Establishing Environmental Flow Requirements

SYNTHESIS REPORT

Conservation
ONTARIO
Natural Champions

ACKNOWLEDGEMENTS

The principle authors of this report were Dave Maunder (Aquafor Beech Limited) and Brian Hindley (Aquafor Beech Limited).

This Report was produced as part of an overall pilot project on establishing environment flow requirements in Southern Ontario. A total of three pilot project reports were prepared, along with this Synthesis Report under project management by Aquafor Beech Limited and directed by a Steering Committee composed of representatives from the Ministry of the Environment, the Department of Fisheries & Oceans, Credit Valley Conservation and Conservation Ontario.

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1.0 INTRODUCTION

1.1 General

The Ministry of the Environment (MOE) has been reviewing the Permit To Take Water (PTTW) process in Ontario. The need to do this was underlined by low water level conditions over parts of Southern Ontario in recent years, together with heightened public awareness of the sensitivity of the resource.

A two step process to improve the permitting methods was set out by the MOE in 2001. The first step was to evaluate the Best Scientific Practices available, for assessing the impact of a water taking. The first step has been completed and is summarized in a document entitled Best Practices for Assessing Water Taking Proposals (Gartner Lee Limited, 2002).

A number of projects are being undertaken to complete the second step, including verifying existing methods and applying these methods to characterize instream flow requirements for a number of watersheds across the province.

It is anticipated that, as a result of these collective projects, together with other initiatives that are being undertaken, the MOE will be able to continue to improve the permitting process on the basis of sound scientific and public participation principles.

As noted in Section 1.3 below, this initiative should be of interest to and be built upon by a number of important studies and initiatives including watershed/subwatershed planning, source water protection planning, stormwater management and reservoir operations. On the other hand, the study did not address environmental flow requirements for groundwater extraction or hydropower production, although some of the methods reviewed and the decision-making process (including the Adaptive Environmental Management Approach - Section 8) are of relevance to these water management issues as well.

1.2 Study Objectives

The study objectives, which were identified in the Terms of Reference and supported through discussion throughout the progress of the study are defined as follows:

- ○ to determine the method or combination of methods for establishing instream flows that are best suited to a particular waterbody or condition; and
- ○ to characterize the instream flow requirements for a number of watersheds across the province.

1.3 Regulatory and Inter-Agency Context

This study was initiated out of a desire by MOE to provide a technical assessment of instream flow methods as part of the Ministry's review of the PTTW process. This follows a recommendation in the MOE's Best Practices for Assessing Water Taking Proposals (2002) that the Ministry should undertake a review of instream flow methods and better define instream flow needs of aquatic systems. This initiative, however, may serve several purposes:

- ○ Although the MOE is responsible for managing water taking activities, the responsibility of protecting/ maintaining aquatic ecosystems is shared between many agencies, who face similar challenges;
- ○ Although the main goal in establishing and implementing environmental flow requirements is to better manage water taking activities, the initiative may also have implications on other types of water resource related activities such as source water protection planning, headwater stream protection, stormwater management, land-use development, reservoir operations, stream restoration studies etc. Many of these activities are regulated/ undertaken by other agencies such as the CAs, DFO, Environment Canada, Transport Canada, MNR, OMAF, and municipalities. Each of these agencies may participate and collaborate in the review of PTTW's.
- ○ It is important that the establishment of environmental flow requirements be done in consultation/ partnership with all these agencies, since all are involved in the permit review process as well as in their own related resource management initiatives.

There are countless activities throughout the Province of Ontario that could harm productive aquatic environments. Degraded aquatic environments result not only in reduced fish production but also in degraded water quality; both are generally considered to be barometers of the quality of human life.

In Ontario, many federal, provincial and municipal agencies (see above) have a role in the protection and conservation of aquatic environments. In addition, each of these agencies typically has a specific role in water resources management. While each of these agencies has their own jurisdiction, mandate and legislative authority in the management of natural resources including water, each agency uses the opportunity to review PTTW's as one mechanism to fulfil their respective water management responsibilities. Collaboration on and agreement amongst these agencies, on the methods for determining environmental flow requirements is critical to ensuring that aquatic ecosystems are protected and that the PTTW approval process is as expedient as possible.

2.0 STUDY APPROACH

2.1 General

Conservation Ontario (CO) under Agreement with MOE managed the process. The initial step involved circulating a "Request for Expressions of Interest" to all 36 Conservation Authorities. The intent was to select three Conservation Authorities (CA's) to carry out pilot projects on behalf of Conservation Ontario to satisfy the MOE request. The three submissions would run in parallel and would be overseen by a Steering Committee comprised of staff from CO, MOE, Department of Fisheries and Oceans (DFO) and Credit Valley Conservation (CVC).

In addition, a Project Manager (Aquafor Beech Limited) was retained to report on progress of the three projects, to coordinate with the Steering Committee and to prepare this synthesis report.

Three qualifying proposals were selected: Long Point Region Conservation Authority (LPRCA), Cataraqui Region Conservation Authority (CRCA) and Grand River Conservation Authority (GRCA). These proposals were selected in order to comprehensively represent a number of diverse issues related to physiography, land use, water taking, environment, watershed type and size and anticipated ecological thresholds.

The studies in each pilot area were organized into two components; Component A focused on testing instream flow methods and Component B focused on developing a framework or process to apply instream flows methods in different watersheds.

Study A: Testing Instream Flow Methods

The goal of study A was to test, compare, and validate a number of different approaches for setting environmental flow requirements (such as Hydrologic and Hydraulic Methods) in a variety of watersheds. Particularly, this component focused on identifying easy to use, hydrologic-based approaches for Ontario that give ecologically meaningful threshold flows.

Study B: Assigning Instream Flow Requirements

The goal of study B was to develop a process or framework to estimate environmental flow requirements within a given watershed to avoid adverse ecological impacts while trying to accommodate water users. The goal of this study was to characterize the environmental flow requirements within a number of watersheds in Ontario.
The results from each of the three pilot studies will be used as a basis for testing alternative flow methods and for assigning instream flow requirements for a number of streams and rivers across Ontario.

This Synthesis Report assesses the results of the three pilot studies and provides recommendations for future initiatives, should they be required. The Synthesis Report focuses on the following items:

- ○ The effectiveness/value of each project, including the approach used as well as methods used and findings;
- ○ The data requirements, level of detail, types of information to be collected/summarized in the field component and in the review and synthesis of available information including historical data;
- ○ The applicability of the approach and findings to other watersheds;
- ○ Discussing the various methods evaluated in terms of cost, suitability, accuracy and transferability; and
- ○ Presenting major conclusions and recommendations, including identifying additional steps for the Steering Committee

2.2 Report Outline

The content of each of the report chapters is outlined below. Chapters 1 - 6 address Study A, and Chapters 7 - 9 address Study B.

Chapter 1 - Introduction

This chapter describes the study goals and objectives and the regulatory and inter-agency context.

Chapter 2 - Study Approach

An outline of the study approach, committee structure and report outline is provided

Chapter 3 - Description of Three Pilot Project Watersheds

A description of the watershed and selected streams where field programs were undertaken is provided.

Chapter 4 - Description of Alternative Instream Flow Assessment Tools

A description, based on a literature review, of alternative instream flow assessment tools together with the requirements to use each tool and the appropriateness of use for various conditions.

Chapter 5 - Overview of Field Program and Use of Historical Data

This chapter describes the various tools that were used to collect and interpret data. The various tools include use of historical data, computer modelling and collection of data in the field.

Chapter 6 - Water Uses and Permits to Take Water

A description of the water users in the the pilot study watersheds and an overview of the provincial context of water taking is provided.

