir operations.

The E-Flows WG is comprised of local experts on e-flows (see Section 9.2 for the expert group members). The E-Flows WG convened to compile a suite of processes or functions necessary for "**a flow regime that supports healthy river processes**". The Group focused on a flow regime for watercourses that have been altered by land use conversion, dams and reservoirs. The identified river flow processes are felt to be the most critical to ensuring the health of the river system.

As rivers that are regulated by reservoirs can become incised, armoured or entrenched, there are particular geomorphic processes to help restore a more natural system. For instance, valley forming flows will aim to alter the riparian and floodplain areas outside of the main flow of water within the channel. In natural channels, a channel maintenance flow may be sufficient to perform similar geomorphic process of channel refreshment, but where the channel and valley have become affected by entrenchment, such as the Grand River, the valley forming flow may be needed instead.

The E-Flows WG developed a series of flows necessary for a flow regime that would support a healthy ecology in the reaches below and affected the reservoirs. The group arrived upon three major categories of processes that would be necessary to meet the objective for regulated reaches of the Grand River watershed. The flows that are necessary for ecological function and maintenance are divided into three categories, including 1) channel maintenance and formation, 2) nutrient management or biological functions and 3) low flows. Under these categories, there are eight thresholds/functions total as listed in **Table 6**.

Table 6. Key thresholds for healthy flow regime functions and processes in regulated reaches

Category	Threshold
1. Channel Maintenance and Formation	a. Valley Forming Flows
	b. Bed Mobilizing flows
	c. Scour/Deposition Flows (similar to *flushing flow* in the 2005 report)
2. Nutrient Management and Biological Functions	a. Floodplain Inundation for Spawning
	b. Floodplain Nutrient Cycling Flows (similar to *bankfull flow* in the 2005 report)
	c. Macrophyte Flushing Flows
3. Low Flows	a. Littoral zone maintenance flows
	b. Longitudinal Connectivity

Each flow threshold/function is described in more detail in the following sections; each have their specific characteristics including the necessary frequency, timing and duration that would be optimal for these processes to occur. The flow rates may be similar or overlapping with one another, yet each has a specific function to perform. The description will also highlight how the particular flow function may compare and contrast to other familiar e-flow functions on natural systems and how regulated systems will require slightly different characteristics.

A summary of how the thresholds were calculated and the implications for not meeting the threshold are given.

Four study areas were selected to apply the flow thresholds. Following the threshold descriptions, these four areas – the Grand River near Doon and at Brantford and the Speed River near Guelph and Cambridge – are described and thresholds are presented.

4.2 Channel Maintenance and Formation

Flows that cause geomorphic alterations of the channel are critical for the creation of habitat, sediment movement, water quality and for overall maintenance of the channel for it to reach equilibrium. They are especially important in regulated reaches as the natural flow variability could have been lost and typical channel adjustments may not be occurring under reservoir operations for a very long time. As mentioned, stream corridors (channels and valleys) with upstream reservoirs often get incised, entrenched and armoured, thus more extreme geomorphic flow thresholds are needed to help the stream enhance its ability towards reaching a more natural form and function. Once the stream geomorphology has returned to a more natural state due to these geomorphic flow processes, or via stream rehabilitation, more naturally occurring e-flow processes typical in natural stream corridors may be more relevant. However, return periods and frequencies will only reflect the reservoirs' outputs unless they mimic the natural tendencies of river flows. Until the river morphology and flows mimic nature, the e-flows thresholds suggested here should be considered.

The following three flow thresholds (Group 1) focus on sediment movement for channel maintenance, refreshment (i.e. of riffles and pools) and formation. These types of moderate to high flows would naturally occur most often during the spring freshet, but could be executed at any time of year when an event flow allows.

4.2.1 Valley Forming Flows

Valley forming flows have been documented as having an important role in shaping the riparian and floodplain zones to maintain flood capacity, improve habitat and re-sort substrate (Gordon, 2004; King, 2002). For the Grand River regulated reaches, the focus of this valley forming flow is for readjustment and stream rehabilitation.

Often, dam regulation has a tendency to dampen natural flow variability, including higher flows that would maintain the river's capacity to transport sediments. Without this capacity, often substrate settles where it would not naturally occur and causes homogeneity in the streambed where riffles and pools used to reside (Annear, 1998). In the Grand River watershed, the hydrology, flow and sediment regime were historically altered by land use conversion to agriculture and drainage of wetlands, as previously mentioned. This caused valley form and channel adjustment, such as over-widening and entrenchment. Implementation of large reservoirs was an attempt to put storage back on the landscape and shift the altered flow regime back to a more natural and original state. However, the valley and channel may not be able to recover physically from the original adjustments using flow modifications, especially after years of regulation. Valley form rehabilitation could be a consideration for restoring some of the lost geomorphic functions (e.g. such as ensuring lateral connection to the floodplain).

The valley forming flow is a very high flow that will rehabilitate the stream corridor up to the valley walls, including the floodplain and riparian areas, as well as the channel within. Valley forming flows should occur once every 10-15 years. The duration is dependent on upstream drainage area, but should be the typical duration of a large flood event (12 to 36 hours). One event may be insufficient to shape the valley; several events may need to occur to result in the cumulative effects of shaping the valley, as valleys and river channels are dynamic.

To determine the valley forming flows, a threshold, equivalent to moving the 90th percentile grain size (D_{90}) (essentially the entirety of the bed materials), was calculated by Parish Geomorphic Ltd. (2013). The 90th percentile grain size is almost the largest particle size (i.e., the grain size where 90% of sizes are smaller). Substrate information, including grain sizes, was collected at each cross section using a modified Wolman pebble count method. The degree of substrate embeddedness, hydraulic roughness and subpavement composition are noted at each transect, which can supplement information on the substrate characteristics. The maximum instantaneous flows that reach this threshold should occur several times over 10-15 years to achieve the function of a valley forming flow.

Valley forming flow in the Grand River watershed would result from river flows in the range of the 1974 flood to the Hurricane Hazel flood event. These types of flows would cause widespread flood damages. While large flooding events will continue to occur in the Grand River watershed, as they would in any watershed, major reservoirs will continue to be operated to reduce the impacts of flooding. Valley forming flows may occur as the natural result of a flood; however, the large reservoir will be operated as to not induce a valley forming flow.

A secondary flow threshold to consider in this category is a channel forming/adjustment flow. Channel adjustment flows cause considerable movement of material in the floodplain, altering the channel but with limited reshaping of the valley. The aim is for readjustment on the longitudinal axis to break up bed armouring that has occurred in the substrate. This process could also be called substrate maintenance, as it is a flow that can rebuild riffles/pools/bars by resorting sediments. In regulated systems, the channel forming flow may not be sufficient to rehabilitate these (bed) armoured or entrenched systems, hence the valley forming flow is the primary flow threshold.

Information on channel-forming discharges, using hydraulic geometry, are detailed in (Annable *et al.*, 2011; Copeland, 2000). This type of channel adjustment can lead to instability of steep banks along the river, similar to the events of several large floods that occurred during the mid-1970's along regulated reaches of the Grand River. Channel adjustments subsequently occurred after an event in 1979, enabled by previous instability caused by earlier flooding events (Minshall, 2013, pers. comm). This flow corresponds to a 5- to 10-year natural flood and an estimated 20-year regulated flood. This is an unconfirmed threshold. The 1979 flood flow in the Brantford reach of 1300 m^3/s could be used as an unconfirmed flow threshold to capture this process, which will require additional future investigation.

4.2.2 Bed Mobilizing Flows

A bed mobilizing flow in a regulated system is defined here as a maintenance flow intended for resorting or loosening the top 5-10cm of the bed of the river. The bed mobilizing flow should be a periodic flow that can mobilize the finer sediments that may be embedded within the coarser sediment matrix. Areas downstream of dams often have less sorting capabilities due to the dampened flow regime caused by reservoir operations altering the natural flow regime. Sediment can often settle or erode in places where it normally would not under natural flows. When the stream is out of equilibrium, fine sediments embed into the coarser matrix. After several decades of flow regulation, the stream needs to loosen out the finer sediments such as the median grain size (D_{50}) that have accumulated, and mobilize them downstream or onto the floodplain.

Under natural flow conditions (unregulated), the bed mobilizing flow is often also defined as the bankfull flow, but due to flow regulation and armouring, the ability to mobilize the D_{50} may be different and the return period definition of a bankfull flow will also be misleading. The bed mobilizing flow for regulated reaches will be defined by the ability to move the D_{50} sediments.

The bed mobilizing flow for regulated reaches should occur once every 2 years (same as a natural, unregulated bankfull flow return period). There is no specific time of year that the flow is necessary, the e-flow could occur at any time during the year, but is most likely during the spring freshet. Any flow event that reaches the flow threshold for a day (i.e. the average daily flow is at or above the threshold) should be sufficient duration for this e-flow requirement.

The calculation of this flow involves estimating the critical discharge for mobilizing the median grain size using a shear stress equation and back-calculating from the critical flow depth on a simplified cross-section and Manning's equation (Parish Geomorphic Ltd., 2006).

4.2.3 Scour/Deposition Flows

A flow for channel maintenance via sediment transport is needed to suspend and move superficial fines (2-20µm) and organic material. The removal of these materials helps to create or increase heterogeneity and vertical habitat, as well as move organic matter into the floodplain. Heterogeneity is increased by scouring pools – to make them deeper – and by depositing gravel into the riffles, creating a higher crest. The flow should prevent homogeneity and smoothness from occurring in the channel by flattening out the slope. It should also provide sufficient energy to re-entrain finer sediments/organic matter that may have settled throughout the year.

Ideally, this flow process and flow rate coincides with the macrophyte flushing flow described in Section 4.3.3 (detailed below). The same or similar event could satisfy both these requirements, but perform different functions that are both necessary. The scour/deposition flow could also be aided by the Nutrient Cycling Floodplain flows (described later in Section 4.3.2), which removes some sediments out of the main channel and onto floodplain areas.

Parish Geomorphic Ltd. determined that the scour flows would involve entraining the median grain size (D_{50}) or finer. They re-calculated the D_{50} flows using the Shields Function and extension of work by Fishenich (2001). The scour/deposition flows should occur twice annually, ideally during spring and fall flow events. Any flow event that reaches the flow threshold for a day (i.e., the average daily flow is at or above the threshold) should be sufficient duration for this e-flow requirement.

4.3 Healthy Floodplain Functions

Small floods play a very important role in the ecological integrity of rivers. They "stimulate spawning in fish, flush out poor-quality water, mobilize smaller sediment and contribute to flow variability" (King, 2002). Small floods are flows that inundate the floodplain, which is necessary for keeping a lateral connection of flows throughout the channel and the floodplain.

These moderately high flows are important for improving water quality through nutrient cycling between aquatic and riparian ecosystems, as well as being necessary for various life stages of specific fish species. Often in regulated reaches, flood peaks are reduced (in flow magnitude or duration), or there is a reduction in the frequency or extent of the inundation, resulting in a loss of connection to the floodplain (Ward and Stanford, 1995). Disconnection laterally to the floodplain can also occur due to the channel becoming entrenched as a result of the flow regulation, reducing the frequency of inundation as higher flows are needed in these reaches to overtop the banks.

This next group of e-flows thresholds (Group 2) addresses the need to maintain healthy floodplains adjacent to the main channel. Three e-flows consider spawning habitat in the floodplains and water quality considerations for removing excess nutrients and nuisance aquatic vegetation.

The time of year of these e- flows is critical, to coincide with the biological functions that rely on and are cued by these events. The previous geomorphic e-flows (Group 1) can happen any time during the year, as the more important factor is the frequency. Regular flood pulses included in reservoir operations could allow for organisms to adapt to this flow regime, permitting efficient utilization of the floodplain area as habitat and resources. This replicates what would occur with natural flow regimes with floodplain inundation (Junk *et al.*, 1989).

The inundation of the floodplain would often be a flow that exceeded the bankfull flow, but in some areas where the floodplain is low-lying, it can be inundated at flows below bankfull. Bankfull discharges were calculated using field data collection of cross sections (Parish Geomorphic Ltd., 2005a), such as bankfull width and depth and bank materials, collected in-situ. Bankfull flow is then calculated using the Mannings equation to determine velocity and using the channel shape to determine the flow volume. The calculated bankfull flow was verified using a more rigorous estimate of bankfull flow is obtained from the calibrated hydraulic models and stream flow gauges where the bankfull elevation can be related to the rating curve. Finally, the thresholds for healthy floodplain functions could be adjusted if necessary, to meet the flow reconnection needs based on the channel geometry.

4.3.1 Floodplain Inundation for Spawning Flows

Floodplain inundation is necessary for keeping a lateral connection of flows throughout the channel and the floodplain. Certain fish species, including northern pike and pickerel, need to access the floodplain in early to late spring (March through to May) to spawn (Scott and Crossman, 1998). The flows during this time need to be sufficiently high and of long duration to accommodate access for both the floodplain spawning adults and for the hatched young to return to the main channel (King *et al.*, 2003). The timing of spawning is also cued by water temperatures, ranging between 7^0C and 12^0C (Scott and Crossman, 1998), depending on the species. The timing is also critical, as temperature and flows and possibly light variations often factor as triggers for spawning in floodplains (Junk *et al.*, 1989).

The successful recruitment of fish is 2 weeks, or 14 consecutive days (Scott and Crossman, 1998). Allowing for long flow durations or multiple events is ideal for providing fish more opportunities to spawn (King, 2002). To maintain healthy populations of fish species that spawn on the floodplains, this e-flow should occur in the spring spawning period once every 2-5 years.

The speed of flood recession is an important consideration. A slow recession mimics the natural recession curve of an unregulated flood, allowing fish to be cued for migration back to the channel. A fast recession time may strand fish in the floodplain as waters recede. The timing of the floodplain inundation for spawning should occur as close to the natural cycle as possible, be predictable and coincide with the adaptations made by the riverine fish that require this flow (Junk *et al.*, 1989). Floods occurring later in year may prevent juvenile fish from reaching maturity, inhibiting their ability to survive the winter season (King, 2002). **Figure 8** (Bayley, 1995) shows the progression of conditions suitable for floodplain spawning to be triggered.

The inundation of the floodplain also provides additional surface area to receive nutrients from the terrestrial environment, providing food for aquatic organisms (e.g. falling seeds or leaves). Shelter from the main channel's high velocity flows can also be found during floodplain inundation.

For the Grand River watershed, floodplain spawning is more prevalent in the lower order streams and the northern half of the watershed (Messier, pers. comm, 2013). The inundation may be most important at certain sections along the regulated reaches, such as lower lying vegetated areas similar to Snyders or Wilson's Flats, where spawning has been known to occur in the past. These low-lying floodplain areas could be lower and inundated at flows less than bankfull flow. In the southern Grand River, backwater areas, provided by run-of-the-river dams or backwater flooding of tributaries in the southern Grand (such as Fairchild, Big and McKenzie Creek), can provide additional spawning habitat that meet the criteria for floodplain spawning. The main southern Grand River, historically used for habitat, may now be too wide and not preferred habitat for floodplain spawners; however, low-lying floodplains on tributaries along this section of river may provide suitable habitat for spawning; or restoration projects here could be opportunities for habitat rehabilitation.

To determine the flow threshold for floodplain spawning, several criteria needed to be fulfilled. First, areas that appear to be suitable as floodplain spawning areas along the Grand and Speed Rivers within the study areas were verified with GRCA Aquatics staff. Low-lying floodplain areas along the Grand and Speed Rivers with vegetated banks are suitable floodplain spawning areas. Within these areas, a flow depth of 0.30m was determined to be the minimum depth necessary for adult spawning fish to have their backs submerged while spawning (Imhof, pers. comm. 2013).

The GRCA's floodplain hydraulic modeling (HEC-RAS) was then utilized to estimate flows that would allow for the low-lying areas to begin flooding. The flow range associated with the start of inundation, as well as the flows needed to achieve the minimum depth necessary for adult fish to enter the spawning area (i.e. minimum floodplain water depth of 0.30m), were estimated from the hydraulic model.

Flow events suitable for spring spawning need to occur during the months of March through June and must be maintained above the threshold for a minimum of 14 consecutive days to meet the criteria as the e-flows for floodplain spawning. A reduction in the duration of small inundation flooding during the spring limits the number of chances for spawning and therefore reduces the population of young-of-the-year fish.