Chapter 7 - Determination of Environmental Flow Requirements

This chapter describes how environmental flow requirements were established for each of the pilot studies. The chapter discusses strengths and weaknesses of each method assessed and highlights findings of each study.

Chapter 8 - Transferability and Implications for Watershed-Wide Environmental Flow Requirements

A discussion of how suitable the alternative flow assessment tools were for each of the selected watersheds is provided. The transferability of the alternative methods to other locations and subwatersheds is discussed and recommendations are made concerning what tools are best for different watershed conditions. A discussion of how the findings of each of the Study A parts of the pilot projects can be used to characterize instream flow requirements for major zones and reaches of other watersheds is provided. A proposed framework for assessing environmental flow requirements is presented.

Chapter 9 - Conclusions and Recommendations

A list of conclusions, recommendations and important next steps is provided.

3.0 DESCRIPTION OF THE THREE PILOT WATERSHEDS

3.1 Introduction

The three projects were selected because collectively they represented a range of watershed conditions and types of water taking permits across southern Ontario. The projects also included both regulated and unregulated streams and occurred in areas typical of a range of fish community types including tolerant warmwater fisheries and sensitive coldwater fisheries. The general location of the three study areas is shown in Figure 3.1. Table 3.1 provides a summary of general watershed characteristics for each study.

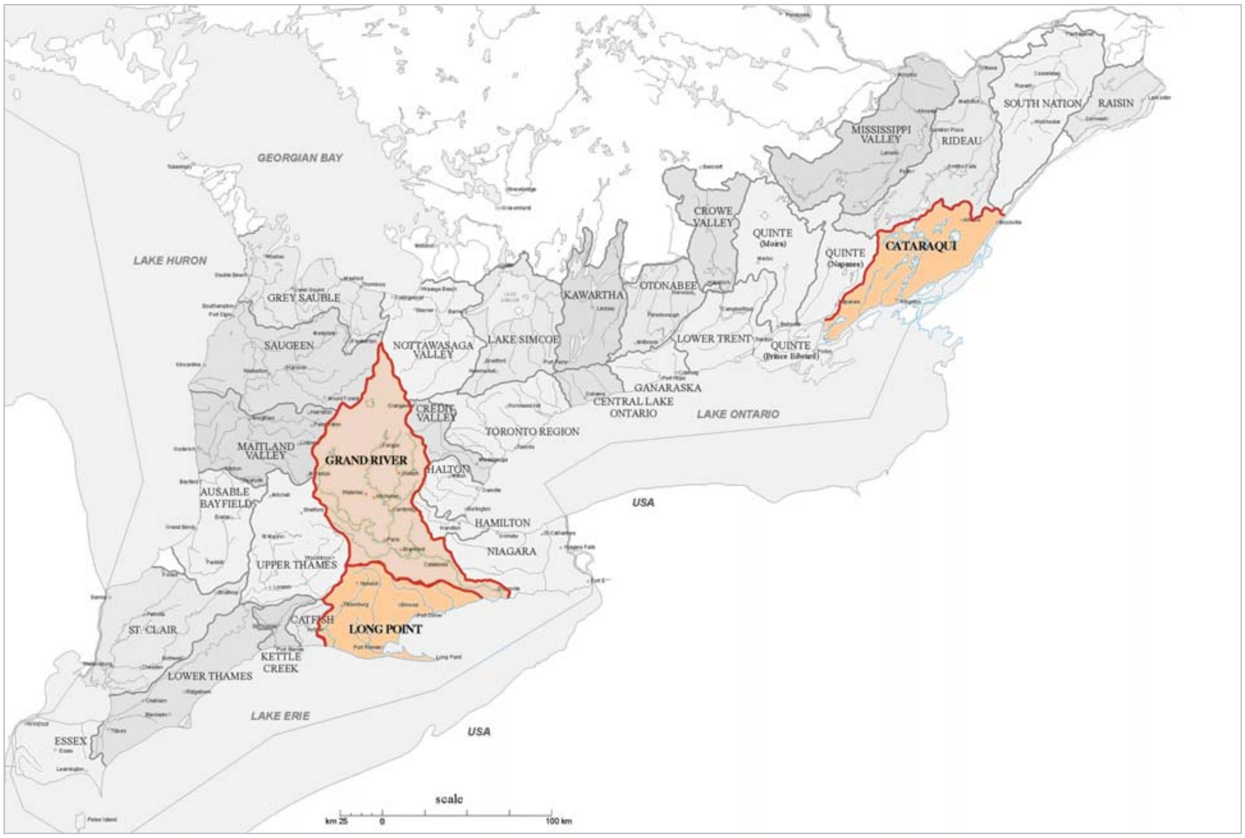


Figure 3.1 Study Area locations

Table 3.1. General characteristics of study watersheds

Watershed Characteristic	Milhaven Creek (CRCA)	Big Creek (LPRCA)	Grand River (GRCA)
Area (km2)	176	750	Small - <100 Medium - 100 - 1000 Large - > 1000
Degree of Regulation (relative to basin size)	high	moderate	Low to moderate
Type of Study	Watershed wide	Watershed wide	8 Reaches evaluated for small, medium and large watersheds (see avove)
Stream Type	Bedrock controlled	alluvial	Alluvial
Water Taking Permit Type	Reservoirs, municipal	Reservoirs, municipal, agriculture	Reservoir, municipal, industrial, agricultural
Density/Volume of Water Taking Permits	low	high	Moderate - high
Physiography	Canadian Shield	Moraine and Sand Plain	Moraine and Sand Plain
Other Sources of Water Loss	Evaporation, small water users (no permit required)	Small water users (no permit required)	Small water users (no permit required), evaporative losses, groundwater taking
Soils	Clays, loams, bedrock	Sandy loams, aggregate	Sandy loams, aggregate
Vegetation Cover (forest and wetland)	38%	18%	18%
Dominant Land Use	Rural, Agricultural	Agricultural, Rural	Agricultural, Rural (some Urban)
Land Use Activity	Static	Static	Static (some changing)
Stream and Precipitation Gauges	Yes	Yes	Yes
Hydrologic Model	Yes	Yes	Yes
Fish Community	Tolerant, warmwater (perch, pike, baitfish)	Cold water (brook/brown trout, salmon)	Cold / cool water (brook/brown trout, salmon, walleye, pike)
Base flow characteristics	low	high	Moderate - high
Runoff generation	low	low	Low - moderate
Topography	Variable, exposed bedrock	variable	Variable (areas of hummocky topography)

3.2 Milhaven Creek (Cataraqui Region Conservation Authority)

The Cataraqui Region Conservation Authority (CRCA) was formed in 1964, contains 10 watersheds draining to Lake Ontario and the St. Lawrence River, and covers greater than 3500 km2 . The jurisdiction reaches from Napanee in the west, to Brockville in the east, to Newboro in the north, including portions of 11 municipalities. The two largest watersheds, the Greater Cataraqui and Gananoque Rivers, account for approximately 50% of the CRCA jurisdiction, and are heavily regulated for navigation and power generation. Millhaven Creek is located in the western portion of the CRCA jurisdiction (Figure 3.2). It is a reasonably small watershed for Eastern Ontario, with headwaters in the Canadian Shield, flowing generally southwest over a limestone plain to Lake Ontario. Land use in the area is generally agricultural.