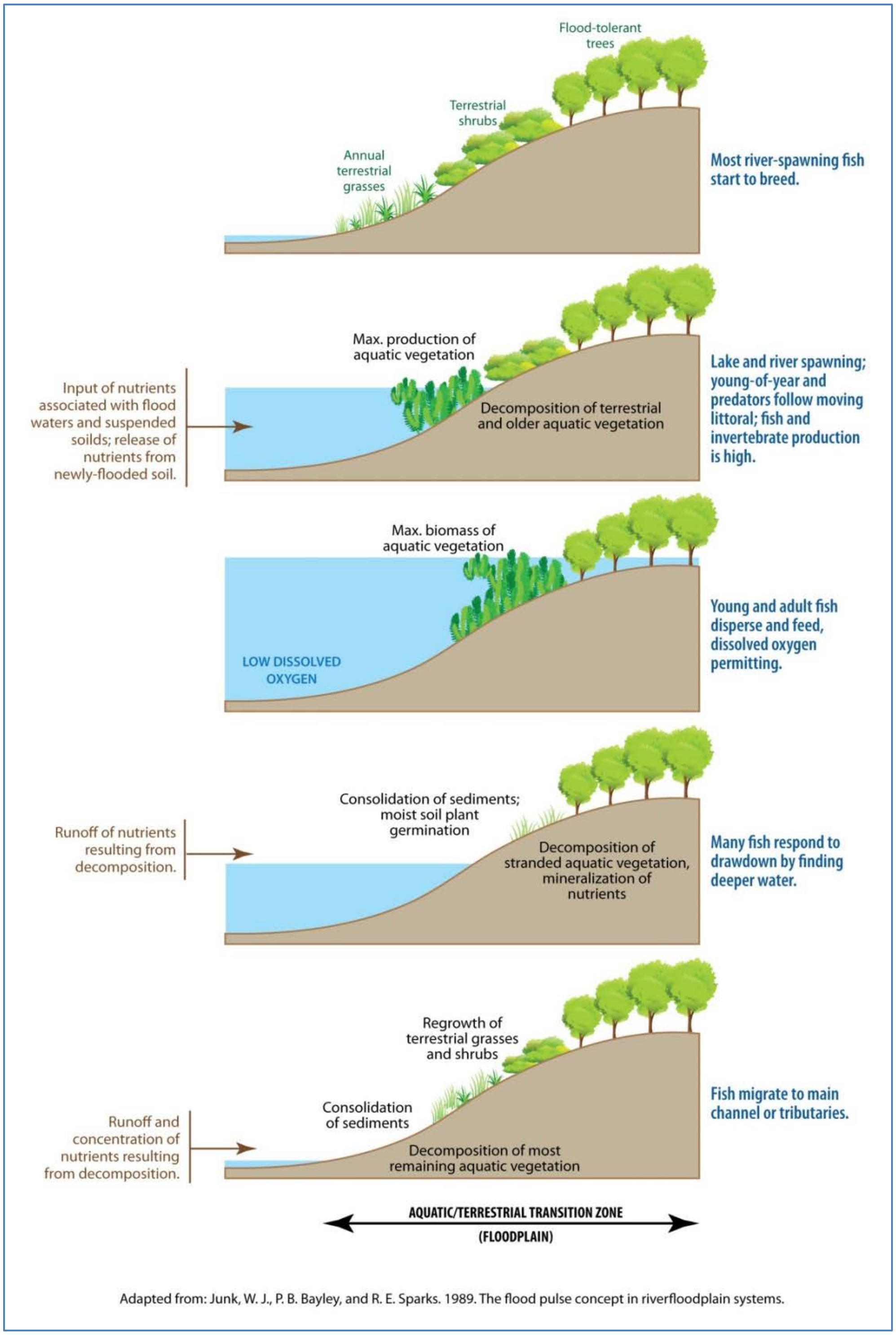

Figure 8. Schematic showing needs for floodplain spawning flows

Increasing spawning potential may be aided by modifications to the floodplain morphology when flow modifications are limited. Flow modifications to reduce downstream flooding and store water for summer flow augmentation, limits the number and duration of opportunities for spawning downstream of the large reservoirs. In addition, altered channel shape due to entrenchment has reduced lateral connectivity between the main channel and the floodplain. Collectively, the altered natural hydrology, flow regulation and changed channel shape have reduced the number of opportunities that would have originally occurred and that would be desirable. As an adaptive measure, restoration could be pursued to improve opportunities for spawning and enhancement of species diversity by reconnecting floodplains.

Thresholds and durations for floodplain spawning could be used to guide the design of effective restoration. Water temperature information, coupled with flow information, can be used to identify the timing of the cues that trigger spawning. Observed flow information, reflective of the current regulated flows regime and characteristic flow durations in the recommended 14 consecutive day duration, could be combined with hydraulic model information to guide the design of floodplain spawning habitat restoration - similar to that constructed at Synder's Flats. The Snyder's Flats restoration project included floodplain ponds, which are connected during small flooding events and were designed to be preferred habitat for floodplain spawners.

As updated digital floodplain mapping becomes available, analysis of floodplain inundation could be completed to assess where existing habitat occurs today and where viable restoration opportunities may exist. A restoration approach may be the most effective means for restoring spawning opportunities and function. As run-of-the-river dams are considered for removal, it may be possible to create complimentary floodplain pool spawning habitat in place of the reservoirs that were created upstream of the dams.

4.3.2 Nutrient Cycling Floodplain Flows

Similar to floodplain inundation for spawning, nutrient cycling flows for water quality maintenance utilize a lateral connection to the floodplains. The purpose of these flows is the removal (uptake) or redistribution of suspended sediments and associated nutrients from the channel by depositing them onto the floodplain during higher flows. The removal of the nutrients from the main flow allows for settling onto the floodplain, thereby improving water quality downstream of uptake areas and reducing the amount of nutrient loads ultimately reaching Lake Erie.

Removal of nutrients and sediments from the main channel, and their deposition onto the floodplain, is beneficial for habitat improvement for both aquatic and terrestrial (riparian) ecosystems. Fine sediments often have high nutrient content, which would be better utilized on the floodplain for riparian vegetation growth, instead of in-stream aquatic vegetation growth. Primary productivity in periodically inundated floodplains has been observed to be much higher than in permanent lotic (flowing water) or terrestrial systems (Junk *et al.*, 1989). The sorting of sediments by the flood waters creates more diverse habitats and, in turn, more biodiversity and biomass along the floodplain areas (Junk *et al.*, 1989).

For the Grand River system, the bulk of the annual suspended nutrient load in the river results from the spring freshet (Sources Report, 2013). Therefore, this e-flow is most effective when it occurs annually, during the spring flooding period, for durations of a few hours to days.

To estimate the nutrient cycling e-flow, bankfull flow was used as a surrogate. When bankfull flows are exceeded, the floodplain should begin to be inundated. Sediments can be trapped on the floodplain as the flows are slowed by increased friction from floodplain vegetation and debris. As previously mentioned, bankfull flows were calculated as the minimum width-to-depth ratio and verified with the hydraulic modeling results. The instantaneous maximum flows (i.e. hourly flow) were used to assess whether this e-flow is meeting the desired frequency duration requirements. However, longer durations of flows on the floodplain will increase the capture of sediments and nutrients and remove them from the water column.

4.3.3 Macrophyte Flushing Flows

A flow to remove excess and nuisance aquatic vegetation is useful to flush or remove decomposing and sloughing aquatic vegetation (especially cladophora) out of the channel and into the floodplain or flush it out of the river system. Nuisance aquatic vegetation can become an oxygen sink overnight during respiration, or during the decomposition phases. By removing the oxygen sink of decomposing vegetation from the river, the dissolved oxygen content of the flows improves. Certain areas of the Grand and Speed River can be choked by these nuisance aquatic macrophytes, reducing the quality of water for other aquatic species, especially fish that require dissolved oxygen levels to remain above 4mg/L overnight.

Cladophora is a filamentous algae that grows in the Grand River system. It has two growing stages - late spring/early summer and late summer. After the growth periods, the algae start to die off and becomes a floating mat of decomposing vegetation. Algal cladophora breaks down rapidly as they are a collection of smaller units. A flushing flow is needed at these times (i.e. approximately mid-June and mid-September) to remove floating macrophyte debris from the river. In addition, removal from the main channel onto the floodplain allows for rapid recycling of organic matter and nutrients in the floodplain zone (Junk *et al.*, 1989).

To estimate flow requirements for removing nuisance aquatic vegetation, Parish Geomorphic Ltd. was hired to research information on shear stress from the literature. They found that a shear stress in Biggs and Thomsen (1995) related to detachment and entrainment of macrophyte and periphyton communities due to hydrological disturbance. The shear stress values of several filamentous algae and diatoms were tested in this study and adapted for use in calculating flows associated with cladophora removal. The two boundary shear stresses that were selected were 91.8N/m^2 and 10N/m^2, relating to "major sloughing of all communities" and 50% of biomass removal for *Spirogyra sp.*, *Gomphoneis herculeana* and *Ulothrix zonata*, respectively. A discharge value was calculated at certain cross sections using these boundary shear stress values and other channel characteristics (hydraulic radius, slope and roughness coefficient) to determine the threshold e-flow value for macrophyte flushing.

Other abundant macrophytes in the Grand River watershed, including milfoil and potamageten, could also be beneficially removed from the river. However, they will need higher flows to pull them out from their root systems, due to a higher tensile stress. If the hydraulic stress on the channel bed is enough to cause bed instability, Fovet *et al.* (2011) suggest that there may be removal of the algae or macrophytes as a consequence of these erosion processes. In this case, the bed mobilizing flow may have enough shear stress to cause failure of the substrate and attachment of the macrophytes to the bed. Therefore, the bed mobilizing flow could be used as a surrogate to flushing macrophytes. Thresholds for removal will vary by reach and substrate material and will vary with both summer and fall thresholds, as the tensile strength of the macrophytes will be weaker in the fall near the end of their life cycle.

The average daily flow, at or above the threshold, will determine whether this e-flow is meeting the duration requirements.

4.4 Low Flows

The low e-flow thresholds are the minimum flows that should be exceeded to ensure protection of healthy river processes. Certain aquatic species require a low flow season to complete a life cycle stage; for instance, aquatic insects emerge during the low flow season when turbulence is low (King, 2002). More importantly, the low flow period has the lowest volume of habitat space and therefore creates a cap on the maximum population density of fish species. Below this flow, populations are limited, the ecosystem will begin to suffer and will have less resilience against other stressors such as predation, climate change or increased water takings. Low flows must consider aspects of duration, frequency and timing throughout the year to fully understand the needs of the river system.

4.4.1 Littoral Zone Maintenance Flows

Littoral zone maintenance flows maintain a minimum level of flow above the thalweg in the channel and represent low flows, which are an important component of the natural flow regime. The littoral zone maintenance e-flow threshold accounts for water quantity and quality considerations, including allowing for sufficient flow depth (0.1m) for fish to reach groundwater discharge zones of cool, deep pools for refuge. The littoral zone of a stream, depicted in **Figure 9**, is defined as the areas located towards the side edges of a stream in cross section view, along the stream margins. These littoral zone areas create habitat in low flow conditions that have shallow depths and slow water velocities (Gordon, 2004).

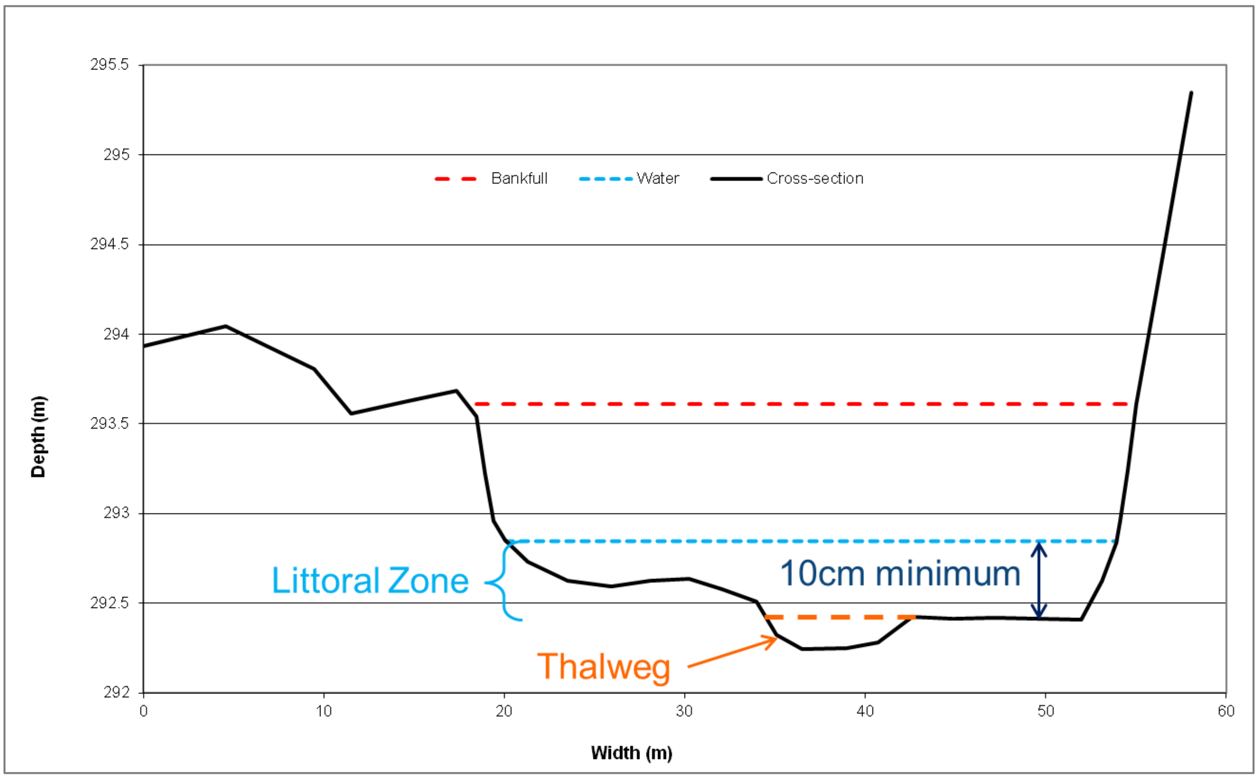

Figure 9. Cross section diagram showing stream littoral zone areas above a thalweg

These zones are important fish nursery habitat and areas of refuge, and flows should continue to pass over these areas to avoid stagnation. Even in the absence of a thalweg, the margins that are sustained during low flow periods with sufficient flow depth still represent important nursery habitat, where flows velocity is low and often shelter is available along the edges from riparian or bank vegetation. The moving flow in fringes or littoral zones prevents stagnation and supports aquatic habitat productivity (Junk *et al.*, 1989).

In addition, the conservation of littoral zone maintenance flows below reservoirs is a requirement for water quality interests, including assimilative capacity for sewage treatment plants and aeration or turbulence for dissolved oxygen requirements (Dortch, 1997). This flow should be sufficient to maintain flow turbulence around riffles to allow for additional dissolved oxygen production.

To maintain littoral zone maintenance flows and to mimic the 'natural' meteorological flow regime, the E-Flows WG suggests a minimum 7-day average flow threshold, during low flow season in summer (May-Oct).

Littoral zone maintenance flow values were determined based on the geomorphology of the through hydraulic modeling analysis. The shape of the channel and the flow to maintain 0.1m of water depth was derived through the hydraulic modeling.

To locate cross sections that have a littoral zone, plots of width-to-depth ratios versus flow for each cross section show hydraulic inflection points (changes in slope or curvature of the line), where abrupt changes in the flow depth occur as the flow decreases. This inflection point means much less hydraulic habitat is available with a small change in flow. Once the inflection point is located, analysis using the hydraulic model determines the flow needed to maintain 0.1m above this inflection point, indicating the littoral zone maintenance threshold. Hydraulic rating methods, including the wetted perimeter inflection point method, are described in the Prairie Province Water Board Report #145 (Prairie Provinces Water Board, 1999).

4.4.2 Longitudinal Connectivity Flows

The longitudinal connectivity of a river is when a certain water depth allows flow to remain above the highest riffle crests, allowing for migration of fish along the river corridor or thalweg. Pools become isolated below that flow depth, which prevents migration of fish away from predators and to preferred habitats and food. In coldwater streams, this flow depth is suggested at 0.20m at the riffle crest (Imhof, 2004), or for warm water species, 0.10m (GRCA, 2005). Additional information on the calculation of longitudinal connectivity can be found in Parish Geomorphic Ltd. (2005a).

The flow volume at which there is no flow over the riffles is called the 'residual pool flow', an extreme low flow when shallow water levels isolate the pools, or when the longitudinal connectivity of the flows is completely lost. It should be minimized and avoided if possible. This target is an extreme, catastrophic flow target meant to be avoided. To ensure there is flow depth to permit migration, the longitudinal connectivity flow is used instead of the residual pool flow.

During low flow seasons in summer/fall (May-Nov) and winter (Dec-Mar), the requirement is to maintain the 7-day average flows at or above the threshold for the given season, recognizing the physical ability of the reservoirs to maintain a given flow.

Table 7 below provides a summary of the e-flows thresholds described, including pertinent information on the ideal frequency, duration and time of year requirements of each threshold.

Table 7. Summary of E-Flow Thresholds needed for a healthy flow regime for regulated reaches

Flow Process	Description/ Importance	Frequency	Time of Year Requirement	Duration
Channel Maintenance/ Formation				
a. **Valley Forming Flows**	Shape channel and valley for creating more habitat, flood capacity, resorts bed material into new riffles and pools Channel adjustment flows alter the channel within the floodplain but limited change in valley shape	Every 10-15 years	Could be year-round. Most likely during natural flood period associated with spring freshet or the fall hurricane season	12 to 36 hours
b. **Bed Mobilizing (D_{50}) flows**	Resort substrate from top 5-10 cm10cm	Once every 2 years	Could be year-round, most likely during spring floods	1 Day
c. **Scour/ Deposition Flows**	Suspend and move superficial fines and organic material	Twice per year	Spring and fall events	1 Day
Nutrient Management/Biological Functions				
d. **Floodplain Inundation for Spawning**	Later connection to floodplain for spawning fish	Once every 2-5 years	Spring spawning period	2 weeks minimum
e. **Floodplain Nutrients Cycling Flows**	Remove sediments and nutrients onto floodplain	Annually	Could be year-round,most likely during spring floods.	Event (3 to 12 hours)
f. **Macrophyte Flushing Flows**	Remove nuisance aquatic vegetation (macrophtes), deposit onto floodplain	Twice per year	Mid-June and Mid-September	1 Day
Low Flows				
g. **Littoral zone maintenance flows**	Maintenance of littoral zone for habitat as the minimum flow	Year round	Could be year-round. Most important to maintain during summer low flow season (May-Sep)	7-day running average
h. **Longitudinal Connectivity**	Maintain connection between riffles and pools with 0.2m of flow depth over riffles	Minimize (at most once every 15-20 years)	Summer low flow period (May-Sep) and over-wintering period (Nov-Mar)	Do not exceed 2-3 days below threshold

5 Thresholds for Regulated Reaches

This section will detail the four sites along the Grand River and Speed River, where the e-flow thresholds were calculated. The four sites include two on the Grand River (near Doon in the central Grand and near Brantford in the Exceptional Waters reach) and two on the Speed River (just below Guelph and in Cambridge-between Hespeler Road down to the confluence to the Grand). The e-flow threshold values are given and the historic frequency of occurrence are described to determine whether the conditions are being met at the four locations.

To describe the historic occurrence, daily average flow records between 1984 and 2012 were used to assess the occurrence of most of the flow thresholds. This period coincides with the current operating policy schedule for the large reservoirs and gives 29 years of historic daily flows. The exceptions are for the valley forming and nutrient cycling flows, where the instantaneous maximum hourly flows were used to assess occurrences of exceedance for these thresholds.