The Creek has a drainage area of approximately 176 km2 , is approximately 55 km long, and has an average drainage area width of 4 km. There are three major lakes, and five major water control structures along the creek. The Millhaven Creek Watershed covers three municipalities, Loyalist Township, City of Kingston, and South Frontenac Township. Gould Lake, located in the headwaters is a deep coldwater lake that supports lake trout and has a natural outlet; Sydenham Lake is a moderate, warmwater lake that supports pike and bass and is controlled by the Sydenham Lake Dam. Odessa Lake is a shallow, warmwater lake that supports pike and bass, includes extensive wetland habitats, including a provincially significant wetland and is controlled by the Wilton Road Dam.

Over the years, five major water control structures have been constructed on the Creek:

- Wilton Road Dam - built in 1973: The Wilton Road Dam was built by the CRCA to provide flow augmentation for the Hamlet of Odessa, which took its water supply from the Creek until the year 2000. The dam holds water back from the spring freshet and releases it throughout the summer and fall, which are times of general low flow in the creek. It provides flood and erosion control for the Hamlet of Odessa, and creates a Provincially Significant Wetland upstream. The dam is also used for general low flow augmentation to maintain riparian rights, and adequate dilution of wastewater plant effluent in the Hamlet of Odessa. The operating range is in the order of 1.75 m.
- Sydenham Lake Dam - rebuilt in 1977: The Sydenham Lake Dam was originally built in the early 1900s to provide power for a grist mill. The original mill burned around 1919, but was soon rebuilt. The dam and mill were purchased by the CRCA in 1976 and the dam was rebuilt in 1977 to provide flood control, erosion control and recreation on the Lake. The Hamlet of Sydenham is in the process of finalizing plans to build a water treatment plant which will take water from Sydenham Lake. In the future, a wastewater treatment plant, intended to discharge below the dam, may be considered. The operating range is in the order of 1 m.
- Potter's Dam, Babcock Mill Dam, Lucas Road Dam: Potter's Dam, Babcock Mill Dam, and Lucas Road Dam are all old, historic dams, presumably built to provide power for adjacent mills, located in the lower portion of the watershed. These structures are currently not operated.

The surficial geology of Milhaven Creek is representative of eastern Ontario watersheds with its headwaters in granitic shield deposits, midreaches dominated by limestone and shale plains and lower reaches consisting of lacustrine deposits. Much of the creek system is either bedrock controlled or flows through extensive shallow wetland features.

Land use is predominantly rural with agriculture representing 54% of the watershed area and woodlands representing 38%. Urban land uses are limited to small hamlets, such as Odessa and Sydenham, and cottage development around Sydenham Lake.

There are 6 existing PTTW including Ducks Unlimited and the decommissioned Odessa water treatment facility. Livestock watering is common, however there are no agricultural PTTW. A significant number of cottagers also withdraw water from Sydenham Lake. The Odessa Waste Water Treatment facility also discharges to Milhaven Creek.

Wetlands, associated with the lake and dam systems cover about 10 km2 and lakes about 10 - 12 km2 or about 12% of the watershed area. There is one stream flow gauge in the watershed. Average peak flows exceed 6m3/s, with typical spring and fall flows between 1 and 3 m3/s and average low flows less than 0.2 m3/s. Periods of zero flow have been reported and a recommended flow of 0.12 m3/s has been established to address WWTP outflow assimilation requirements. This target has proven difficult to maintain, particularly during dry conditions in 2001.

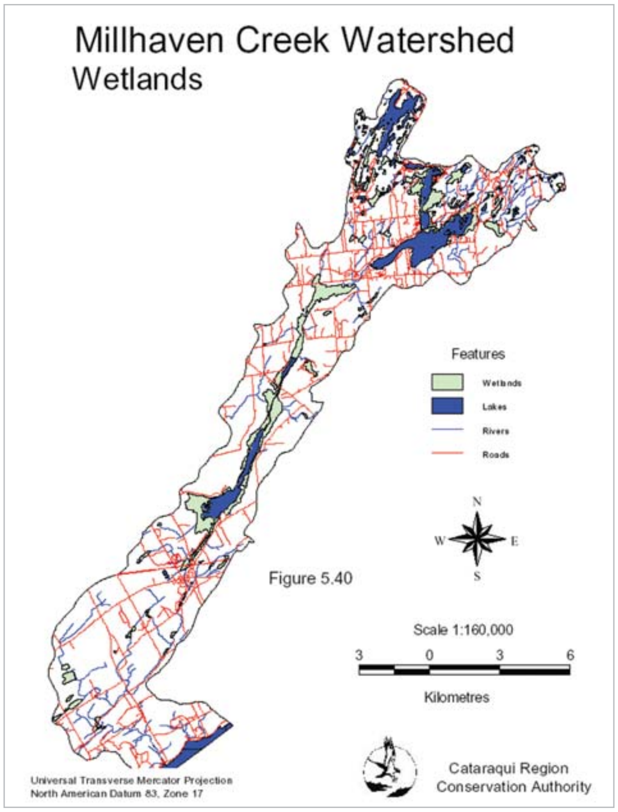


Figure 3.2 Milhaven Creek Watershed (CRCA)

3.3 Grand River (Grand River Conservation Authority)

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

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

Eight Pilot Study Reaches were selected for detailed investigations within the Grand River Watershed.

Selected sites in the Grand River watershed were classified by watercourse size, sensitivity and available data. Eight sites in the Grand River watershed were selected for potential investigation (Figure 3.3). Some sites have existing hydraulic and hydrologic information readily available, reducing the level of effort required to analyze these sites and allowing additional effort to be focused on sites where less information existed. The sites are listed below with some attributes and concerns outlined.

Large River Sites

- ○ Grand River at Blair
  - Upstream drainage area: 2592 km2
  - River regulation, available data, possible species at risk, water taking
  - Warm and coldwater fish communities
- ○ Grand River Exceptional Waters Reach
  - Upstream drainage area: 5157 km2
  - River regulation, species at risk, up to date data
  - Warm and coldwater fish communities
- ○ Nith River at Canning
  - Upstream drainage area: 1016 km2
  - Available hydraulic model, long-term flow information, some biological data
  - Warmwater fish community

Intermediate River Sites

- ○ Eramosa River
  - Upstream drainage area: 242 km2
  - Water taking, municipal, flow variability, available data, subwatershed plan completed
  - Coldwater fish community

Small Stream Sites

- ○ Blair Creek
  - Upstream drainage area: 15 km2
  - Urban impacts/landuse change, subwatershed plan completed
  - Warmwater fish community
- ○ Whitemans Creek
  - Upstream drainage area: 414 km2
  - Water takings, high quality coldwater stream
  - Coldwater fish community
- ○ Mill Creek
  - Upstream drainage area: 84 km2
  - Aggregate extraction, land change impacts, subwatershed plan completed
  - Coldwater fish community
- ○ Carroll Creek
  - Upstream drainage area: 45 km2
  - Available data, agricultural impacts
  - Warmwater fish community

Collectively, these sites fall within the middle physiographic region of the Grand River Watershed, referred to as the Central Moraines (including the Orangeville, Paris/Galt and Waterloo Moraine complexes), that are generally characterized by low runoff and high groundwater discharge. The central portion of the watershed is dominated by moraines and remnant outwashes of the last ice age. The central moraine area is the most hydrologically complex area of the watershed. The soils and topography found in the moraines can more easily hold water therefore the tendency in these areas is for more water to enter the ground than run off. This area of the watershed is characterized by coldwater streams, strong base flows and high quality and quantities of groundwater. The groundwater system in the central moraine area is typically characterized by single or multiple overburden aquifers overlying fractured bedrock.

Land cover in the Grand River watershed is dominated by agricultural production, which represents 80% of the land cover in the watershed.