More detailed information on the calculation of several of the flow processes and values can be found in (Parish Geomorphic Ltd., 2005b). Other flow thresholds completed for this study are unconfirmed calculations done by Parish Geomorphic Ltd. (2012-13) (Parish Geomorphic Ltd., 2013). The flows will need to be verified in-situ (especially the macrophyte flushing flows) to confirm whether the flow value meets the intended purpose. However, the thresholds give a preliminary indication of the magnitude of flows needed and the variability in flow for a healthy flow regime to be met.

5.1 Central Grand River near Doon

The central Grand River reach uses the Grand River at Doon station for streamflow records from 1984-2012, with adjustments made for ice conditions. The closest reach analysis using geomorphological fieldwork is located just downstream at Blair, completed for the 2005 CO study. The Doon reach has been subjected to many stressors, being below large urban areas and thus affected by anthropogenic issues affecting water quality. Over 60% of the upstream drainage area is regulated by large reservoirs.

Table 8 provides the e-flow regime suggested for the central Grand River reach and summary of historic frequency of occurrences.

Table 8. Suite of e-flows thresholds and historic occurrences analysis for the central Grand near Doon

E-Flows Thresholds	Flow (m^3/s)	Historic Occurrences Frequency	Frequency Requirements Met?	Comments
a. Valley Forming Flows **Channel Adjustment Flows**	1965 650-850	None on record since 1914 Three occurrences (1974, 1975, 1979)	No	Not practical to achieve
b. Bed Mobilizing (D_{50}) flows	187	83% of years	Yes	
c. Scour/ Deposition Flows	85	Many occurrences each year	Yes	Only 1999 didn't have a scour flow
d. Floodplain Inundation for Spawning	100-150	5 of 29 (17% of years) (1985, 1996, 1997, 2005, 2008)	Adequate	11 other years had potential, but needed a few more days of higher flows (38% of years)
e. Floodplain Nutrients Cycling Flows	400 (bankfull flow)	31% of years (hourly) Six mean daily occurrences in 5 years	No	Less frequent than desired due to incised channel and loss of floodplain connectivity
f. Macrophyte Flushing Flows **Using bed mobilizing flow as surrogate:**	297 187	2 years (1986, 2000) 3 of 29 years (1986, 2000, 2010)	No No	Once in June (2000) and one occurrence in Sept (1986) One more occurrence if bed mobilizing flow is used as a surrogate
g. **Littoral zone maintenance flows (May -Oct)**	8.5	In excess of 95% of the time	Adequate in most years	1998-99, 2012 summers were low
h. Longitudinal Connectivity (May-Oct) and (Nov-Mar)	6.8	Less than 1% of the time in summer	Adequate in most years	1998, 1999, 2003 2007 were worst winters

5.1.1 Historic Occurrences

a) The valley forming flow threshold would require a very high flow that has only been approached once -during the major flood of 1974 - but was still inadequate to be achieved. It is not practically achievable, as this calculated flow is very high due to the level of shear stress needed to move the very large D_{90} bed material; it would result in wide spread flood damages and risk to life. The unconfirmed channel adjustment flow occurred three times in the 1974 to 2012 period, corresponding to large floods. The unconfirmed channel adjustment thresholds were estimated based on prorating the Brantford threshold based on drainage area (650 m^3/s) and based on the 20-year regulated flow frequency estimate (850 m^3/s).

b) The bed mobilizing flow occurred frequently, often more than once a year. Only a handful of drier years did not experience the bed mobilizing flows. This threshold was adequately achieved over the period of record with current reservoir operating policies.

c) The scour/deposition flow threshold occurred frequently and was adequately achieved over the period of record with current reservoir operating policies. Runoff from urban areas may deposit, on occasion, a blanket of fine sediment that remains in place between scouring flow events.

d) Floodplain Inundation flows for spawning occurred in certain low-lying areas, triggered at flows of 100 m3/s. This allowed fish to access the floodplain, but 150m3/s is needed to ensure their backs are covered while spawning. The flow rate was often available, but the number of consecutive days was inadequate. A few more days of the inundation flows would have allowed for the successful recruitment of fish after spawning.

Figure 10 depicts the types of areas that are potentially ideal locations for floodplain spawning in the Grand River near Doon reach.

Figure 10. Aerial imagery of a potentially ideal floodplain spawning site in the Grand River near Doon reach

e) Nutrient Cycling flows onto the floodplain need to occur more frequently. However, with certain low-lying floodplain areas, some nutrient cycling occurred at much lower flows than the bankfull flow estimate.

f) Macrophyte flushing flows at the 297 m^3/s threshold only occurred once in June and once in September, which was inadequate. However, anecdotal reports say flows are lower than the calculated flow threshold, at approximately 150-200 m^3/s. For the interim, the bed mobilizing flow threshold of 187 m^3/s could be used as a surrogate, given the assumption that if the stability of the substrate is compromised, the macrophytes will also be mobilized. The bed mobilizing flow occurred in 3 years in either June or September.

g) Littoral zone maintenance flows during the winter are critical for ensuring that fish can overwinter with enough depth of flow to maintain oxygen levels and the ability to migrate if needed. There were a few occurrences where the flows were insufficient, such as in the winter of 1998-99 and Jan-Mar of 2003, where flows dipped well below the threshold (monthly flows between 3.94 to 5.71 m^3/s). Years such as these should be avoided if possible.

h) There were six years where longitudinal connectivity flows were below the threshold, but only three years when the duration was longer than a week below the threshold. These years were 1998, 1999 and 2007, and were known to be very dry years.

Figure 11 shows the daily flows and the e-flows thresholds for the central Grand River near Doon.

5.2 Grand River near Brantford

Further downstream on the Grand River, there is a long-term WSC gauge (02GB001) at Brantford, and geomorphic analysis for the Exceptional Waters Reach is from the 2005 study. More detailed information on the calculation of several of the flow processes and their values can be found in (Parish Geomorphic Ltd., 2005b) for the Exceptional Waters reach upstream of Hwy 403 to Penman's Dam.

The Exceptional Waters reach is characterized by a wide channel, with approximately 30% of the upstream area regulated by major reservoirs. Therefore, the effects of flow regulation on this reach are less dominant than in the Grand River near Doon reach.

Table 9 provides the e-flow regime suggested for the Grand River near Brantford reach and historic frequency of occurrences.

Table 9. Suite of e-flows thresholds and historic occurrences analysis for the Grand River near Brantford

E-Flows Thresholds	Flow (m3/s)	Historic Occurrences Frequency	Frequency Requirements Met?	Comments
a. Valley Forming Flows **Channel Adjustment Flows (unconfirmed)**	1930 1330	None 6 occurrences since 1948	No	Not practical to achieve 1974 and 1979 were last occurrences
b. Bed Mobilizing (D_{50}) flows	161	Many times annually	Yes	
c. Scour/ Deposition Flows	78.5	Many times annually	Yes	
d. Floodplain Inundation for Spawning	300-350	None (2008 had 9 days in April)	No	14-day duration requirement not met in any year
e. Floodplain Nutrients Cycling Flows	>405 (bankfull flow)	62% of years	Moderately	Should be annually. Is occurring almost every other year since 1995
f. Macrophyte Flushing Flows	102	44% of years (30% in June, 17% in Sep)	Moderately	Flush occurred in either June or Sep. Only 1 year with both.
g. Littoral zone maintenance flows (May-Oct)	19	Met majority of the time (>50% of years)	Moderately	Very low years include 1989, 1998, 2007, 2012
h. Longitudinal Connectivity (May-Oct, Nov-Mar)	8.8	Below threshold once in winter	Yes	Flows dropped below in January 1999

Historically, the flow thresholds in the Grand River near Brantford are generally attainable and have been meeting the frequency requirements. Only during the very dry years have the flows not met any of the thresholds. However, if other years are maintaining the flow regime, then there should be resilience in the system to buffer the impacts of very dry years.

5.2.1 Historic Occurrences

a) Valley forming flows in the Brantford reach were not observed in the period of record. The unconfirmed channel adjustment flow threshold was exceeded in 1974 and 1979 during large floods. Flows of this magnitude have not been seen since the existing reservoir operating policy was put in place, and are likely not practical for achievement without significant impact to infrastructure and human safety.
b) The bed mobilizing flow occurred frequently, often many times each year. This threshold was adequately achieved over the period of record with current reservoir operating policies
c) The scour/deposition flow threshold occurs frequently and this threshold is being adequately achieved over the period of record with current reservoir operating policies.
d) Floodplain spawning in the low-lying floodplain areas starts to occur (fish will be triggered to move onto the floodplains) when flows reach 300 m^3/s, but the flow depth on the floodplains of 0.3m requires 350 m^3/s. There were no occurrences of these flows occurring consecutively for a 14-day period, although the flows did reach these levels for much shorter durations (3 days) in most years. The longest duration was 9 days in April, 2008, and two 5-day periods in March of 2011.
e) Flows further downstream in the main Grand River were often not sufficient to exceed the bankfull flow capacity, and the large volume of sediment from these events is deposited in the river downstream or to Lake Erie.
f) For the macrophyte flushing flow, 44% of years experienced flows over this threshold either in June or in September, with one year (1996) having events in both June and September. While the flushing flow should occur annually, the historic occurrence is almost every other year, which helped to improve water quality in those years.
g) Littoral zone maintenance flows were just above the reservoir flow target in Brantford of 17 m^3/s, but are still often met using the current operating policy. There have been some years that flows dropped below this threshold (19 m^3/s) for several weeks at a time in 1998, 2007 and 2012.
h) Longitudinal connectivity flows are well below the reservoir flow target. However, during the winter months, these flows are also necessary for overwintering habitat, and there was one year (1999) that flows dropped below the connectivity threshold for just over a week. Otherwise, there were no other issues meeting this flow requirement in the Exceptional Waters reach.

Figure 12 shows the daily flows and the e-flows thresholds for the Grand River near Brantford.

5.3 Speed River at Guelph

The Speed River at Guelph has a gauge (02GA015) at the Hanlon Expressway with a period of record starting from 1950. The Guelph Lake dam came online in 1976 and the current reservoir operating policy in 1984. Geomorphic fieldwork has been completed along the entire stretch of the Speed River from Guelph to the confluence at the Grand River. The reach characteristics for the Speed River at Guelph are characterized in the Speed River report from Niska to Edinburgh Roads (Parish Geomorphic Ltd., 2006). The baseflow threshold was estimated using hydraulic modeling to determine where the littoral zone had 10cm of flow depth. Longitudinal connectivity was calculated with 7-10cm of depth on riffle crests, as this is a warmwater fish community (Parish Geomorphic Ltd., 2013).

Table 10 provides the e-flow regime suggested for the Speed River at Guelph reach and historic frequency of occurrences.

Table 10. Suite of e-flows thresholds and historic occurrences analysis for the Speed River at Guelph

E-Flows Thresholds	Flow (m3/s)	Historic Occurrences Frequency	Frequency Requirements Met?	Comments
a. Valley Forming Flows **Channel Adjustment Flow (unconfirmed)**	160 120	3 occurrences since 1950 2 occurrences since 1974	No	None since regulation Not practical to achieve
b. Bed Mobilizing (D_{50}) flows	25.6	Many times annually in 90% of years	Yes	Not reached in 1999, 2003, 2012
c. Scour/ Deposition Flows	7.9	Many times annually	Yes	
d. Floodplain Inundation for Spawning	24	2 years (14%) (1985, 2008)	Inadequate	Flows often available but not for duration requirement
e. Floodplain Nutrients Cycling Flows	>37.6 (bankfull flow)	55% of years	Moderately	Should occur annually
f. Macrophyte Flushing Flows **Using bed mobilizing flow as surrogate:**	56.7 25.6	Once in Sep 1986 Sep 1986, June of 1993,2000	Poor	Difficult to achieve time of year requirement for such high flows
g. **Littoral zone maintenance flows (May-Oct)**	1.1	Below for 8-9 days in 1984, 1997	Yes	Reservoir flow target is above this threshold
h. **Longitudinal Connectivity (7-10cm depth) (May-Oct) and (Nov-Mar)**	0.52	None	Yes	Never fell below this requirement

For the Speed River in Guelph, many of the higher flow thresholds are adequately being met, same for the floodplain flows, which are only occurring every other year instead of annually.

5.3.1 Historic Occurrences

a) Valley forming flows on the Speed River at Guelph have not occurred since flow regulation began on the Speed River. There were three historic occurrences (1950, 1954, 1974) of this flow threshold, but no documentation to determine whether the geomorphic processes were achieved. This flow rate is not practically achievable, as this calculated flow is very high due to the level of shear stress needed to move the very large D_{90} bed material. The unconfirmed channel adjustment flow threshold was approached in the fall of 1986.

b) The bed mobilizing flow occurred frequently, often more than once a year. Only a handful of drier years did not experience bed mobilizing flows. This threshold was adequately achieved over the period of record with current reservoir operating policies.

c) The scour/deposition flow threshold occurs frequently in all seasons and this threshold has been adequately met over the period of record with current reservoir operating policies.
d) Floodplain spawning flows need to be 24 m^3/s in the Speed River at Guelph to inundate the floodplain and have the flow depth requirement. The 14 consecutive day requirement was achieved in two years since 1984. In other years, the flow rate was achieved but the flow duration requirement was not fulfilled (namely 1997 when the flow duration was only two days shy of the requirement at 12 days).
e) The nutrient cycling flows only occurred every other year, but should occur annually. In the years the flow threshold was achieved, they occurred multiple times.
f) The macrophyte flushing flow at 57 m^3/s may be above the requirement to slough senescing macrophyte material in June and September. For the interim, the bed mobilizing flow threshold of 25.6 m^3/s could be used as a surrogate, given the assumption that if the stability of the substrate is compromised, the macrophytes will also be mobilized. However, both flow thresholds were not achieved adequately in the time period required (June or September).
g) The littoral zone maintenance flow was adequately achieved in most years for this stretch, as the reservoir flow target is above this flow threshold. There were only a couple instances where the flows dropped below the littoral zone maintenance flow threshold for over a week.
h) There have been no occurrences of flows below the longitudinal connectivity threshold since 1984.

Figure 13 shows a chart of the daily flows and the e-flows thresholds for the Speed River at Guelph.

5.4 Speed River in Cambridge (Hespeler)

The Speed River in Cambridge (Hespeler) reach describes the portion of the Speed River from Hespeler Road to the confluence to the Grand River. The Speed River in Cambridge (Hespeler) has a gauge at Beaverdale Road (Beaverdale, 02GA047), which has a period of record since 1973. The Speed River in this area is impacted by upstream urban areas, two sewage treatment plants from large urban centres, flows that are regulated by Guelph Dam, and several other smaller weirs and dams.

The Speed River in Cambridge (Hespeler) reach was completed in 2007 for the purpose of completing the geomorphic cross sections and longitudinal profile. No formal report or e-flows thresholds were calculated at that time. The thresholds were subsequently calculated for this report and therefore are not as comprehensive as the other study reaches.

The littoral zone maintenance flow threshold was estimated using hydraulic modeling to determine where the littoral zone had 10cm of flow depth. A longitudinal connectivity threshold was calculated based on 7-10cm of depth on riffle crests(Parish Geomorphic Ltd., 2013), as this is a warm water fish community.

Table 11 provides the e-flow regime suggested for the Speed River in Cambridge (Hespeler) reach and historic frequency of occurrences.

Table 11. Suite of e-flows thresholds and historic occurrences analysis for the Speed River in Cambridge

E-Flows Thresholds	Flow (m3/s)	Historic Occurrences Frequency	Frequency Requirements Met?	Comments
a. Valley Forming Flows **Channel Adjustment Flow (unconfirmed)**	400 130	None 2 occurrences since 1974	No	Not observed in period of record Not practical to achieve
b. Bed Mobilizing (D_{50}) flows	47	55% of years	Yes	Met on average every other year
c. Scour/ Deposition Flows	36.6	83% of years	Moderately	Need more occurrences in fall months
d. Floodplain Inundation for Spawning	50	None	No	2008 had 12 days in April
e. Floodplain Nutrient Cycling Flows	>31.7 (Bankfull flow)	90% of years	Adequate	Only 3 years not meeting requirement of 29
f. Macrophyte Flushing Flows	30.8	2 mid summer events (1993, 2000); 1 mid-fall event	No	Time of year requirement not being met
g. Littoral zone maintenance flows (May-Oct)	1.5	Met 100% of the time	Yes	Flows have been maintained above this threshold
h. Longitudinal Connectivity (7-10cm depth) (May-Oct) and (Nov-Mar)	1.1	Met 100% of the time	Yes	Flows have never been below this threshold for more than 3 days

For the Speed River in Cambridge (Hespeler), many of the higher flow thresholds are adequately being met, same for the macrophyte flushing flow, which has very specific time of year requirements.

5.4.1 Historic Occurrences

a. The valley forming flow has never been seen during the period of record. It is not practically achievable, as this calculated flow is very high due to the level of shear stress needed to move the very large D_{90} bed material. The unconfirmed channel adjustment flow threshold was approached in the fall of 1986.
b. The bed mobilizing flow occurred almost every other year, and was adequately achieved over the period of record with current reservoir operating policies.
c. In the years that the scour/deposition flows occurred, they adequately met the spring requirement. However, there were years where they were achieved at all, and there was only one year that the scour/deposition flow threshold was reached in the fall.
d. The floodplain spawning flows were estimated based on observed flooding of low lying areas and verified using the hydraulic modeling. There were no occurrences of floodplain spawning flows for the entire 14 day duration. The flows in 2008 were two days short of the requirement, which may have allowed spawning; however, stranding of the fish (adults or young) may have occurred.

e. Bankfull flows, to support nutrient cycling on the floodplains, occurred frequently in the Speed River in Cambridge (Hespeler) reach.
f. Flows to flush macrophytes in the Speed River have not been adequately achieved, as only three events occurred since 1984. The time of year requirements for mid-June and mid-September are not being met.
g. The littoral zone maintenance flow threshold was below the reservoir operating flow target (1.7 m^3/s) and 7-day running average flows were maintained throughout the period of record during the months of May through October.
h. There were no occurrences of mean daily flows at or below the longitudinal connectivity flows in the period of record.

Figure 14 shows a chart of the daily flows and the e-flows thresholds for the Speed River in Cambridge (Hespeler) reach.