It is estimated that 60 to 70% of the original wetlands have been drained. This clearing and drainage dramatically changed the hydrology in the watershed. Clearing and drainage resulted in less storage capacity on the landscape and more efficient drainage systems conveyed water off the landscape more quickly to streams and rivers. This had the effect of increasing the magnitude and frequency of both floods and droughts.

The human response to the changed hydrology was to build reservoirs to replace some of the lost storage. Looking at the location of reservoirs with respect to geology, it appears that where till plains were cleared and drained, reservoirs were implemented on, or at the fringe of, the altered till plains. Major reservoirs regulate flows along several reaches in the watershed. A distinct aspect of the Grand River watershed is that the main river itself is very regulated.

Water budget modeling of the Grand River watershed has quantified areas contributing to recharge and runoff in the watershed. Upstream of the Exceptional Waters Reach (the lowest reach studied in the watershed) surface water takings accounted for 9.2m3/s with municipal, agricultural and industrial takings representing the largest "takers". However, many water takings are seasonal (for example golfcourses represent 7% of the total takings, but 24% of the seasonal takings). The recharge, runoff, permitted takings and regulated reaches are important information that provides context when considering water takings and environmental needs. There are 16 of 26 sewage treatment plants located on regulated reaches of the Grand River watershed.

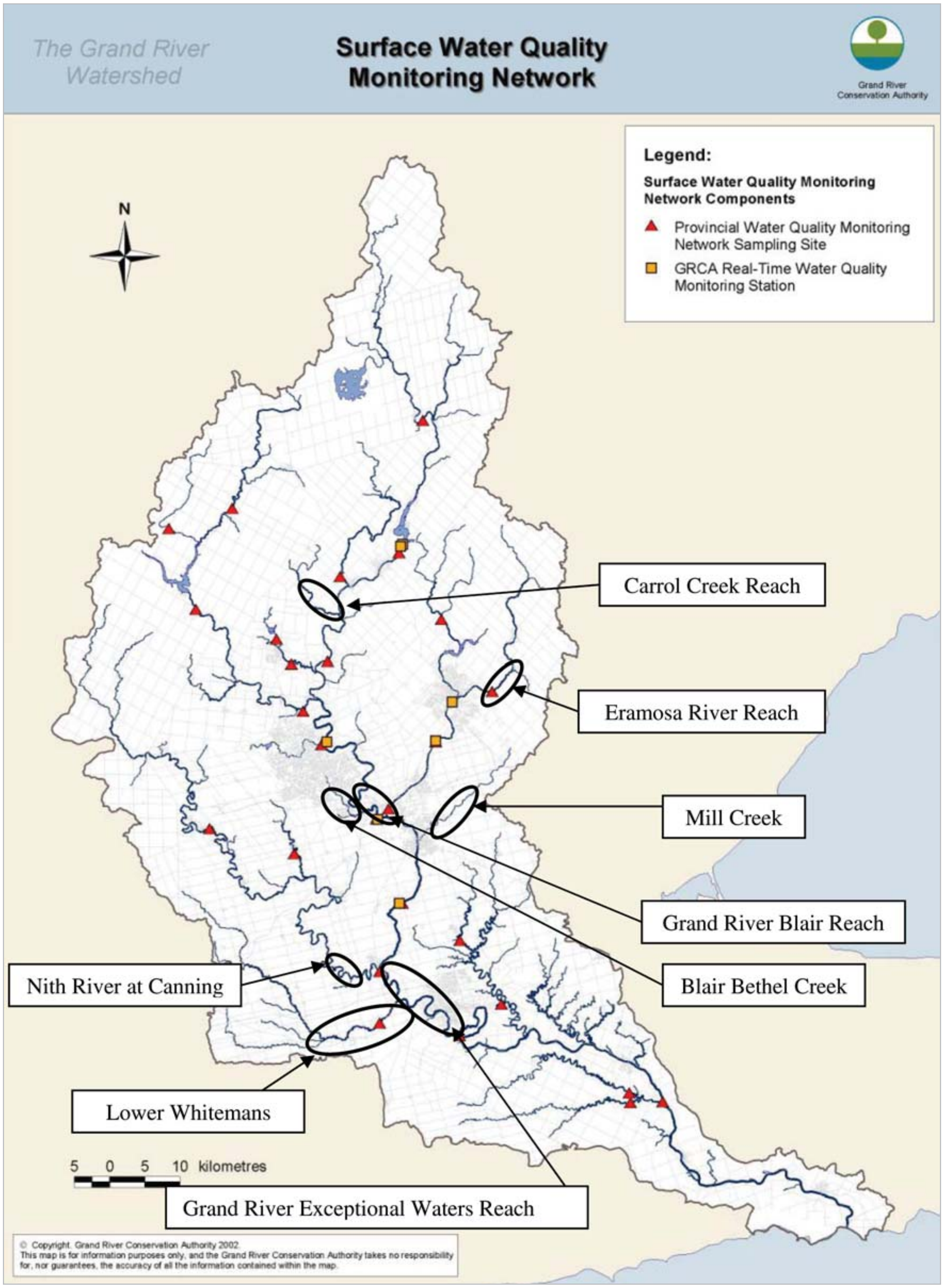


Figure 3.3 Pilot Study Reaches for Instream Flow Methods

3.4 Big Creek (Long Point Region Conservation Authority)

The major watersheds (Figure 3.4) that comprise the Long Point Region Conservation Authority (LPRCA) drain a total area of 2,890 km2 along the north shore of Lake Erie in southwestern Ontario. The major drainage basins to the north and east of the LPRCA are the Upper Thames and the Grand River, whereas to the west there is Catfish Creek. Agricultural activities are the predominant land uses in the LPRCA watersheds, with major urban areas including Norwich, Otterville, Tillsonburg, Straffordville, Vienna, Port Burwell, Courtland, Delhi, Langton, Port Rowan, Waterford, Simcoe, Port Dover, Hagersville and Jarvis. The total population of all the urban centres in the LPRCA watersheds is about 50,000 which is also approximately equal to the total rural population.

For the areas west of a north-south line drawn through Waterford and Port Dover, the watersheds are located on the Norfolk sand plain comprised of higher permeability sand and gravel, whereas the eastern basins are situated on the Haldimand Clay Plain with its low relief, low permeability lacustrine clay.

Most of the western watersheds (e.g. Big Otter, Big and Dedrick-Young's Creek) contain cold water fisheries, and have the highest number of surface water takers. The LPRCA has among the highest number of surface and ground water takers of any area in southern Ontario.

Big Creek was selected for detailed investigations within the LPRCA, because of its high number of water taking permits, sensitive coldwater features and detailed background information including a detailed hydrologic model using GAWSER (Figure 3.4).

Big Creek has a drainage area of 750 km2 and has over 1000 PTTW. Surficial geology is predominantly sands and gravels associated with the Norfolk Sand Plain with about 15% of the watershed in forests. The majority of the creek supports coldwater fish communities. Numerous flow gauges exist on Big Creek, including one at Delhi (drainage area - 362 km2). Mean monthly flows range from over 8 m3/s in March to about 2 m3/s in July and August. Mean monthly flows for the remainder of the year generally range between 2 and 5 m3/s. Looking at the long term record for this gauge, mean monthly flows in excess of 10 m3/s and low flows of about 1 m3/s are also not uncommon. Approximately 60% of the mean annual flow occurs as baseflow.

In recent years, flows in Big Creek have dropped below the 3 levels in the OLWR.