5.5 Charts of Daily Mean Flows and E-flow Thresholds

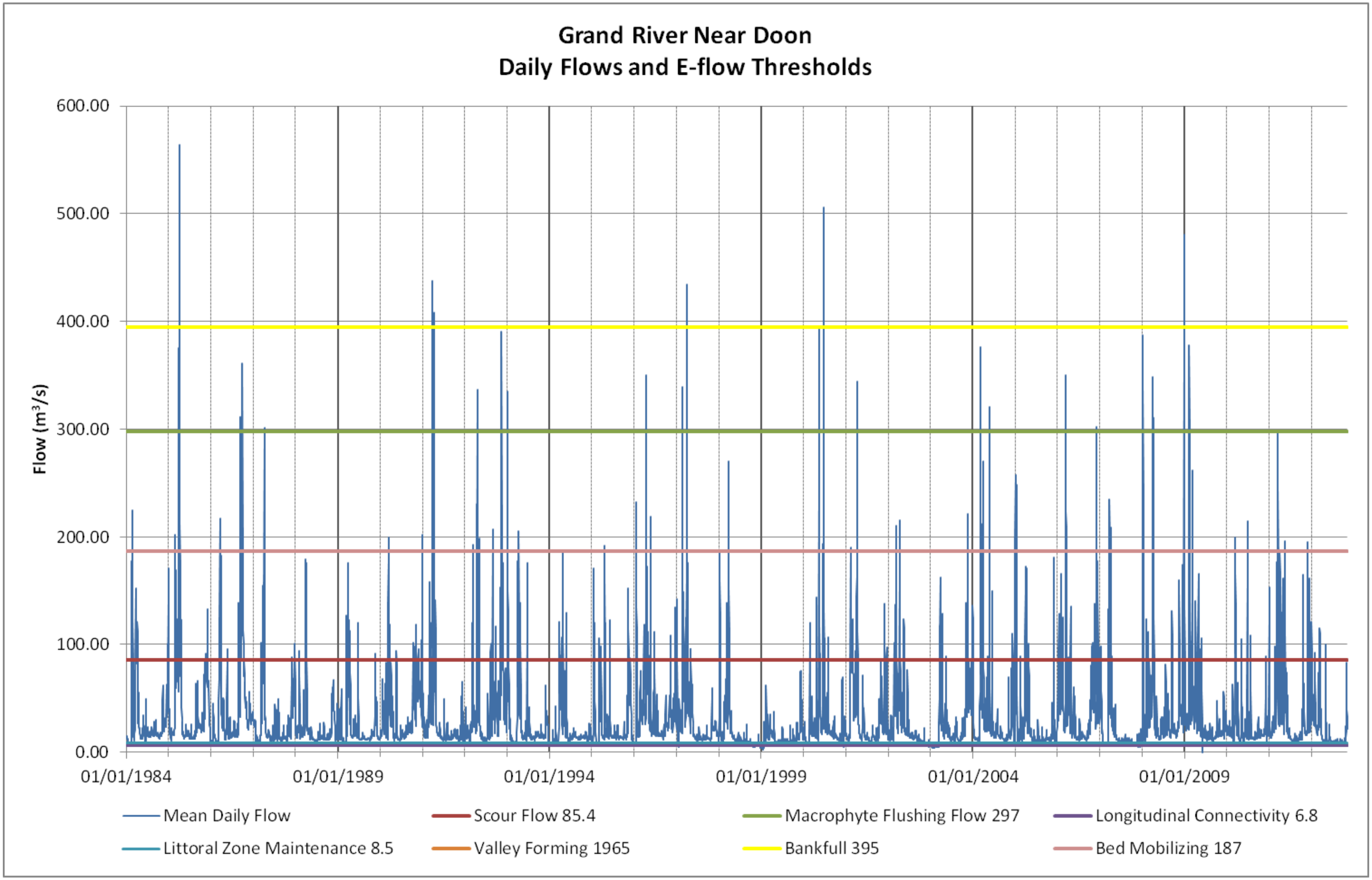

Figure 11. Chart of daily flows and e-flow thresholds for the central Grand River near Doon

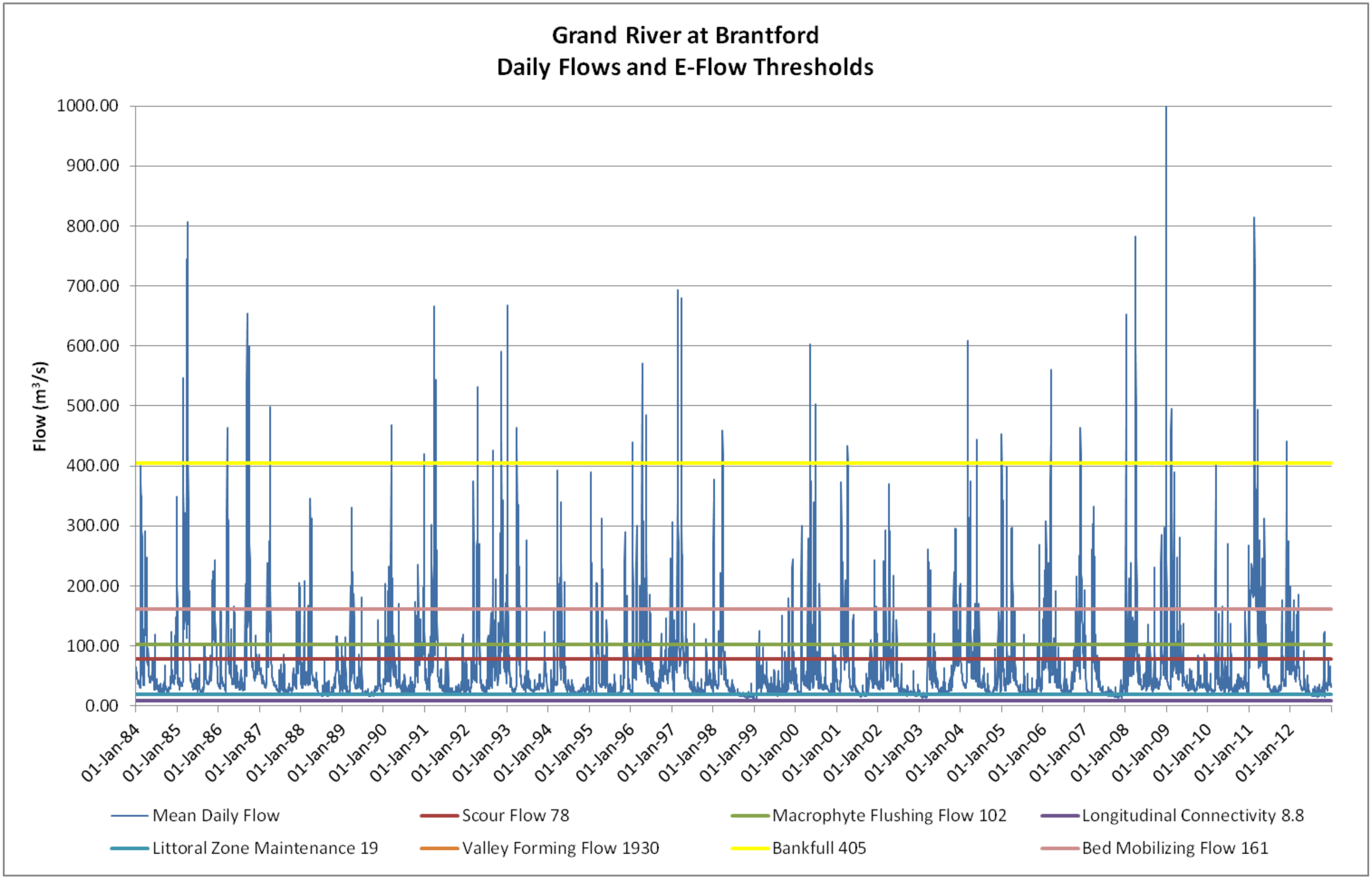

Figure 12. Chart of daily flows and e-flow thresholds for the central Grand River near Brantford

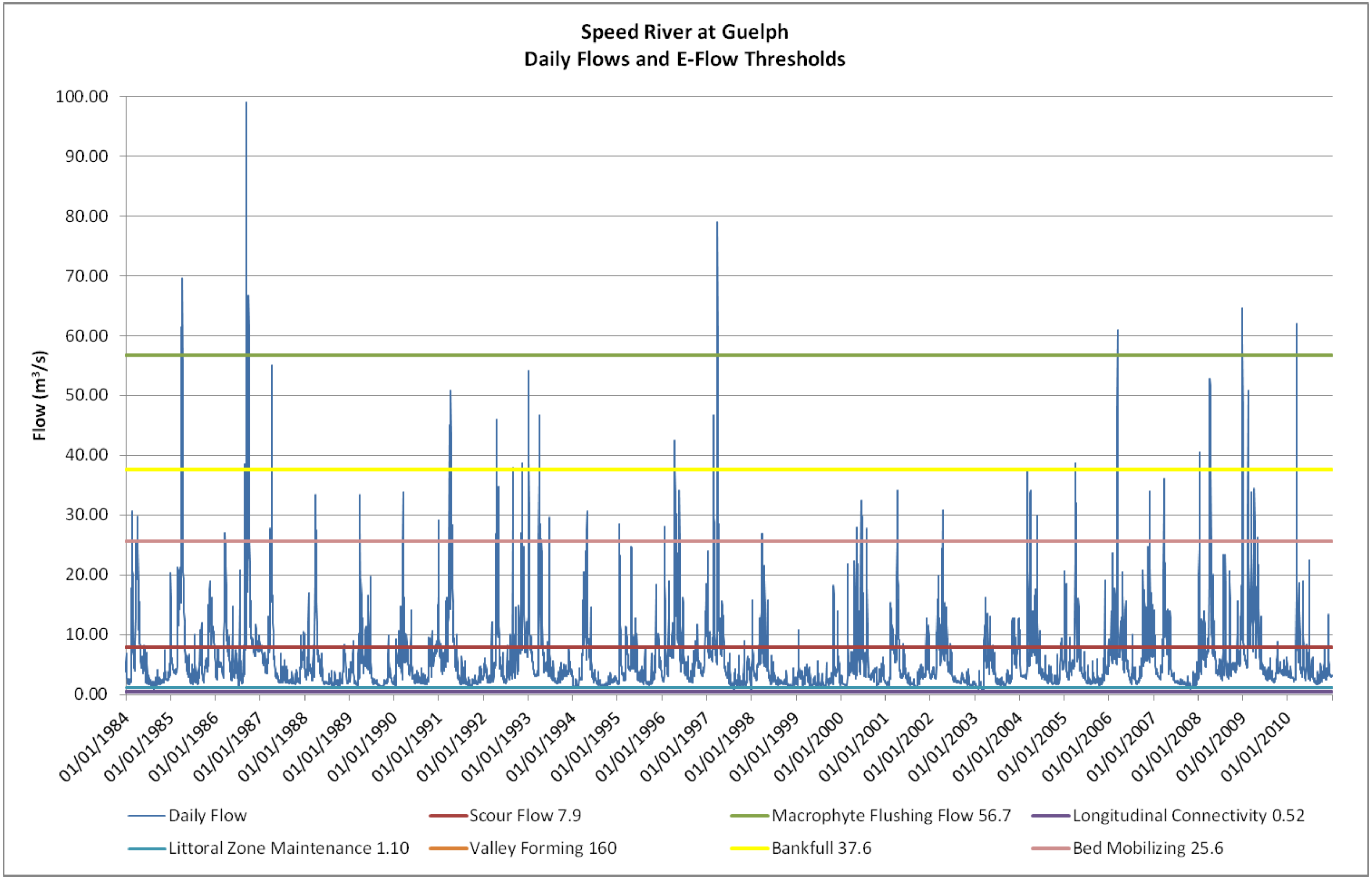

Figure 13. Chart of daily flows and e-flow thresholds for the Speed River at Guelph

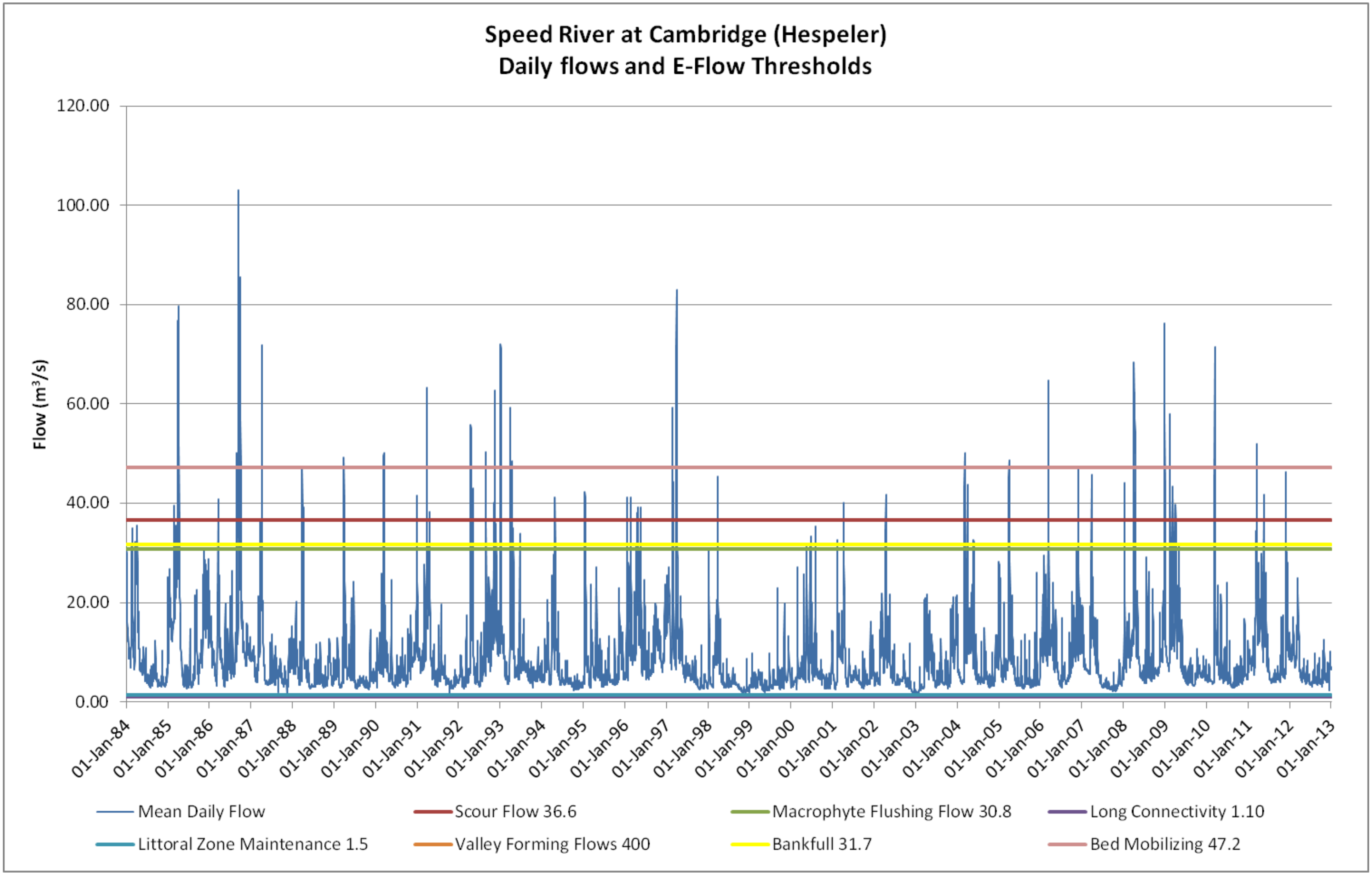

Figure 14. Chart of daily flows and e-flow thresholds for the Speed River at Cambridge

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6 Low Flow Thresholds for Unregulated Tributaries

The unregulated tributaries of Whitemans Creek and the Eramosa River in the Grand River watershed are areas of concern regarding low flows. There are numerous agricultural water takings on both these tributaries and maintenance of flows above a low e-flow threshold would benefit the ecological integrity of these systems. This section will detail the rationale for selecting a low e-flow threshold for these two rivers. These case studies show areas where dam control is not available to help augment e-flows and water managers rely on the landscape and the people to meet e-flow thresholds by managing land use and water takings.

6.1 Whitemans Creek

The Whitemans Creek subwatershed in the Grand River (Figure 15) is an area with a high concentration of agricultural water taking permits on well-drained sandy soils. Low water conditions are a perennial issue, which impacts users of the creek, including the fish and wildlife that depend on the river flows.

The flows in Whitemans Creek are largely dependent on groundwater from the high water table and shallow sand aquifer, especially during periods of no precipitation. The shallow sand aquifer that feeds Whitemans Creek with cold groundwater provides sustained cold baseflows, to support a good cold-water fishery for brown and rainbow trout.

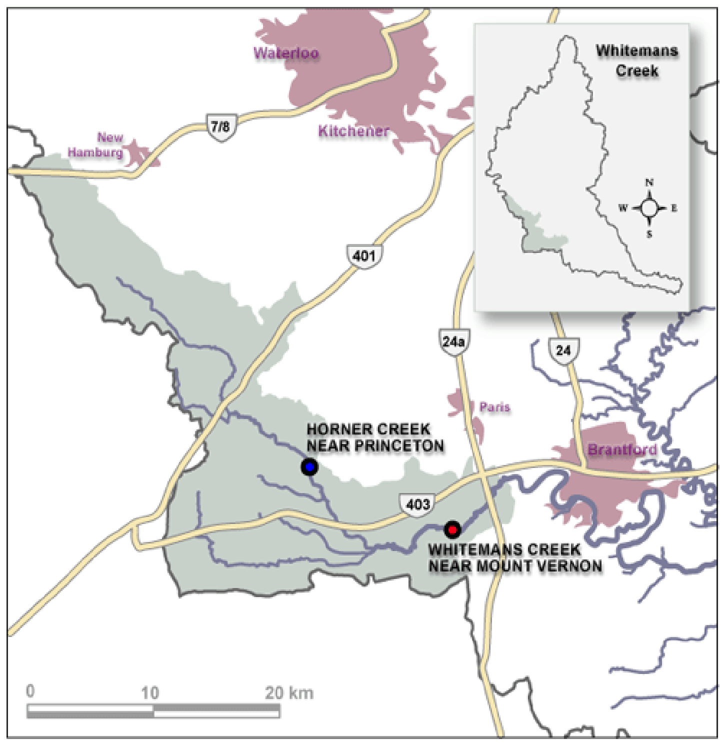

Figure 15. Whitemans Creek subwatershed

The majority of water demand is sourced from groundwater (Wong, 2011), yet with the close connection between ground and surface water, a substantial demand for water is placed on the Creek during the summer months, when flows are at their lowest.