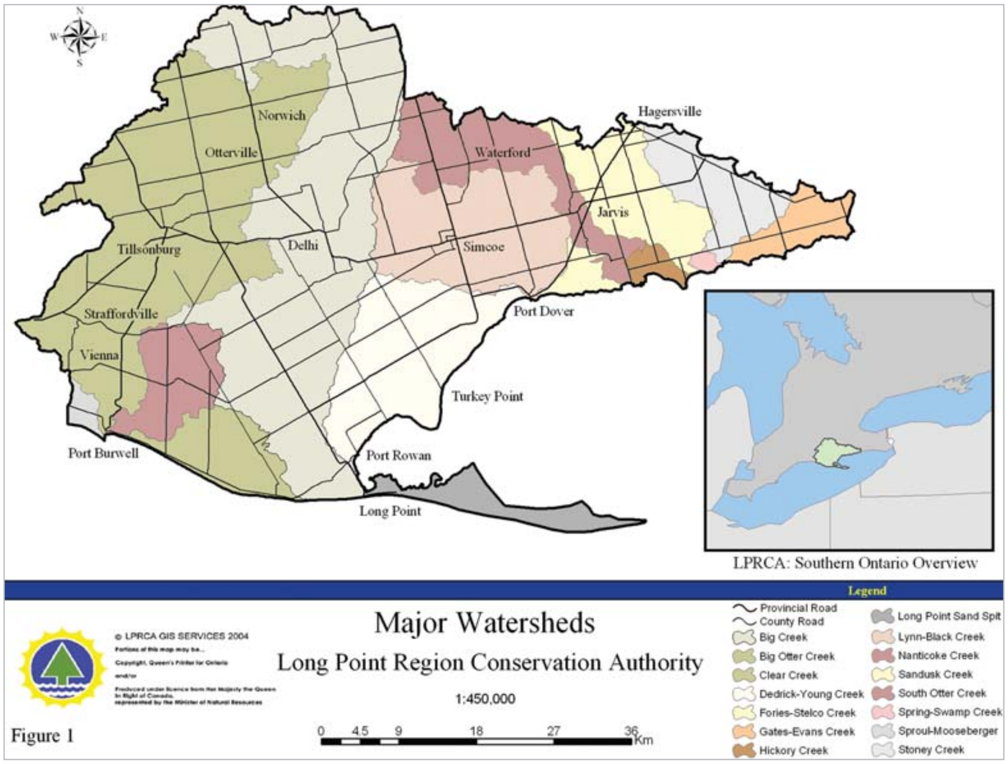


Figure 3.4 Big Creek Watershed shown in light grey (LPRCA).

4.0 DESCRIPTION OF ALTERNATIVE INSTREAM FLOW ASSESSMENT TOOLS

4.1 General

One component of the study involved retaining Dr. A. Bradford (University of Guelph) to undertake a review of alternative Instream Flow Assessment Tools. In addition, Jack Imhoff, National Biologist for Trout Unlimited provided background information on ecological relationships.

Collectively, these sections provide useful information on the reasoning behind calculating instream flow requirements. This chapter leads into the application of the tools and the assessment of environmental flow requirements, which are discussed in subsequent chapters.

In reviewing this material two things should be noted. The first is that the application of instream flow assessment tools is evolving rapidly. Secondly, a considerable amount of literature defining alternative assessment tools already exists. Two reference books of particular note are:

- ○ Nature Conservancy Site
  http://www.freshwaters.org; and
- ○ Instream Flow Council Site
  http://www.instreamflowcouncil.org

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

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

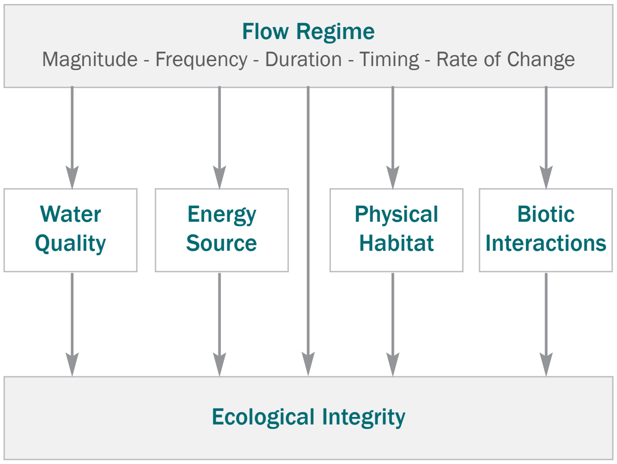
Water management is also no longer driven by single issues: an ecosystem/based approach to water management is now the norm not the exception. The establishment of instream flows typically should begin with a thorough analysis or understanding of the management objectives for the watershed, which typically would include fish and wildlife, water quality, water quantity, channel morphology and sediment regime, aesthetics and groundwater. Likewise, setting instream flow requirement requires a multidisciplinary approach and must consider hyrologic, hydraulic,fluvial geomorphic, water quality and aquatic habitat elements.

4.2 The Natural Flow Regime

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

There is a trend towards the use of the "natural flow regime" (Richter et al., 1996; Poff et al., 1997) as a basis for determining instream flow needs (Annear et al., 2002). The approach considers flow to be a "master variable" determining the form and function of streams, and in fact, streamflow is strongly correlated with many physicochemical characteristics such as water temperature, channel geomorphology, and habitat diversity, which are critical to sustaining the ecological integrity of streams and rivers (Poff et al., 1997). In some cases, the effects of flow are direct, in other cases the effects of flow are indirect and in essence, flow characteristics are used as surrogates for other instream conditions or ecosystem requirements (e.g. water temperature and concentration of dissolved oxygen) (Figure 4.1).

Figure 4.1: Direct and Indirect Influences of Flow Regime on the Ecological Integrity of Flowing Water Systems



[Source: Poff et al., 1997 after Karr, 1991]

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

Characteristics of the Natural Flow Regime with Ecological Significance

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

Droughts (infrequent low flows) have a role in sustaining overall ecosystem integrity, with either negative or positive effects on individual species. Although natural droughts can benefit the aquatic community, frequent or prolonged low flows will have negative consequences such as: physiological stress or mortality due to increased temperature and low dissolved oxygen (DO); disruption of fish migration; reduced invertebrate production; and increased predation by birds and mammals (Annear et al., 2002). In other words a low-flow event of a particular magnitude may be healthy as long as it can be described as a stochastic event (say with a recurrence interval on the order of a decade), whereas flows of the same magnitude which become chronic or repeating (say with a recurrence interval on the order of one year) are likely to be unhealthy. High flows may have negative effects on individual species (e.g. by displacing eggs and fry and limiting reproductive success) but are critical for sustaining ecological processes (Poff et al., 1997):

- fine sediments may be deposited between coarser streambed materials and in the absence of flushing flows, species with life stages that are sensitive to sedimentation, such as the eggs and larvae of many invertebrates and fish, are negatively affected
- many channel features, such as river bars and riffle-pool sequences, are formed and maintained by discharges that can move significant quantities of sediment and that occur frequently enough to continually modify the channel
- flows that exceed the capacity of the channel (overbank flows) are important for maintaining riparian wetlands, providing connections to complex biophysical habitats outside the stream channel, and supporting biogeochemical processes
- high flows are required to import organic matter and woody debris (which provides high quality habitat) from the floodplain
- moderate flows are needed to maintain streambank vegetation and stability, although flows that periodically scour beds, banks, and floodplains provide opportunities for rejuvenation and diversification of plant communities and prevent encroachment of vegetation into the stream

Timing / Predictability: The life cycles of many aquatic and riparian species are timed to either avoid or exploit flows of certain magnitudes (See Section 4.3). The timing of events is important since migratory and reproductive behaviours must coincide with access to and availability of habitat. Human-induced changes in the timing of various conditions may cause reproductive failure, stress, or mortality of aquatic species.

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

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

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

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

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

4.3 Considerations for Aquatic Communities

The following discussion is taken from a summary provided by Mr. J. Imhof for the project.

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

Headwater streams of first (lst) and second (2nd) order are more sensitive to daily and seasonal fluctuations in flow because of the characteristics of their channel structure (i.e., relatively shallow pools and refuge areas). If minimum low-flow events occur more frequently (compared to historical trends - i.e., changing from irregular to frequent events) this can lead to loss of spawning success, loss of juvenile fish and depletion of adult fish.

Medium order streams (3-4 order) usually have deeper water refugia and because flow is contributed by a larger stream network, they may have more variability in flow but low-flow characteristics are not as variable in relation to channel characteristics as in headwater systems. Large order streams (i.e., 5-8 order) have dampened flow patterns that generate longer high and low flow durations. Major droughts also affect these channels but the return periods are less frequent (i.e., 20-50 years for 5- 8 order streams versus 2 - 5 years for 1 - 2 order streams). In summary, stream order is significant: a lower stream order generally infers greater sensitivity to change and a reduced ability to accommodate water takings.

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

The physical habitat requirements at certain life stages of fish can be linked to the timing of occurrence during the year. Coldwater fish such as brown trout and brook trout and warmwater fish such as walleye, smallmouth bass and pike are described visually in Figures 4.2 and 4.3, respectively, linking the timing of occurrence to life cycle requirements. Life stages and streamflows were the basis for Figures 4.2 and 4.3. These figures show the relationship between life stages of coldwater (Figure 4.2) and warmwater (Figure 4.3) fish throughout the year, and the hydrological requirements at that life stage. These figures can be used 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.

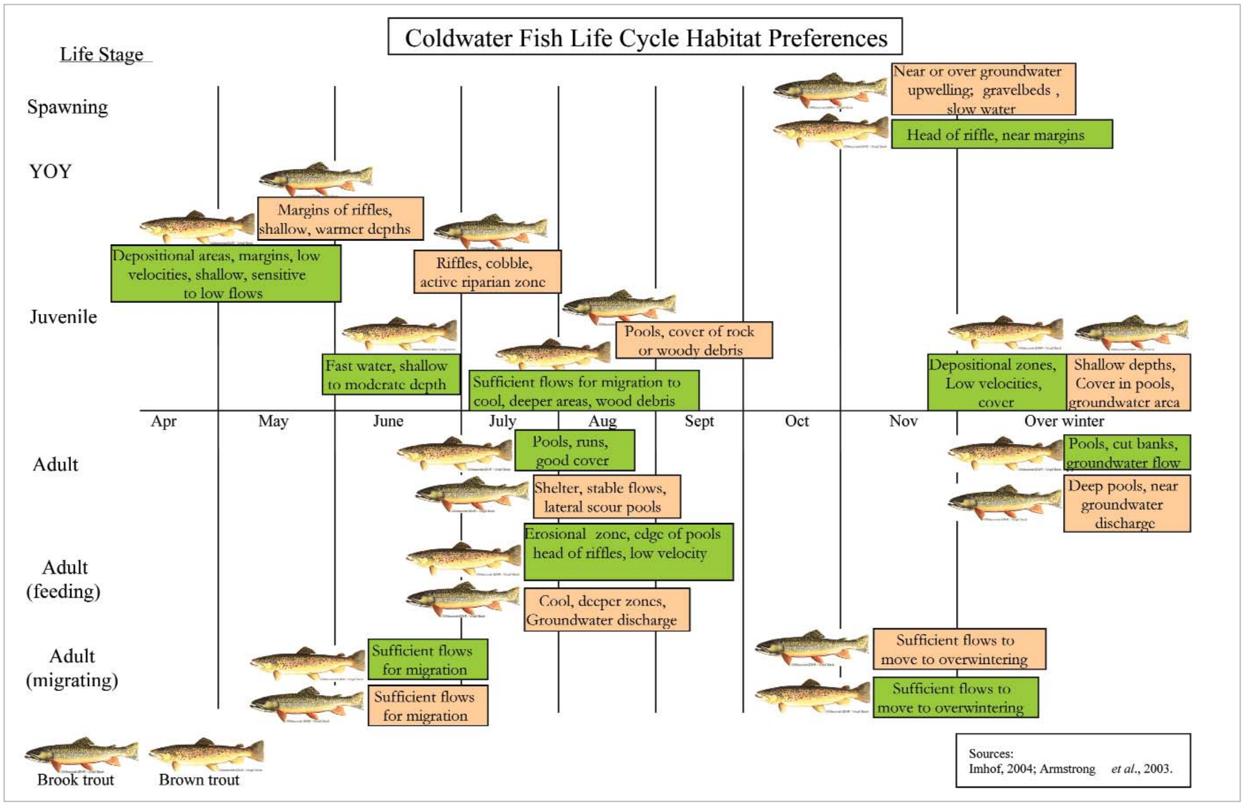
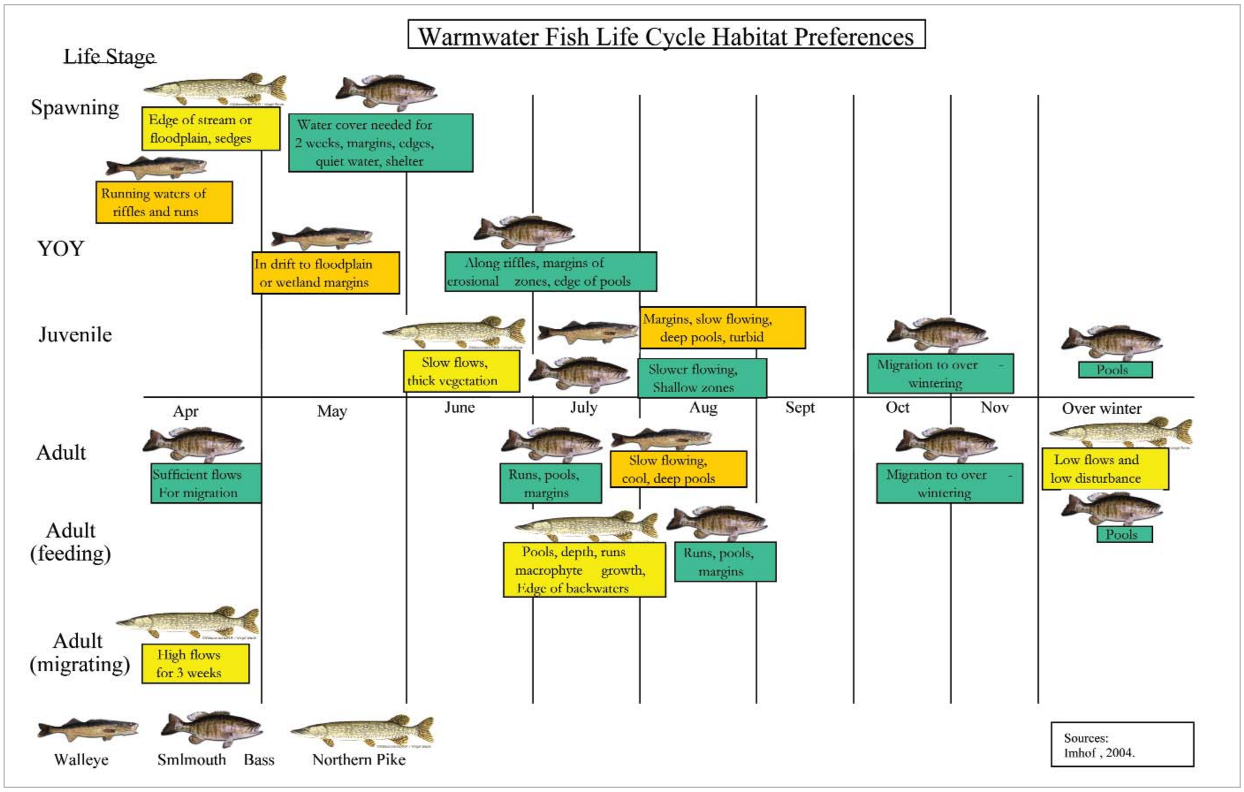


Figure 4.2 Hydrological life cycle habitat preferences of coldwater fish during the year.