Low water on Whitemans Creek can have a significant impact on the ecosystem. The habitat for fish and other aquatic species suffer as the water levels drop and food sources die off in what is normally one of the richest habitats in the region.

6.1.1 Low Flow History

The flow history for Whitemans Creek extrapolates the OLWRP thresholds to compare dry years to the severity of historic droughts or low flow years. **Figure 16** shows the number of occurrences of running 7-day average stream flows reaching each of the OLWRP levels, as well as the annual rainfall totals. The red dots show the number of days the flows were at, or below, the Level 3 threshold.

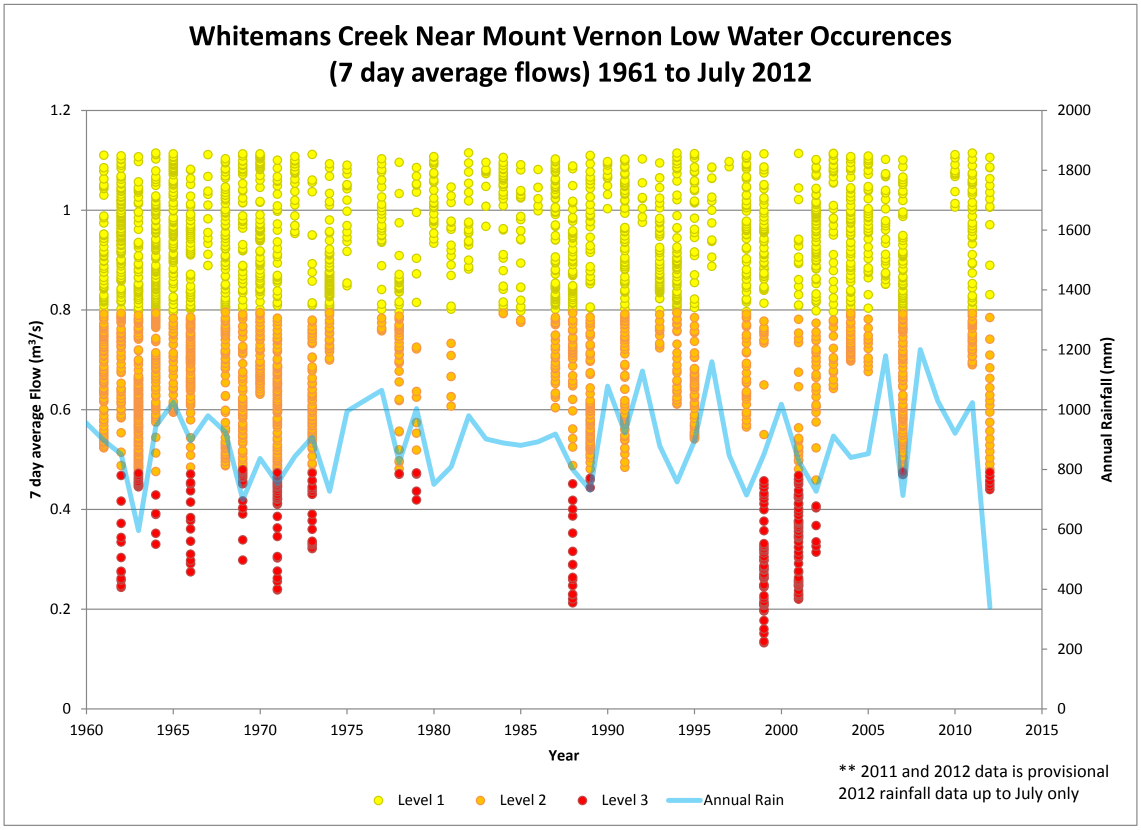

Figure 16. Whitemans Creek near Mount Vernon low water occurrences

Upon further examination of the data from **Figure 16** , the flows show that September has the greatest occurrence of low flows. In some years, entire months are at or below the Level 2 threshold. The Whitemans Creek system shows over 90% of years having high occurrences of reaching low water thresholds .

6.1.2 Geomorphic Field Investigation and Analysis

Geomorphic field investigation was completed along a 780m reach of Whitemans Creek bounding the Water Survey of Canada gauge station located at Cleaver Road. The field survey included the survey of 10 hydraulic cross sections spaced along this reach (Parish Geomorphic Ltd., 2005a).

Flow Analysis was completed using the Water Survey of Canada daily stream flow data from the Whitemans Creek gauge 02GB008 near Mount Vernon for the period of record from 1961 to 2003.

6.1.3 Environmental Low Flows for Whitemans Creek

Three low flow thresholds have been calculated for Whitemans Creek near Mount Vernon, including a summer baseflow and two longitudinal connectivity flows, seen in **Table 12** (GRCA, 2005). Other values calculated in the 2005 study can be seen in **Appendix B**.

It should be noted that the observed flows for Whitemans Creek are heavily influenced in the June through September period by agricultural water takings from the creek. The resulting baseflows are not representative of the sustained flows maintained by groundwater discharge, as might be the case on other streams. Similarly, the flow statistics shown in **Appendix A** are not representative of the natural flow regime in the creek. For this reason, more weight has been given to the information derived from the hydraulic analysis of the creek channel in determining the ecological flow needs in the creek.

Table 12. Low flow thresholds for Whitemans Creek near Mount Vernon gauge

Threshold Name	Description	Flow Rate (m^3/s)
Longitudinal Connectivity (significant loss):	Hydraulic connectivity for fish migration associated with significant loss	0.8
Longitudinal Connectivity	Hydraulic connectivity for fish migration (20 cm flow depth)	1.0

6.1.4 Key E-Flow Threshold: Longitudinal Connectivity

The conservation of the coldwater fishery in Whitemans Creek is the key consideration for the maintenance of low environmental flows. Therefore, the key threshold to consider for Whitemans Creek is the longitudinal connectivity flow maintaining 20cm of flow depth over riffles.

From the analysis in the GRCA 2005 report, the connection for fish migration is first lost at 1.0m^3/s, interpreted from the hydraulic modeling results based on the 20cm depth criteria (see Appendix D in GRCA, 2005). Flows should be maintained between 0.8 to 1.0 m^3/s. Below the cut-off flow of 0.8m^3/s, 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, ultimately impacting the fishery. To avoid significant loss, the key e-flow threshold is recommended to be 1.0 m^3/s.

While connectivity flow was the key consideration, other statistics and hydraulic inflection points were calculated for consideration when identifying these thresholds (see **Appendix B**).

6.1.5 Field Observations to Support E-Flows

To verify the key e-flow threshold with more current and in-situ information, field measurements were available from 2012. In 2012, the Creek had fallen to the 1.0 m^3/s threshold by June 21, 2012 and the 0.8 m^3/s threshold by July 1, 2012 (Wong, 2012b). Field observations on July 13th (mean daily flow of 0.51 m^3/s) indicated that certain riffle crests had flow depths below 20cm (i.e. measured 17 cm at riffle crest by gauge station). In addition, field staff from the MNR on June 21st (mean daily flow of 1.02 m^3/s) and July 18th (mean daily flow was 0.45 m^3/s) documented fish stress indicators, including crowding by a coldwater tributary inlet to Whitemans Creek. These observations indicated that ideal conditions had been compromised due to the low flows and high temperatures of 2012.

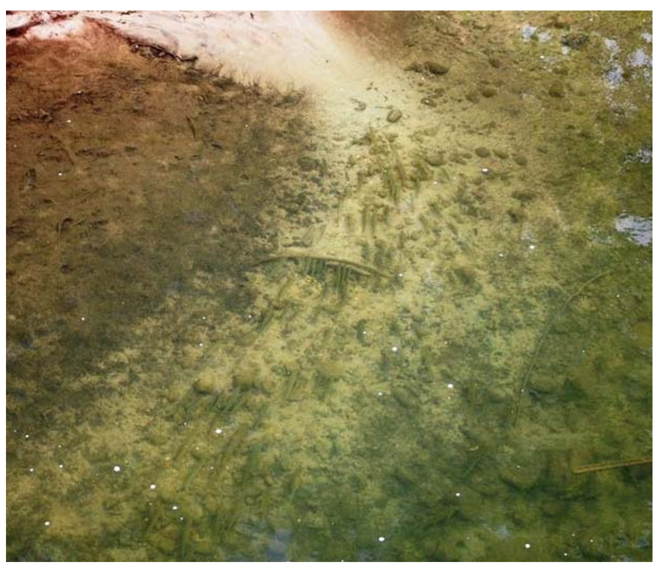

Figure 17. Picture of stress behavior in trout populations of Whitemans Creek. The largest trout in this picture is about 35 cm. (Photo taken July 18, 2012 by L. Halyk)

Stress behavior was observed in fish, including little movement and absence of territorial behavior, (see Figure 17). Fish were tolerant of crowding, were stacked together in a dense mass and were not hiding under cover (Halyk, 2012). Reported observations by MNR staff also stated “personal observations confirm that trout in Whitemans Creek are under severe stress due to low flow and high temperature conditions during the 2012 drought and that some mortality has already taken place.” Daily flows on June 21st were 1.02 m^3/s, but by July 18th, had dropped to 0.45 m^3/s (Wong, 2012b).

While the observations from 2012 are the most comprehensive, additional observations at the 1.0 m^3/s and 0.8 m^3/s flow rates would be beneficial. However, these observations are currently not available. A similar e-flows study was conducted by the Long Point Region Conservation Authority (LPRCA) in 2005. The LPRCA e-flow thresholds were based on more detailed aquatic ecology data. The stream studied in the Long Point Region project (see LPRCA, 2005) – Big Creek – has very similar watershed and stream geomorphological characteristics to Whitemans Creek. The LPRCA approach, when applied to Whitemans Creek, yielded similar e-flows thresholds, confirming a threshold of 0.8 m^3/s for longitudinal connectivity (for significant loss) that were tied to aquatic ecological needs (pers. comm. Boyd, 2005).

6.1.6 Comparison with Reserve Flows used in the Tier 2 Water Quantity Stress Assessment

The Tier 2 Water Quality Stress Assessment (Tier 2 WQSA) uses a reserve flow based on the 90th percentile observed flow (AquaResources Inc., 2009). The reserve flow and percent water demand calculations for Whitemans Creek are shown in **Table 13**. The low e-flow threshold of 1000 L/s is approximately an order of magnitude larger than the reserve flow in the later summer months. Because the observed flows are so heavily influenced by agricultural water taking in the summer months, the statistically derived reserve flow used in the Tier 2 WQSA is not comparable to the e-flow needs in the creek. Note that the key low e-flows threshold generally exceeds the supply in July and August.

Table 13. Whitemans Creek Tier 2 WQSA existing scenario supply and reserve estimates (ARI, 2009)

Assessment Area: Whiteman's Creek	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q_{SUPPLY}	4,870	4,160	5,490	5,940	4,470	1,870	790	930	1,060	2,380	4,870	5,490
$Q_{RESERVE}$	2,730	2,190	3,530	3,660	2,020	540	210	110	70	120	620	3,480
Difference	2,140	1,970	1,960	2,280	2,450	1,330	580	820	990	2,260	4,250	2,010

In the 2009 Tier 2 WQSA, Whitemans Creek (under existing conditions) had moderate potential for surface water stress. The percent water demand for July was above the 20% moderate threshold (at 38%), with August just below at 18%. However, if the reserve estimate is replaced by the key low e-flow threshold (1000 L/s) for June through September, there is a deficit of supply for July and August (see **Table 14**). When the significant loss low e-flow threshold (800 L/s) is used, only July is in deficit, but very little water supply is available in August (see

Table 15). This suggests that agricultural water takings in the summer months are not sustainable from an ecological perspective and a potential for conflict and constraint exists.

Table 14. Whitemans Creek refined surface water supply flows for longitudinal connectivity threshold

Assessment Area: Whiteman's Creek	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q_{SUPPLY}	4,870	4,160	5,490	5,940	4,470	1,870	790	930	1,060	2,380	4,870	5,490
$Q_{RESERVE}$	2,730	2,190	3,530	3,660	2,020	**1000**	**1000**	**1000**	**1000**	120	620	3,480

Difference	2,140	1,970	1,960	2,280	2,450	870	-210	-70	60	2,260	4,250	2,010
Note:	**1000**	Denotes replacement of reserve estimate with the key low e-flow threshold										

Table 15. Whitemans Creek refined surface water supply flows for significant loss threshold

Assessment Area: Whiteman's Creek	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q_{SUPPLY}	4,870	4,160	5,490	5,940	4,470	1,870	790	930	1,060	2,380	4,870	5,490
$Q_{RESERVE}$	2,730	2,190	3,530	3,660	2,020	**800**	**800**	**800**	**800**	120	620	3,480
Difference	2,140	1,970	1,960	2,280	2,450	1,070	-10	130	260	2,260	4,250	2,010
Note:	**800**	Denotes replacement of reserve estimate with the key low e-flow threshold										

6.1.7 Whitemans Low Flow Threshold: Conclusions and Recommendations

The ecological flow required in Whitemans Creek to sustain flow connectivity between the pools in the creek is 1.0 m^3/s (1000 L/s). This flow, if maintained as a minimum for short periods of time, should support a healthy coldwater fishery in Whitemans Creek.

The flow required to avoid impairment of aquatic life during extreme low flow periods is 0.8 m^3/s (800 L/s). This latter flow is an extreme condition, and should be used to inform the development of a drought management plan to deal with extreme low flow events such as those that occurred in 2012.

6.2 Eramosa River

The Eramosa River subwatershed of the Grand River (see **Figure 18**) supports much of the City of Guelph's water supply, as well as many other permitted takings. The subwatershed boasts the most extensive network of forest habitat in the watershed, with approximately 30% forest cover. The Eramosa River generally has a steady flow of high quality water, even during most summer months, due to significant groundwater discharge. The Eramosa River and its main tributary of Blue Springs Creek have some of the best coldwater water quality in the watershed.

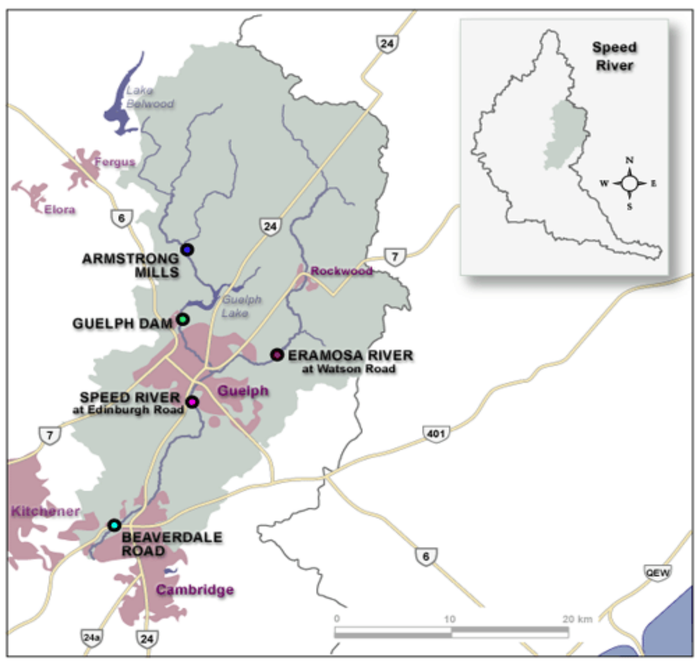

Figure 18. Eramosa and Speed River subwatersheds

The variety of water takings in the Eramosa River subwatershed and the need to maintain groundwater discharge are important considerations for establishing the low e-flow thresholds. The Eramosa

River supports healthy populations of brook trout in the headwaters to midwater reaches, and its main tributary of Blue Springs Creek also supports brown trout. Wetlands and karst topography help to buffer the system from water takings by providing baseflows.

Annual precipitation for the Eramosa River is 890 mm/yr, which is lower than the watershed average of 935 mm/yr. Evapotranspiration, estimated to be 505 mm/yr, is slightly higher than the Grand River watershed average (490 mm/yr). Due to the pervious soils and high percentage of hummocky topography, runoff (135 mm/yr) is significantly lower than the watershed average (260 mm/yr), and groundwater recharge (250 mm/yr) is much higher than the watershed average (180 mm/yr). The majority of the groundwater recharge would occur where coarse-textured soils are deposited, or where hummocky topography aids in groundwater recharge on the Galt and Paris Moraines.

6.2.1 Low Flow History

The flow history for the Eramosa River extrapolates the OLWRP thresholds to compare dry years to the severity of historic droughts or low flow years. **Figure 19** shows the number of occurrences of running 7-day average stream flows reaching each of the OLWRP levels as well as the annual rainfall totals. The red dots show the number of days the flows were at or below the Level 3 threshold.