Figure 4.3 Hydrological life cycle preferences of warmwater fish during the year



4.4 Alternative Tools

The summary as provided in this section in primarily taken from Dr. Bradford's findings. The summary has been augmented by findings from the document entitled Instream Flows for Riverine Resource Stewardship (2002), as the three pilot projects also referenced this document in their reports.

For the purpose of this document, the terms methods and framework will be used in this, and subsequent sections. A method may be defined as the approach (or method) that is used to interpret the requirements for the reach under study while a framework may be defined as how you use the methods in order to manage issues within the reach. These equate to "methods" and "methodologies", respectively in Dr. Bradford's review (included in individual pilot study reports).

Tharme (1996) defined methods as "procedures or techniques (which are) used to measure, describe or predict changes in important physical, chemical or biological variables of the stream environment" and frameworks as "collections of several instream flow methods which are arranged into an organized iterative process which can be implemented to produce results".

This section will define the methods while section 4.5 will define the frameworks.

In the various reviews of instream flow assessment tools, different categories of the methods have been used. A common approach is to group the methods as historic flow (or hydrologic or discharge) methods, hydraulic methods, and habitat methods (e.g., Jowett,1997; PPWB, 1999, GLL, 2002).

The Instream Flow for Riverine Resource Stewardship document categorizes the techniques for assessing instream flows as standard setting, incremental, and monitoring/diagnostic. Table 4.1, from the Riverine Stewardship Document summarizes the techniques (Categories), general descriptions and representative examples.

Table 4.2 summarizes the instream flow assessment methods by categories as defined by Dr. Bradford in her findings. The categories are based on the approach as developed by Annear et al (2002).

In reviewing the methods it must be emphasized that there is no single method or combination of methods that is appropriate for all conditions (Annear et al., 2002). Selection of a method depends upon the

- Present state of the aquatic ecosystem;
- Nature and complexity of the management issue(s);
- Level of controversy of a particular project or purpose;
- Habitat homogeneity at various scales;
- Data requirements of models; and
- Expertise of the personnel (Annear et al., 2002)

Table 4.1 Instream Flow Assessment Techniques (Categories), General Descriptions and Representative examples.

Technique	Description	Examples
Standard Setting	Sets limits or rules to define a flow regime	Tennant, Wetted Perimeter, R2-Cross, Aquatic Base Flow (ABF), Bankfull Discharge
Incremental	Analyzes single or multiple variables to enable assessment alternatives	Instream Flow Incremental Methodology (IFIM) Physical Habitat Simulation (PHABSIM) Riverine Community Habitat Assessment Restoration Concept (RCHARC)
Monitoring/ Diagnostic	Assesses conditions and how they change over time	Index of Biotic Integrity (IBI), Habitat Quality Index (HQI) Indicators of Hydraulic Alteration (IHA) Range of Variability Approach (RVA) Stream Network Temperature (SNTEMP)

Table 4.2 Instream Flow Assessment Methods (from A. Bradford 2004)

Method	Comments on Applicability
Hydrology	
Indicators of Hydrologic Alteration (IHA Method)	RECOMMENDED IF a natural flow record of daily streamflows can be developed. Parameters can be used to evaluate intra- and inter-annual variability that should be incorporated into the flow regime.
Range of Variability Method (RVA Method)	RECOMMENDED When used in conjunction with the IHA Method. Range of Variability method provides a typical range for statistics generated by the IHA Method.
Biology	
Flow Duration Methods	RECOMMENDED IF the underlying relation of hydrology to biology (habitat) is substantiated within the target region.
Tennant / Tessmann	
Aquatic Base Flow	NOT RECOMMENDED. This approach, developed in the Connecticut River and then expanded to the New England area, should not be used in other regions.
Seven-Day, Ten-Year Low-flow (7Q10)	NOT RECOMMENDED. As a minimum flow standard to sustain aquatic life; 7Q10 lacks any scientific or common sense foundation and can be expected to result in severe degradation of riverine biota and processes.
Single Transect / Wetted Perimeter	NOT RECOMMENDED. May be used to check minimum flow recommendation for low flow season on a site specific basis.
Physical Habitat Simulation (PHABSIM)	NOT RECOMMENDED. Life stage-specific habitat suitability requirements are not available for a broad range of species. May be used for specific projects to assess the habitat tradeoffs for one or two key species associated with alternative flow regimes.
Biological Response to Flow Correlation	Regression relationships would need to be developed. Can provide valuable info (especially general trends) where correlations are significant, but rarely capture all sources of variability affecting biological or habitat response.
Geomorphology	
Channel Maintenance Flows	Applicable for gravel alluvial streams because it is based on bedload transport. Not recommended for determining releases below dams. Based on bankfull flows; Does not account for low flows.
Flushing Flow Determinations	Numerous methods provide varying results. Based on effective discharge (bankfull flow) but could be higher flows in some systems i.e. is bankfull the flushing flow? Designed for gravel streams. Channels downstream of reservoir may be sediment starved and will not respond the same to method. Accounts for high flows but not low flows.
Geomorphic Stream Classification Systems	Is Rosgen the appropriate classification system? Depends on identification of bankfull. Involved hierarchical system (large data requirement). Does not account for low flows.
Width/Depth Ratio	Theoretically, would identify low flow, bankfull and high flow channel dimensions. Does not depend on grain size. Identify thalweg dimensions and low flow habitat availability. Generally accepted as a technique to identify bankfull elevation.
Water Quality	
Stream Water Quality Models	RECOMMENDED IF water quality parameters may impose a constraint on in-stream flows.
Stream Temperature Models	RECOMMENDED IF stream temperature based flow prescriptions may be required.
Connectivity	
Floodplain Inundation	RECOMMENDED FOR floodplain reaches of rivers.

A select number of the methods as listed in 4.2 are discussed below. The methods described below were chosen since they were assessed and/or employed in the three pilot studies.

4.4.1 Historic Flow Regime (Hydrologic or Discharge) Methods

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

Historic flow regime (or discharge) methods include:

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

As Jowett (1997) indicates, historic flow approaches will maintain the character of a river (i.e. a large river will still be relatively large compared to a small river). However, as Beecher (1990) cautions, "Using flow as the unit of measurement in an instream flow standard does not ensure a consistent level of resource protection. Neither a flow nor an exceedance flow has a consistent relationship to habitat or production across a range of stream types or sizes." The morphological relationships between discharge and width, discharge and depth, and discharge and velocity will vary from reach to reach. So, a flow requirement based on a given percentage of flow will result in different hydraulic conditions in different places (Jowett, 1997). The percentage of flow required to protect a stream is expected to vary from headwaters to mouth. However, different flows can be recommended at different times of the year to mimic the natural hydrograph, at least to some extent, and to accommodate seasonal biologic needs (e.g. Tessmann adaptation of Tennant method).

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

Tessman (modified Tennant method): The Tessman method is a modification of the Tennant method, both of which are based on an analysis of long term stream gauge records. The basic data for these methods are the long term mean annual (MAF) and mean monthly flow (MMF) records for the watercourse being studied, augmented by limited field measurements and photographs taken at multiple discharges.