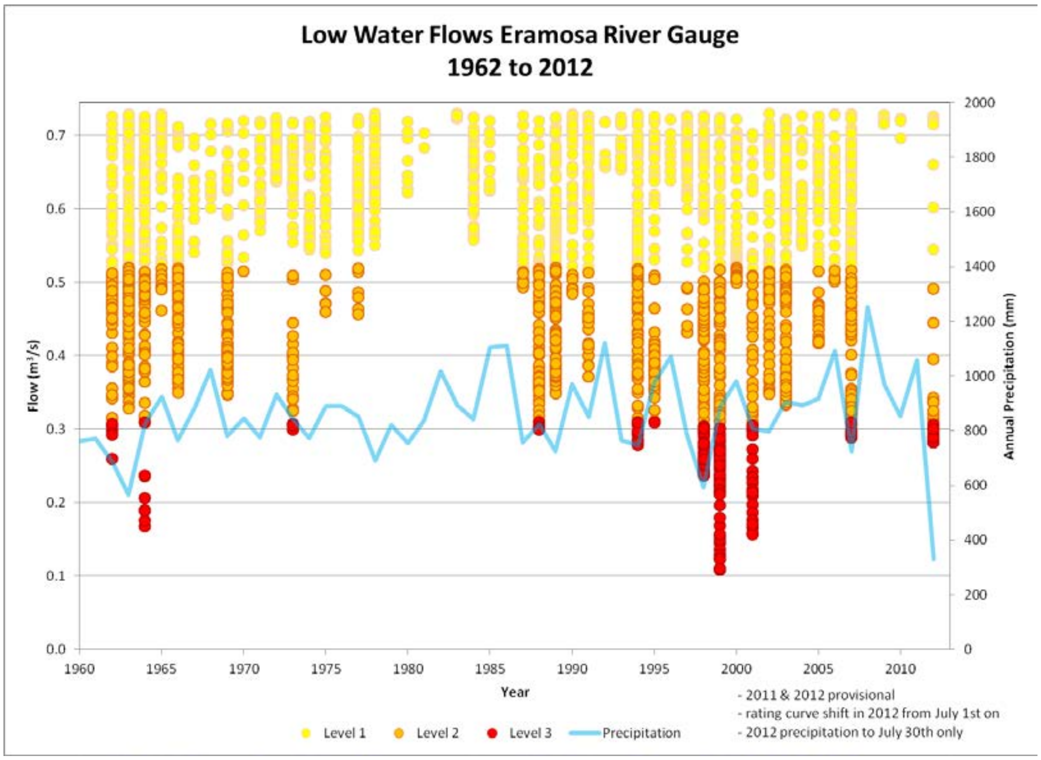

Figure 19. Eramosa River low water history

The greatest occurrence of low flows occurs in the month of September for the Eramosa River. A low flow month in August usually is a precursor to worse conditions in September. The worst years for low flows were 1989, 1998, 1999 and 2007.

6.2.2 Geomorphic Field Investigation and Analysis

The December 2003 survey was completed in the Eramosa River immediately upstream of the Watson Road gauge. Ten bankfull cross-sectional dimensions were quantified along 435m stretch of river. More information on the survey can be found in (Parish Geomorphic Ltd., 2004).

6.2.3 Environmental Low Flows for Eramosa River

Several e-flow thresholds were calculated for the Eramosa River at Watson Road as part of the 2005 study, these are summarized in **Appendix B**. The longitudinal connectivity flow is the key ecological flow threshold for low flows. At this flow, not only does fish passage become constrained, but the hydraulic modeling suggests flows start to become confined to the thalweg and the fringes (littoral zone) of the stream begin to be exposed in the study reach. The longitudinal connectivity flow value is seen in Table 16.

Table 16. Low flow thresholds for the Eramosa River at Watson Road gauge

Threshold Name	Description	Flow Rate (m^3/s)
Longitudinal Connectivity:	Hydraulic connectivity for fish migration (20 cm flow depth)	**0.5**

6.2.4 Key E-Flow Threshold: Longitudinal Connectivity

The conservation of the coldwater fishery in the Eramosa River is the key consideration for the maintenance of low environmental flows. Therefore, the key threshold to consider for is the longitudinal connectivity flow maintaining 20 cm of flow depth over riffles.

From the analysis in GRCA (2005), the connection for fish migration is first lost at 0.5 m^3/s, interpreted from the hydraulic modeling results based on the 20cm depth criteria (see Appendix D in GRCA, 2005). Below the cut-off flow of 0.5 m^3/s, 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 and the fishery would be impacted. To avoid significant loss, the key e-flow threshold is recommended to be 0.5 m^3/s.

The Eramosa River currently has a municipal Permit to Take Water (PTTW) for the City of Guelph, which does not permit water takings when river flows drop below 0.42 m^3/s. This PTTW is used to draw surface water for recharging a shallow groundwater aquifer. In terms of protecting the ecology of the Eramosa River, this PTTW seems well designed, aligning with the analysis of e-flow needs of the Eramosa River. The e-flows analysis provides a good confirmation that the PTTW threshold is in the right order of magnitude and there would be no need to adjust PTTW cut-off flow higher to meet the e-flows criteria.

6.2.5 Comparison with Reserve Flows used in the Tier 2 Water Quantity Stress Assessment

The Tier 2 Water Quality Stress Assessment (Tier 2 WQSA) uses a reserve flow based on the 90th percentile observed flow (AquaResources Inc., 2009). The reserve flow and percent water demand calculations for the Eramosa River are shown in **Table 17**. The low e-flow threshold of 0.5 m^3/s approximates the reserve flows from July through October.

Table 17. Eramosa River Tier 2 WQSA existing scenario supply and reserve estimates (ARI, 2009)

Assessment Area: Eramosa River	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q_{SUPPLY}	2,350	2,060	2,660	2,960	2,500	1,780	1,120	830	780	1,250	2,430	2,440
$Q_{RESERVE}$	1,280	1,140	1,750	2,090	1,650	880	610	490	430	440	750	1,210
Difference	1,070	920	910	870	850	900	510	340	350	810	1,680	1,230

In the 2009 Tier 2 WQSA, the Eramosa River (under existing conditions) had moderate potential for surface water stress. The percent water demands for August and September were above the 20% moderate stress threshold (at 25% and 24%, respectively). With the slight increase in the reserve flow to match the key low e-flow threshold, the availability of flow is only marginally lower (see Table 18); however, it may impact water availability for water takings.

Table 18. Eramosa River refined surface water supply flows

Assessment Area: Eramosa River	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q_{SUPPLY}	2,350	2,060	2,660	2,960	2,500	1,780	1,120	830	780	1,250	2,430	2,440
$Q_{RESERVE}$	1,280	1,140	1,750	2,090	1,650	880	610	**500**	**500**	**500**	750	1,210
Difference	1,070	920	910	870	850	900	510	**330**	**280**	**750**	1,680	1,230
Note:	**1000**	Denotes replacement of reserve estimate with the key low e-flow threshold										

It is anticipated that future water use will increase in this subwatershed based on population projections of municipal water demand, as well as increases in other water sector demands. The percent water demands for August and September increase to 26% and 30%, respectively with the change in surface water supplies. The replaced reserve flow does not change the category of potential stress (moderate) for those months.

6.2.6 Eramosa River Low Flow Threshold: Conclusions and Recommendations

The e-flow required in the Eramosa River to sustain flow connectivity between the pools is 0.5 m^3/s (500 L/s). This flow, if maintained as a minimum for short periods of time, should support a healthy cold-water fishery in the Eramosa River.

7 Conclusions

Establishing environmental flow requirements in the Grand River watershed are necessary for a flow regime that supports healthy aquatic ecosystems in both the regulated and unregulated reaches. The Environmental Flows Working Group adapted a suite of flow thresholds to build a flow regime to achieve this objective. Previous work on e-flows has been supplemented continuously since 2005 to refine the needs of the river and has all been utilized in establishing more natural variability in regulated flows. In addition, better understanding of the needs of the aquatic habitat and ecology during low flows has been progressing as thresholds are tested and verified.

Environmental flow needs and opportunities vary by river reach. Characterizing river reaches will be an important step to better understanding environmental flow needs, to identifying barriers and to identifying opportunities for restoration or enhancement. Figures 5 and 6 in this report illustrate how longitudinal profile of a river reach can be used to classify river reaches and identify barriers. The classification of river reaches needs to be complimented with an understanding of the life cycle requirements of a range of indicator specifies. The combination of reach classification, knowledge of a range of life cycle requirements, coupled with flow, hydraulic and water quality information create a framework for analyzing and where possible adapting to the e-flow needs in various river reaches.

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8 E-Flows Regime Recommendations

It is recommended that the newly established e-flow regime flow thresholds be verified during the next several years to determine whether the flows are meeting their intended purpose. This may require adjusting flows and spot verifying in the field as these events occur.

As many of the flow thresholds are deterministic (calculated following a designated procedure), Copeland *et al.* (2000) give the suggestion that deterministic thresholds should be confirmed using field indicators.

In the regulated reaches, the recommendation is to investigate the feasibility of trying to meet the e-flow thresholds requirements without sacrificing their reliability to meet low flow requirements or endangering recreational users or structures and inhabitants in the floodplain. Awareness of the e-flow requirements should be integrated into the operating procedures and the practicality of meeting the e-flows thresholds should be assessed. Generally, this would require slight alterations to the duration, timing or frequency to the operating schedule to accommodate the environmental needs during higher flow periods.

In order to link e-flows to aquatic biology in the Grand River watershed, further investigation and field verification of e-flows thresholds are recommended. More comprehensive observations and data collection, such as that in Whitemans Creek in 2012 (Halyk, 2012), would improve our understanding of the biological targets that the e-flows are trying to achieve and help justify the outlined targets. Biomonitoring could specifically help monitor the ecological conditions of the Grand and Nith Rivers during e-flows thresholds. Research is needed to develop practical cost effective approaches to biological monitoring for a range of water courses from headwaters to larger rivers. This is an area where University researchers could assist by sourcing funding and completing research to develop cost effective practical approaches.

During the low flow periods, often the e-flows thresholds are similar to the reservoir target flows. Considerations of flow augmentation adjustments are limited, as operations must ensure the reservoirs adequately meet other targets throughout the summer and fall. The low e-flow thresholds should be used to inform and compliment drought contingency planning efforts.

An area of research that could advance the understanding of e-flows and assist water managers is in respect to life cycle preferences for a range of indicator species. **Figure 4** in this report illustrates the life cycle preferences for warm water and cold water fish. This sort of information needs to be developed for a range of indicator species. This range of species and their preferences can help better inform water managers, and where possibly operational approaches can be refined to better compliment ecological life cycle preferences for a range of species.

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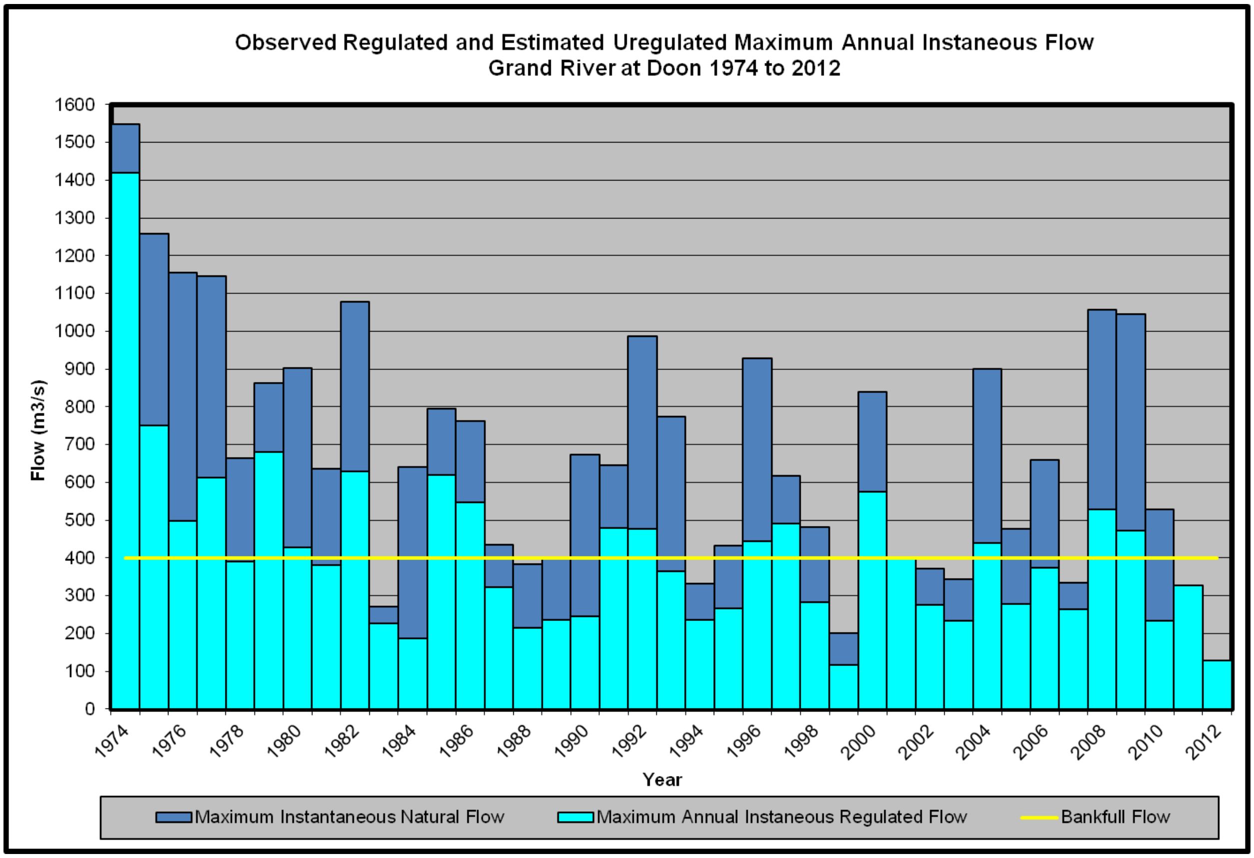
10 Appendix A: Historic Flow Occurrences Tables and Charts

10.1 Central Grand River near Doon



Grand River at Doon Occurrences of Mean Daily Flows Greater than Bed Mobilizing Flow Threshold ($187\ m^3/s$)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1984		1											1	0
1985		1	4	5									10	0
1986			1						6	1			8	7
1987				2									2	0
1990			1									1	2	0
1991			2	2									4	0
1992			1	3	1			2			3		10	3
1993	2			1									3	0
1995				1									1	0
1996	1			3	1								5	1
1997		1	3										4	0
1998	1		3										4	0
2000					3	3							6	6

Grand River at Doon Occurrences of Mean Daily Flows Greater than Bed Mobilizing Flow Threshold ($187\ m^3/s$)														
2001		1		4									5	0
2002			1	1									2	0
2003											1		1	0
2004			6	1	1								8	1
2005	5												5	0
2006			5									2	7	0
2007			2	1									3	0
2008	5			9								4	18	0
2009	2	4	4										10	0
2010			1			1							2	1
2011			3		1						1		5	1
Total	16	8	37	33	7	4	0	2	6	1	5	7	126	20

Grand River at Doon Occurrences of Mean Daily Flows Greater than Scouring Flow Threshold ($85\ m^3/s$)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1984		13	9	9								5	36	0
1985		4	14	16							2	2	38	0
1986			10		1			2	20	9			42	32
1987			8	8							1	5	22	0
1988		3	4	4									11	0
1989			6	6		2					1		15	2
1990			10		1					5	8	6	30	6
1991	2		14	10									26	0
1992			6	9	2			6	3		19		45	11
1993	11		3	11		3							28	3
1994			2	7	2								11	2
1995	10		5	3		1					5		24	1
1996	7		1	13	5	3					2	7	38	8
1997	2	8	11	8	1								30	1
1998	6		7										13	0
2000		3		3	7	8	1	1					23	17
2001		10	4	10						1	1	6	32	1
2002		3	6	6	2								17	2
2003			8	2	1						7	3	21	1
2004	6		12	3	5	1						3	30	6
2005	11	1	3	12							1	2	30	0
2006	9	9	9	3						2	3	9	44	2
2007	4		10	5									19	0

Grand River at Doon Occurrences of Mean Daily Flows Greater than Scouring Flow Threshold ($85\ m^3/s$)

2008	9	5		14					3		5	10	46	3
2009	4	9	6	5	5								29	5
2010			7		1	3	2					1	14	6
2011	4	1	17	9	5					2	1	2	41	7
2012	3	1	3		1								8	1
Total	88	70	195	176	39	21	3	9	26	19	56	61	763	117

Grand River at Doon Occurrences of Hourly Flows Greater than Bankfull Flow Threshold ($400\ m^3/s$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1986									25				25	25
1991			11	24									35	0
1992				1							22		23	0
1996	2												2	0
1997		10	21										31	0
2000					19	26							45	45
2004			10										10	0
2008	14			12								42	68	0
2009		12											12	0
Total	16	22	42	37	19	26	0	0	25	0	22	42	251	70

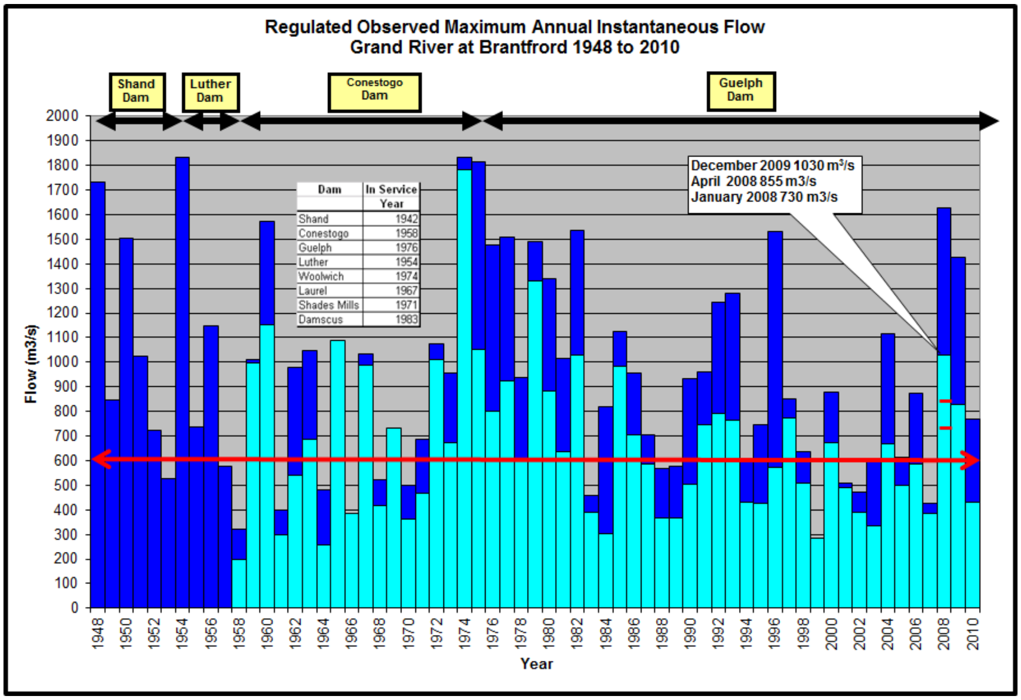
Grand River at Doon Occurences of Mean Daily Flows Greater than Macrophyte Flushing Flow Threshold ($297\ m^3/s$)

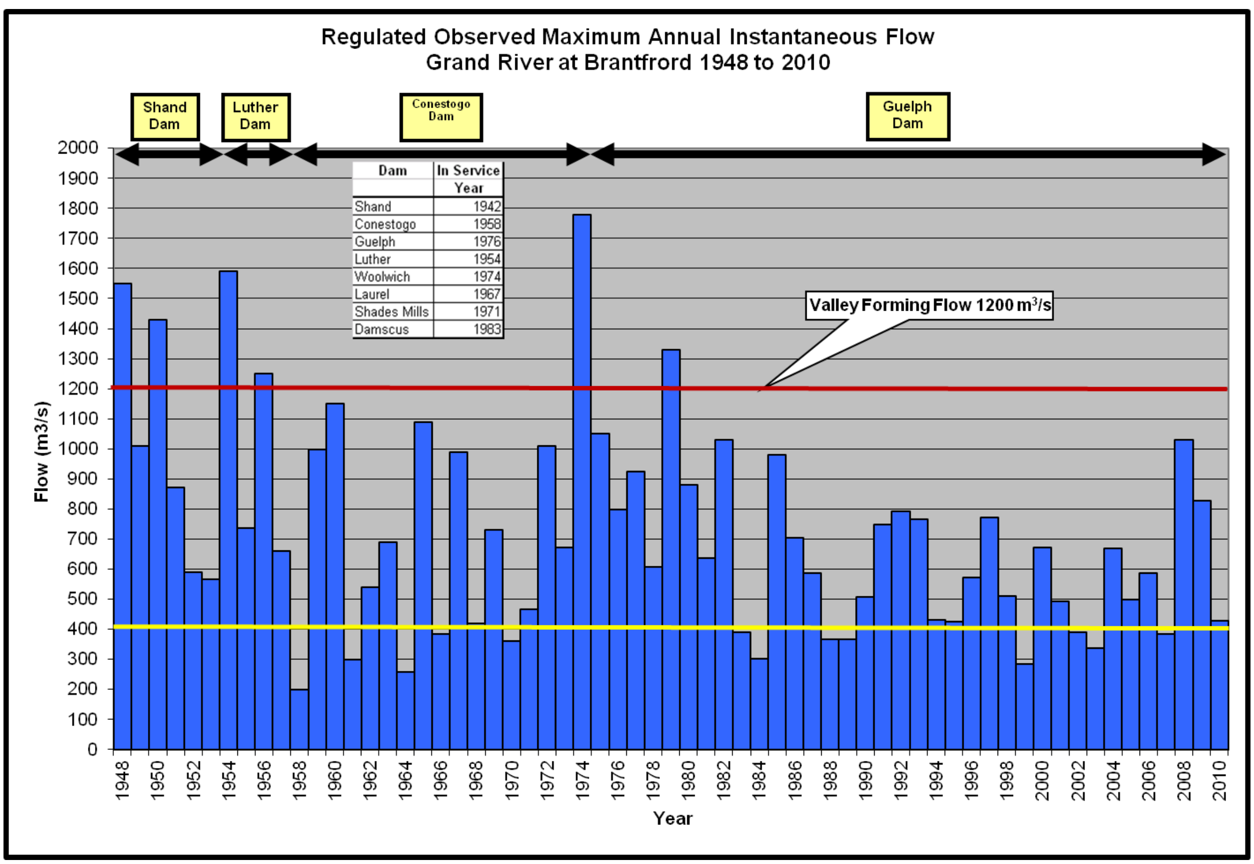
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1985			2	2									4	0
1986									2				2	2
1987				1									1	0
1991			2	1									3	0
1992				1							1		2	0
1993	1												1	0
1996				1									1	0
1997		1	1										2	0
2000					2	1							3	3
2001				1									1	0
2004			1		1								2	1
2006			1									1	2	0
2008	2			5								4	11	0
2009		2											2	0
2011			1										1	0
Total	3	3	8	12	3	1	0	0	2	0	1	5	38	6

Grand River at Doon Occurrences of Mean Daily Flow less than the littoral zone maintenance flow threshold (8.5 m^3/s)														
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1984	6	11											17	0
1986		2	8										10	0
1987	1					1							2	1
1991												10	10	0
1992		6											6	0
1993			4									3	7	0
1994	22												22	0
1995	11	23	6										40	0
1996	2												2	0
1997	7												7	0
1998									2	26	29	29	86	28
1999	22				14	3	3	1					43	21
2000		19										2	21	0
2002										1	23	27	51	1
2003	31	28	15										74	0
2004												1	1	0
2005												9	9	0
2007	1	28	11							29	27	15	111	29
2008	3												3	0
2011												9	9	0
2012							3	17	18	13			51	51
Total	106	117	44	0	14	4	6	18	20	69	79	105	582	131

Grand River at Doon Occurences of Mean Daily Flows Less than Connectivity Flow Threshold (6.8 m^3/s)														
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1984		3											3	0
1987						1							1	1
1993												1	1	0
1995	9	7	4										20	0
1997	4												4	0
1998										21	14	25	60	21
1999	22												22	0
2000		2										1	3	0
2002											3	21	24	0
2003	30	28	15										73	0
2007			10							4	13	9	36	4
2008	1												1	0
2011												9	9	0
2012										1			1	1
Total	66	40	29	0	0	1	0	0	0	26	30	66	258	27

10.2 Grand River near Brantford





Grand River at Brantford Occurences of Daily Mean Flow Exceeding Bed Mobilizing Flow Threshold ($161\ m^3/s$)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1984		14	10	9								3	36	0
1985	3	4	19	15							11	3	55	0
1986			19		1			2	17	9			48	29
1987			10	9								4	23	0
1988		2	5	4									11	0
1989			7	4		1							12	1
1990	2	5	9		1					2	2	3	24	3
1991	2		17	11									30	0
1992			5	6	2			4	2		17	1	37	8
1993	8		4	12		2							26	2
1994			4	8	1								13	1
1995	10		3	5							4		22	0
1996	7	5	2	14	7	3						6	44	10
1997	3	9	11	8	1								32	1
1998	7		7										14	0
1999											2	4	6	0
2000		4		2	5	6		2					19	13
2001		9	3	9								4	25	0
2002		3	5	6	2								16	2
2003			9	3							9	2	23	0
2004	4		11	3	5	1							24	6
2005	10	4	3	10							1	2	30	0
2006	6	8	9	1						2	3	15	44	2
2007	3		9	2									14	0
2008	8	9		14					3		5	9	48	3
2009	4	9	8	5	3								29	3
2010			6		1	2							9	3
2011	23	28	22	8	4					2	1	10	98	6
2012	1	1	2										4	0
Total	101	114	219	168	33	15	0	8	22	15	55	66	816	93

Grand River at Brantford Occurrences of Daily Mean Flow Exceeding Scour/Deposition Flow Threshold ($79\ m^3/s$)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1984		16	14	13		3					2	11	59	3
1985	6	5	31	23				3	4	1	26	16	115	8

Grand River at Brantford Occurrences of Daily Mean Flow Exceeding Scour/Deposition Flow Threshold (79 m^3/s)

1986	7		20	8	6			5	20	21	4	4	95	52
1987			19	15				1			5	21	61	1
1988		5	14	10							12	1	42	0
1989	5	2	9	15		7					7	2	47	7
1990	12	11	17	8	5					14	21	28	116	19
1991	5	8	25	27			3					4	72	3
1992			8	18	4		7	10	19	8	28	14	116	48
1993	16		5	27		4					3	1	56	4
1994		5	9	25	13								52	13
1995	13		17	9	3	2					20	6	70	5
1996	14	9	22	22	17	13			3	2	6	20	128	35
1997	12	16	27	18	16		2				4		95	18
1998	10	10	24	8									52	0
1999	2	4	2						3		8	11	30	3
2000		5	1	6	14	14	6	4	1		3	6	60	39
2001		20	23	15	5					3	3	14	83	8
2002		8	18	17	10	2							55	12
2003			14	9	7						18	21	69	7
2004	7		21	9	16	3					2	9	67	19
2005	15	6	6	19	2		1				4	4	57	3
2006	21	17	12	14	3					19	16	28	130	22
2007	16		17	13								1	47	0
2008	10	21	16	17	2		7	3	8		10	20	114	20
2009	5	14	20	19	12	1				1		2	74	14
2010			11	4	3	3	6					4	31	12
2011	27	28	26	24	21	4				4	2	19	155	29
2012	15	7	12		1					2	3		40	3
Total	218	217	460	412	160	56	32	26	58	75	207	267	2188	407

Grand River at Brantford Occurrences of Hourly Flows Exceeding Floodplain Spawning Flow Threshold (300 m^3/s)

Year	Mar	Apr	May	Jun	Jul	Mar-Jun Total
1985	5	7				12
1986	5					5
1987		3				3
1988	2	1				3
1989	2					2
1990	3					3
1991	4	2				6

Grand River at Brantford Occurrences of Hourly Flows Exceeding Floodplain Spawning Flow Threshold (300 m^3/s)

1992	2	2				4
1993	3	3				6
1994	1	1				2
1995		1				1
1996		6	1			7
1997	3					3
1998	2					2
2000			2	3		5
2001		3				3
2002		1				1
2004	6	1	2			9
2006	7					7
2007	3					3
2008		9				9
2009	4					4
2010	3					3
2011	10		1			11
Total	65	40	6	3		**114**

Grand River at Brantford Occurrences of Hourly Flows Exceeding Nutrient Cycling Flow Threshold (405 m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1985		50	73	95									218	0
1986			21						88	38			147	126
1987				37									37	0
1990			48										48	0
1991			51	45									96	0
1992			5	41				14			55		115	14
1993	58		40	17									115	0
1994			11										11	0
1996				50	24								74	24
1997		62	54										116	0
1998			34										34	0
2000					45	32							77	77
2001				25									25	0
2004			57		22								79	22
2005	26												26	0
2006			74									31	105	0
2008	53			143								96	292	0
2009	1	48	15										64	0
2010			13										13	0

Grand River at Brantford Occurrences of Hourly Flows Exceeding Nutrient Cycling Flow Threshold (405 m³/s)

2011		143	45								5	26	219	0
Total	138	303	541	453	91	32	0	14	88	38	60	153	1911	263

Grand River at Brantford Occurrences of Daily Mean Flow Exceeding Macrophyte Flushing Flow Threshold (102 m³/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1984		14	14	10		1					2	8	49	1
1985	5	5	31	19				1			25	11	97	1
1986	5		20	4	5			3	20	18	2		77	46
1987			16	10							4	10	40	0
1988		4	12	7							4		27	0
1989	1	2	9	10		4					3		29	4
1990	6	8	14	2	3					9	10	10	62	12
1991	3	2	23	21								2	51	0
1992			7	17	4		3	7	11	3	26	9	87	28
1993	13		4	20		3					1		41	3
1994		3	9	22	7								41	7
1995	12		14	8		2					13	1	50	2
1996	12	8	9	19	14	9			2		3	13	89	25
1997	8	12	13	9	7		1				1		51	8
1998	9	4	14	4									31	0
1999		2							1		5	5	13	1
2000		5		5	9	10	1	3					33	23
2001		17	12	14	5					1	1	9	59	6
2002		7	12	10	6	2							37	8
2003			13	4	3						13	11	44	3
2004	6		16	5	12	3						7	49	15
2005	12	5	5	16	1		1				1	3	44	2
2006	16	14	10	7						8	5	24	84	8
2007	7		14	4									25	0
2008	9	15	9	16			3	1	5		8	12	78	9
2009	5	12	13	15	8								53	8
2010			9	2	2	3	3					3	22	8
2011	26	28	25	16	15					3	2	14	129	18
2012	6	3	7							1	2		19	1
Total	161	170	354	296	101	37	12	15	39	43	131	152	1511	247

Grand River at Brantford Occurrences of Daily Mean Flows less than Littoral Zone Maintenance Flow Threshold (19 m³/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1988						12	17	12	6			1	48	47
1989							5	22	27	10			64	64
1991							3	3	3				9	9
1992		5											5	0

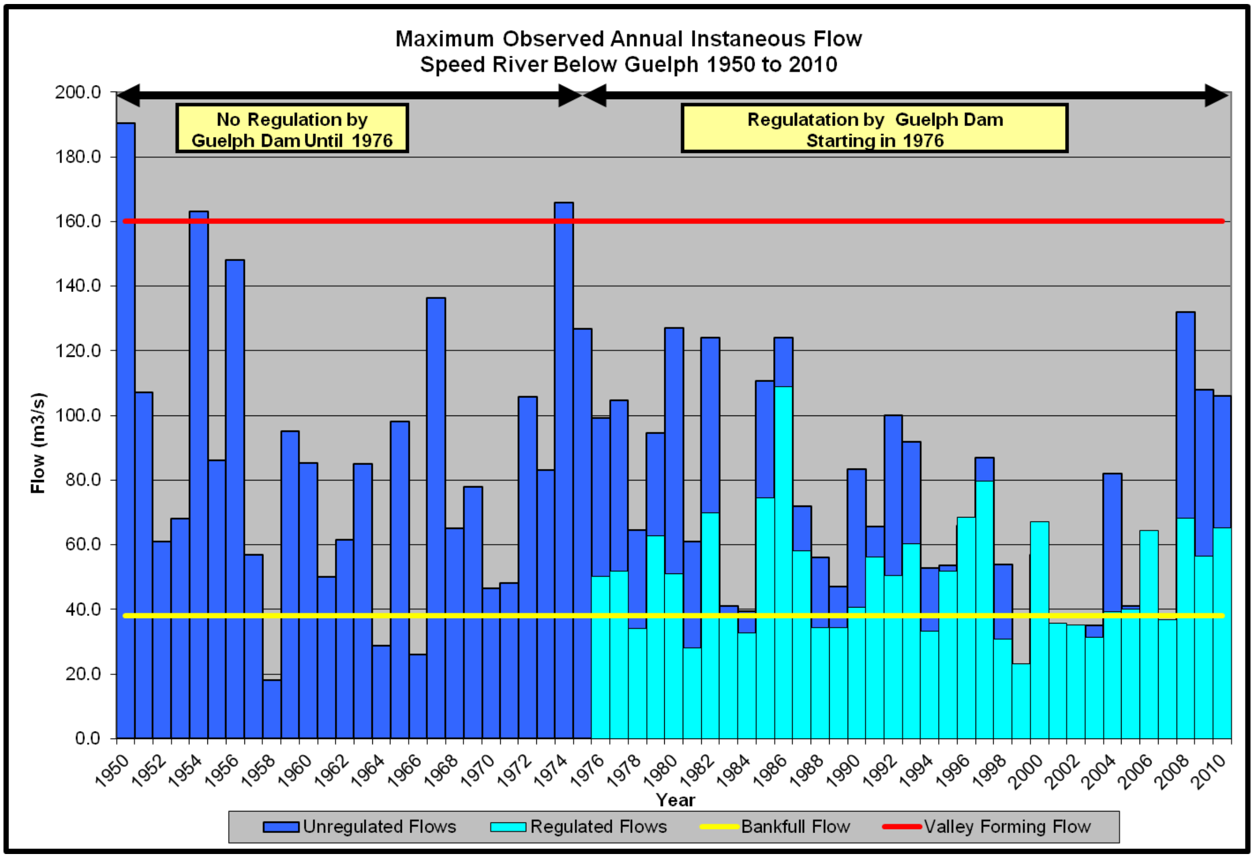
Grand River at Brantford Occurrences of Daily Mean Flows less than Littoral Zone Maintenance Flow Threshold (19 m^3/s)

1994	13								3				16	3
1995	8	3	5					1	3	2			22	6
1998							7	19	28	29	28	23	134	83
1999	22				3		13	8	1				47	25
2000		6											6	0
2001							10	15	14	1			40	40
2002									7	6		6	19	13
2003	17	25	15						10				67	10
2004										2			2	2
2005							11	3	3				17	17
2007						2	13	17	22	27	20	3	104	81
2012						1	22	21	13	10	3		70	67
Total	60	39	20	0	3	15	101	121	140	87	51	33	670	467

Grand River at Brantford Occurrences of Daily Mean Flows less than Longitudinal Connectivity Flow Threshold (8.8 m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1999	9												9	0
Total	9	0	0	0	0	0	0	0	0	0	0	0	9	0

10.3 Speed River at Guelph



Speed River Below Guelph Occurrences of Mean Daily Flows that exceed the Bed Mobilizing Flow Threshold (26 m^3/s)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1984		2		2									4	0
1985			4	10									14	0
1986			2					2	12	6			22	20
1987			1	4									5	0
1988			2	1									3	0
1989			3										3	0
1990			3									1	4	0
1991			3	6									9	0
1992				4	2			3			5		14	5
1993	4		1	3		1							9	1
1994				2									2	0
1995	1												1	0
1996	1			9	2								12	2
1997		7	6	7									20	0
1998			2										2	0
2000					1	3		1					5	5
2001				4									4	0
2002				2									2	0

Speed River Below Guelph Occurrences of Mean Daily Flows that exceed the Bed Mobilizing Flow Threshold (26 m^3/s)														
2004			4	2	2								8	2
2005			1	7									8	0
2006			5									3	8	0
2007			3										3	0
2008	3			13								4	20	0
2009	2	7	5	3	1								18	1
2010			4										4	0
2011			5		3						1	4	13	3
Total	11	16	54	79	11	4	0	6	12	6	6	12	217	39

Speed River Below Guelph Occurrences of Mean Daily Flows that exceed the Scour/Deposition Flow Threshold (7.9 m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1984		16	16	25	2							2	61	2
1985	6	5	31	27			2	3	6		27	23	130	11
1986	1		19	18	7		5	6	28	31	11	18	144	77
1987	2		19	20								9	50	0
1988		3	9	11							2		25	0
1989	1	3	8	15	6	10					3		46	16
1990	2	11	16	6	6					6	5	17	69	12
1991	9	1	24	30	14								78	14
1992			4	20	8		2	8	12	12	27	19	112	42
1993	25		4	28	2	5					1		65	7
1994			8	26	18								52	18
1995	15		13	10	7	4		1			20	7	77	12
1996	12	7	12	26	25	15			3	1		15	116	44
1997	17	8	16	20	18						2		81	18
1998	6		19	11	5								41	5
1999	1										8	3	12	0
2000		5	1	5	15	14	5	7					52	41
2001		17	9	19	5						1	15	66	5
2002		5	20	20	17	1							63	18
2003			12	7	6						10	12	47	6
2004	6		19	19	22	2						5	73	24
2005	12	2	4	21	3						2	4	48	3
2006	10	15	13	22	11		2			22	8	21	124	35
2007	13		11	26	5								55	5
2008	9	20	5	24	10		5	11	10		5	22	121	36
2009	9	17	30	25	21	1				3			106	25
2010			15	6	5	4	1					3	34	10
2011	13	15	20	26	24	13				3	7	19	140	40
2012	11	12	22									1	46	0
Total	180	162	399	513	262	69	22	36	59	78	139	215	2134	526

Speed River Below Guelph Occurrences of Mean Daily Flows that exceed the Floodplain Spawning (26 m^3/s)					
Year	**Mar**	**Apr**	**May**	**Jun**	**Annual Total**
1984	**2**	**3**			**5**
1985	**4**	**10**			**14**
1986	**4**				**4**
1987	**2**	**5**			**7**
1988	**3**	**2**			**5**
1989	**3**				**3**
1990	**5**				**5**
1991	**4**	**9**			**13**
1992		**5**	**2**		**7**
1993	**2**	**6**		**1**	**9**
1994		**3**			**3**
1995		**2**			**2**
1996		**10**	**3**		**13**
1997	**8**	**8**			**16**
1998	**2**				**2**
2000			**1**	**3**	**4**
2001		**5**			**5**
2002		**3**			**3**
2004	**4**	**3**	**3**		**10**
2005	**1**	**8**			**9**
2006	**7**				**7**
2007	**3**				**3**
2008		**14**			**14**
2009	**5**	**3**	**1**		**9**
2010	**5**				**5**
2011	**6**		**3**		**9**
Total	**70**	**99**	**13**	**4**	**186**

Speed River Below Guelph Occurrences of Hourly Flows that exceed the Nutrient Cycling Threshold (38 m^3/s)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1985			9	118									127	0
1986								17	120	64			201	201
1987				64									64	0
1990			9										9	0
1991			52	40									92	0
1992				40	13						26		79	13
1993	36		5	28									69	0
1996				39	2					2			43	4
2000					2								2	2
2004			23										23	0
2005				27									27	0
2006			89										89	0

Speed River Below Guelph Occurrences of Hourly Flows that exceed the Nutrient Cycling Threshold ($38\ m^3/s$)

2008	38			284								78	400	0
2009	35	48											83	0
2010			66										66	0
2011			50								11	37	98	0
Total	109	48	303	640	17	0	0	17	120	66	37	115	1472	220

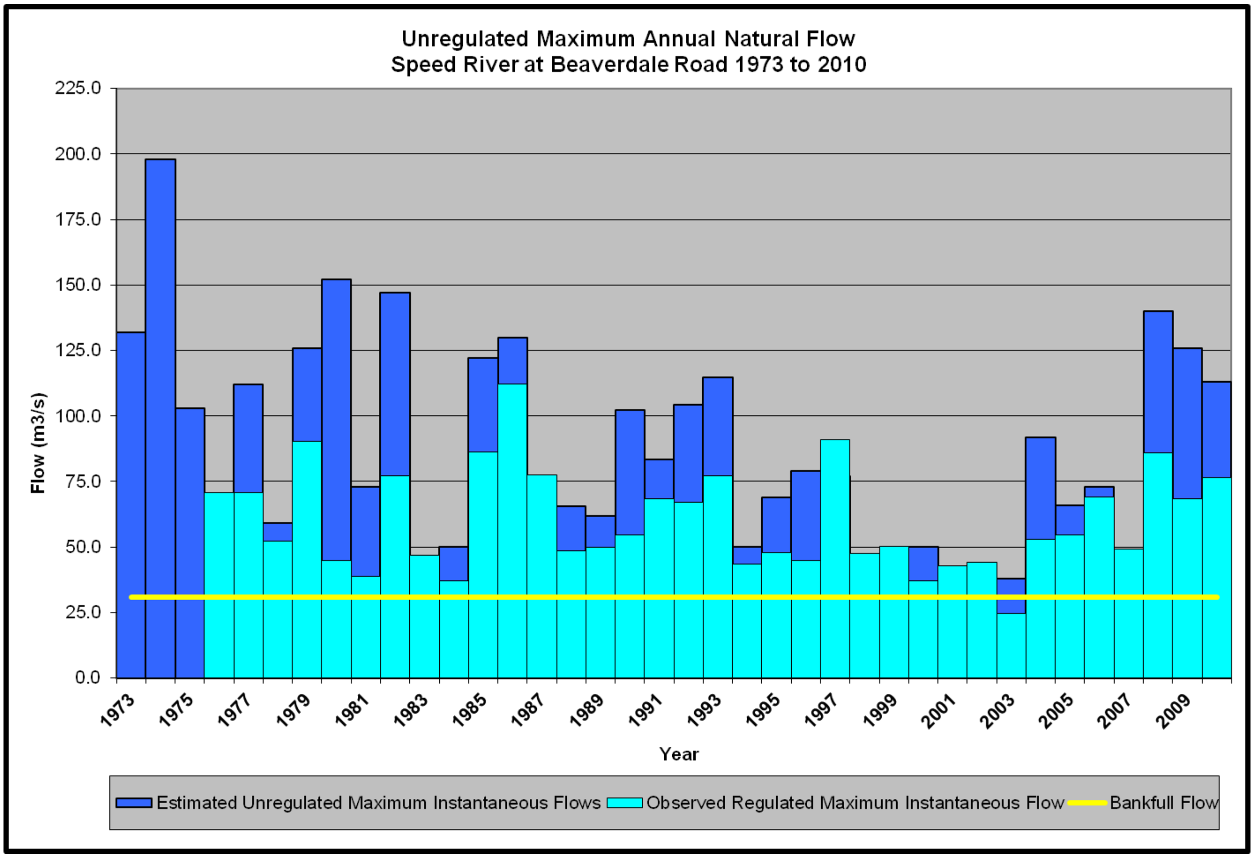
Speed River Below Guelph Occurrences of Mean Daily Flows that exceed the Macrophyte Flushing Threshold ($57\ m^3/s$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1985			2	3									5	0
1986									3	1			4	4
1997			2										2	0
2006			1										1	0
2008												2	2	0
2010			1										1	0
Total	0	0	6	3	0	0	0	0	3	1	0	2	15	4

Speed River Below Guelph Occurrences of Mean Daily Flows less than the Littoral zone maintenance flow Threshold ($1.1\ m^3/s$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1984								8					8	8
1997								9				2	11	9
2001									4				4	4
2003	7	5	15										27	0
2007										1	5	1	7	1
2012												3	3	0
Total	7	5	15	0	0	0	0	17	4	1	5	6	60	22

10.4 Speed River in Cambridge



Speed River at Hespeler Occurrences of Daily Flows Exceeding the Bed Mobilizing Flow Threshold ($47\ m^3/s$)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1985			4	7									11	0
1986								2	6	4			12	12
1987				3									3	0
1988			1										1	0
1989			1										1	0
1990			2										2	0
1991			2										2	0
1992				2				1			3		6	1
1993	3			2									5	0
1997		3	2										5	0
2004			1										1	0
2005				2									2	0
2006			3									1	4	0
2008				12								4	16	0
2009		2											2	0
2010			2										2	0
2011			1										1	0
Total	3	5	19	28	0	0	0	3	6	4	3	5	76	13

Speed River at Hespeler Occurrences of Daily Flows Exceeding the Scour/Deposition Flow Threshold (37 m^3/s)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1985		1	4	8									13	0
1986			2					3	9	7				
1987				3									3	0
1988			3	1									4	0
1989			3										3	0
1990			4									2	6	0
1991			3	1									4	0
1992				2	1			2			6		11	3
1993	4		3	8									15	0
1994				2									2	0
1995	2												2	0
1996	2	1		4	2								9	2
1997		6	6	1									13	0
1998			3										3	0
2001				2									2	0
2002				1									1	0
2004			4	2									6	0
2005			1	5									6	0
2006			4									2	6	0
2007			3										3	0
2008	1			14								4	19	0
2009	1	5	2	1									9	0
2010			4										4	0
2011			4		3							2	9	3
Total	10	13	53	55	6	0	0	5	9	7	6	10	153	8

Speed River at Hespeler Occurrences of Daily Flows Exceeding the Floodplain Spawning Flow Threshold (50 m^3/s)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1985			3	6									9	0
1986								1	5	3			9	9
1987				3									3	0
1990			1										1	0
1991			1										1	0
1992				2				1			2		5	1
1993	3			1									4	0
1997		3	2										5	0
2004			1										1	0
2006			3										3	0
2008				12								4	16	0
2009		2											2	0
2010			2										2	0
2011			1										1	0

Speed River at Hespeler Occurrences of Daily Flows Exceeding the Floodplain Spawning Flow Threshold (50 m^3/s)														
Total	3	5	14	24	0	0	0	2	5	3	2	4	62	10

Speed River at Hespeler Occurrences of Daily Flows Exceeding the Floodplain Nutrient Cycling Threshold (32 m^3/s)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1984		1	1	3									5	0
1985		2	10	10									22	0
1986			3					3	15	7			28	25
1987			3	5									8	0
1988			3	3									6	0
1989			3										3	0
1990			5									2	7	0
1991	1		4	2									7	0
1992				4	2			3			11		20	5
1993	5		3	10		1							19	1
1994				2									2	0
1995	3												3	0
1996	4	1		5	3								13	3
1997		7	8	4									19	0
1998			3										3	0
2000						1		1					2	2
2001		1		4									5	0
2002				2									2	0
2004			5	3	1								9	1
2005			1	8									9	0
2006			8									4	12	0
2007			3										3	0
2008	3			14								4	21	0
2009	2	6	5	3									16	0
2010			4										4	0
2011			7		3						1	2	13	3
Total	18	18	79	82	9	2	0	7	15	7	12	12	261	40

Speed River at Hespeler Occurances of Daily Flows Exceeding the Macrophyte Flushing Threshold (31 m^3/s)														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**	**May-Oct Total**
1984	2	4	2	3									11	0
1985		3	10	10									23	0
1986			3					3	16	7			29	26
1987			3	6									9	0
1988			3	3									6	0
1989			3										3	0
1990			6									2	8	0
1991	1		4	3									8	0

Speed River at Hespeler Occurances of Daily Flows Exceeding the Macrophyte Flushing Threshold (31 m^3/s)

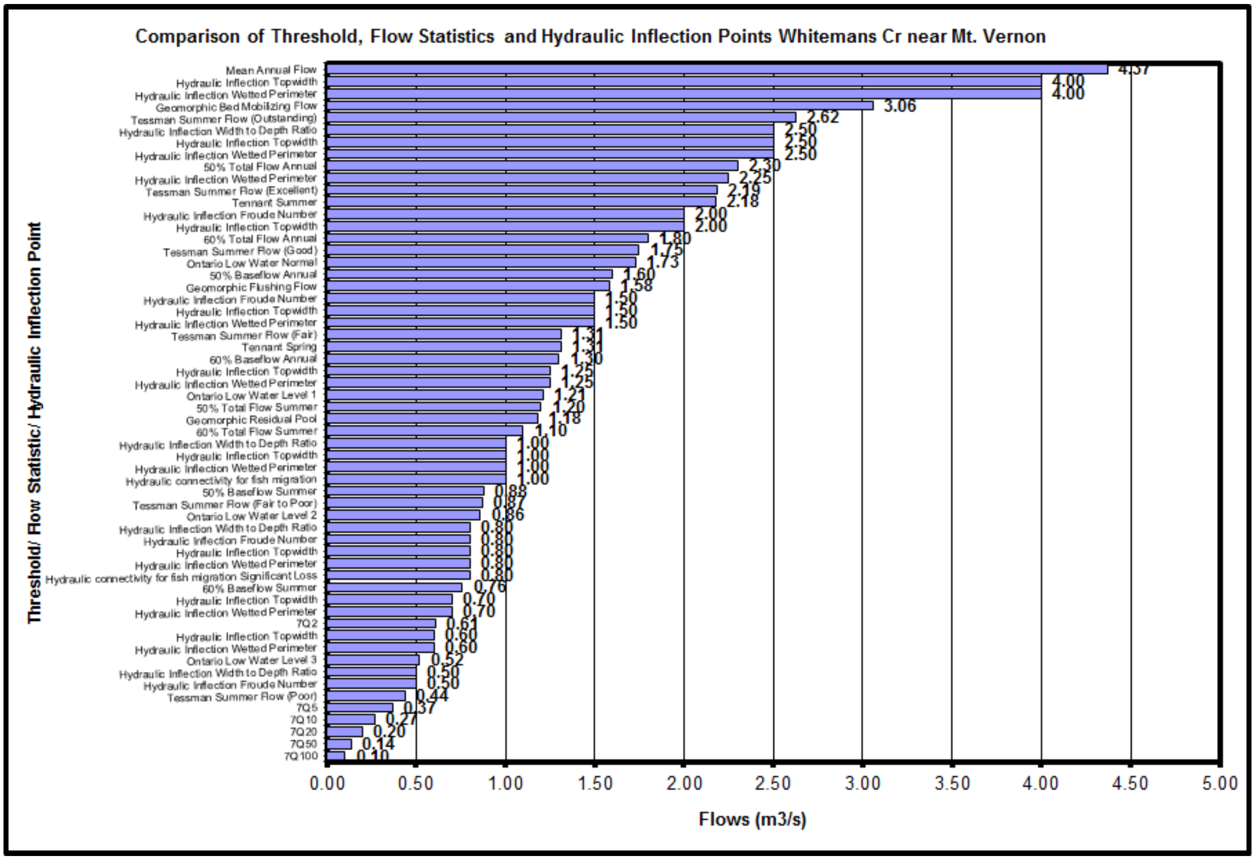
1992				4	2			3			11		20	5
1993	5		3	11		1							20	1
1994				2									2	0
1995	3												3	0
1996	4	1		10	3								18	3
1997		7	8	7									22	0
1998			3										3	0
2000					1	2		1					4	4
2001		1		4									5	0
2002				2									2	0
2004			5	3	2								10	2
2005			1	8									9	0
2006			8									4	12	0
2007			3										3	0
2008	4			15								4	23	0
2009	2	6	5	3	1								17	1
2010			4										4	0
2011			8		3						1	2	14	3
Total	21	22	82	94	12	3	0	7	16	7	12	12	288	45

Speed River at Hespeler Occurrences of Daily Flows less than the Littoral Zone Maintenance Flow Threshold (1.5 m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total	May-Oct Total
1987											1		1	0
1991										1			1	1
2012												2	2	0
Total	0	0	0	0	0	0	0	0	0	1	1	2	4	1

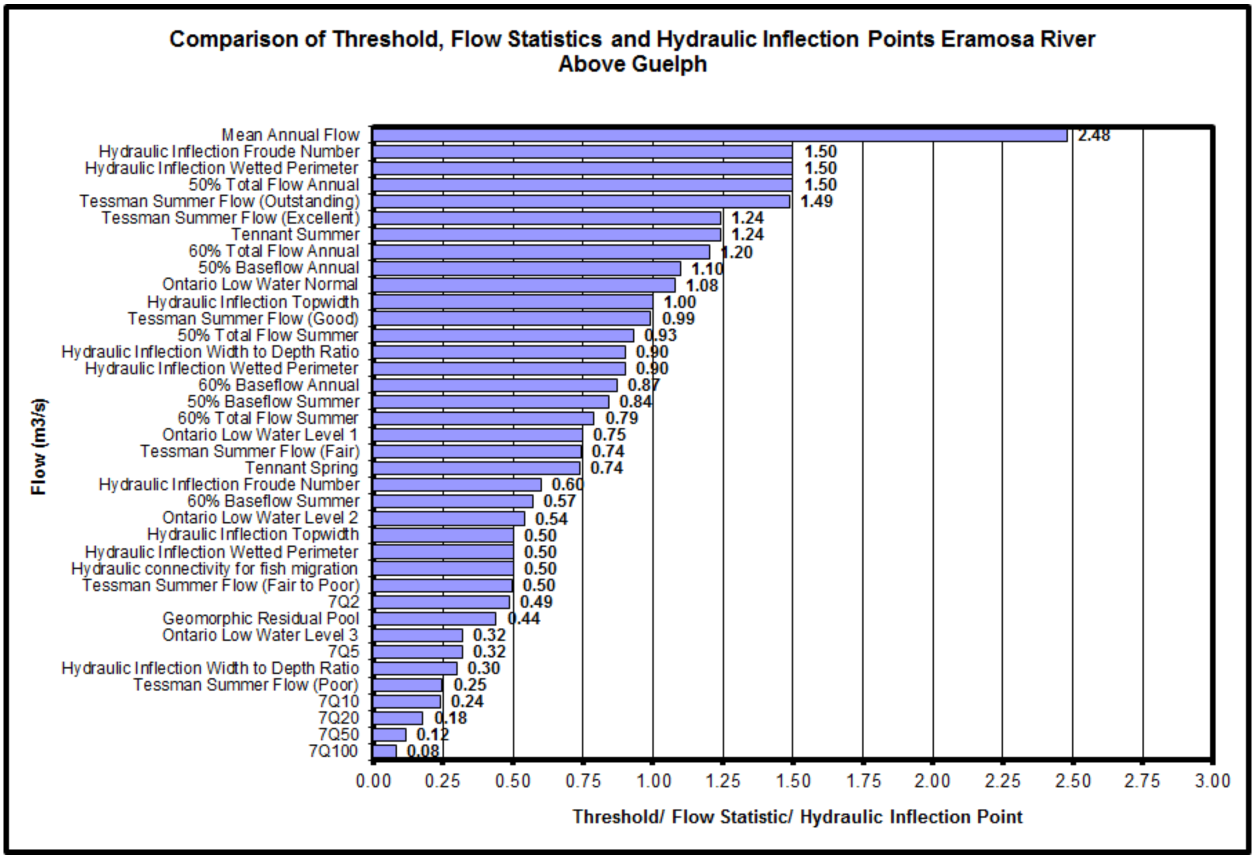
11 Appendix B. Thresholds Calculated for Unregulated Reaches

11.1 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		

11.2 Eramosa River



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