For the Tennant method, various percentages of MAF are calculated and applied to two 6 month periods according to the following table:

Narrative Description of Flow [a]	April to September	October to March
Flushing/maximum flow (from 48 - 96 hours)	200% MAF	na
Optimum range of flow	60 - 100% MAF	60 - 100% MAF
Outstanding habitat	60% MAF	40% MAF
Excellent habitat	50% MAF	30% MAF
Good habitat	40% MAF	20% MAF
Fair or degrading habitat	30% MAF	10% MAF
Poor or minimum habitat [b]	10% MAF	10% MAF
Severe degradation	<10% MAF	<10% MAF

[a] - for fish, wildlife, recreation, and related environmental resources

[b] - this is only for short term survival

Tessman (1980) adapted Tennant's seasonal flow recommendations to calibrate the percentages of MAF to local hydrologic and biologic conditions including monthly variability. Under his changes:

○ Monthly minimum equals the MMF, if MMF <40% of MAF;

○ If MMF > 40% MAF, then monthly minimum equals 40% MAF

○ If 40% MMF > 40% MAF, then monthly minimum equals 40% MAF

○ The flushing flow criteria is still a requirement to be met on an annual basis

The Tessman method provides criteria on a monthly rather than 2 season basis.

4.4.2 Hydraulic Methods

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

The most common hydraulic method is the Wetted Perimeter method. For streams with an approximately rectangular form, the wetted perimeter increases rapidly as discharge increases until the flow just covers the base of the channel and begins to be confined by the banks. The point of inflection, where the rate of wetted perimeter increase slows as discharge increases, is used to define the instream flow requirement. The ecological basis of the hydraulic methods, which are based on stream width or wetted perimeter, is to sustain food production, such as habitat for periphyton and benthic invertebrates (Jowett, 1997).

Hydraulic methods are well suited to studying biologically critical areas (e.g. riffles), if they can be identified. This method is intermediate in cost and complexity. Hydraulic methods are not usually used to assess seasonal requirements as recommendations are typically made only for the low flow season. Typically this method is used in conjunction with other methods.

4.4.3 Habitat Methods

Habitat methods are an extension of the hydraulic methods (Jowett, 1997). The habitat methods establish flow requirements on the basis of the hydraulic conditions needed to meet specific habitat requirements for biota. Some habitat features such as depth and velocity are directly related to flow; other habitat features such as substrate and cover are indirectly related to flow. These habitat features are sometimes referred to collectively as hydraulic habitat. The common methods are the Physical Habitat Simulation System (PHABSIM) model and the Instream Flow Incremental Methodology (IFIM). Although beyond the scope of the current study, habitat based modelling has its place. Where water takings are stressing a sensitive environmental reach or feature and trade- offs have to be considered, habitat based modelling is an approach that may be considered.

4.4.4 Other Hydraulic Assessment Methods

Two other tools which may be used to assess the hydrology component include: **Indicators of Hydrologic Alteration (IHA)** and the **Range of Variability Approach (RVA).**

Indicators of Hydraulic Alteration (IHA)

Richter et al. (1996) provide 33 measures that define the ecologically relevant characteristics of the flow regime including the magnitude, duration, timing, and frequency of extreme events and the magnitude and rate of change of flow conditions. For a data series (e.g. daily mean conditions), the values for each of the ecologically relevant hydrologic parameters for each year can be calculated and inter-annual variability (represented by central tendency and dispersion for each parameter) characterized. Comparisons of inter-annual variability for pre- and post-impact data series or for altered and reference site data series may be made.

The IHA can be used to establish baseline hydrologic conditions, for monitoring and assessment of projects, and for alternatives analysis. It does not, however, provide instream flow requirements.

Range of Variability Approach (RVA)

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

Ontario Flow Assessment Technique (OFAT)

In Ontario, the Ministry of Natural Resources has developed the Ontario Flow Assessment Techniques (OFAT). This tool has the ability to report watershed characteristics and provide flow estimates at both gauged and ungauged sites. This tool was assessed as part of the current study and may offer the ability to easily transfer information from a gauged site to an ungauged site as suggested in the above. Further discussion of OFAT use and limitations can be found in Sections 7 and 8.

4.4.5 Geomorphology

The flushing of flows is needed in order to remove accumulated sediment from riverine habitats. According to Annear et al. (2002), "Flushing flows are a management tool commonly used for improving spawning gravel quality and fish reproductive success, increasing food production, maintaining pool depth and diversity, and preserving channel complexity by preventing channel encroachment, keeping secondary channels functioning, and preventing embeddedness." Flushing will be achieved when flows are high enough to result in streambed mobilization. There are empirical, sediment transport modeling, and office-based hydrologic methods for developing flushing flow recommendations (Reiser et Al., 1981; Annear et al., 2002)

Channel Maintenance Flows are intended to maintain the physical characteristics of the stream channel. This is achieved when the flow regime can transport the quantity and size of sediment imposed on the channel without aggradation or degradation. Annear et Al. (2002) describe a bed load based method for quantifying channel maintenance flows that may be applied to gravel-bed, alluvial streams.

4.4.6 Water Quality

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

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

4.4.7 Connectivity

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

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

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

The next generation Ontario Flow Assessment Techniques will include a sub-component called the Ontario River/Stream Ecological Classification Techniques (ORSECT). This tool allows barriers to fish movement to be easily identified and the drainage layer to be dynamically segmented to identify reaches between barriers.

4.5 Instream Flow Assessment Tools - Frameworks

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

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

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

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

The bottom-up approach appears to be preferred in environmental flow assessments around the world. These methodologies are vulnerable to lack of data and limited understanding of processes such that some critical components of the flow regime may be left out.

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

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

Arthington et al., (1998) allow for a scoping stage after completion of background studies to consider constraints before significant efforts are put into quantifying flows which may not be deliverable. Within the Arthington et al. framework, a three-tiered system of environmental flow assessment is nested:

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

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

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

5.0 OVERVIEW OF FIELD PROGRAM AND USE OF HISTORICAL DATA

5.1 General

Each of the pilot studies was tasked by the Terms of Reference to complete the following to achieve the Study A component:

- ○ The goal of the study is to test, compare, and validate a number of different approaches of setting instream flow quantities (such as Hydrologic and Hydraulic methods) in a variety of watersheds in Ontario. **Particularly the study will focus on identifying easy to use, hydrologic based approaches for Ontario that give ecologically meaningful threshold values**
- ○ The intent of the work (in part) is to develop answers to the following questions:
    - ● What are the "natural condition" flows in the system?
    - ● What are the implications of applying minimum flows to water takings?

Each of the CA's approached this study goal in different ways, based on a number of considerations, such as:

- ○ Watershed size
- ○ Availability of existing and historical data, particularly stream gauge data
- ○ Existence of hydrologic/hydraulic models
- ○ Availability and level of expertise of staff/consultants
- ○ Local knowledge of watershed characteristics/functions (hydrologic, hydraulic, ecological) and relationships; and water taking permits

A fundamental requirement of each study was to incorporate methods that would address instream flow requirements to cover a range of hydrologic conditions and specifically address critical requirements to sustain natural hydrologic conditions, fluvial geomorphological/channel morphology conditions and sediment regime, and aquatic habitats and fish production.

The CRCA study selected a relatively small watershed (Milhaven Creek) of 176 km2 that contains three lakes, two of which are regulated by dams operated by the CA. The lakes exert a significant level of hydrologic regulation on the watershed and CA staff have a thorough understanding of water management effects on the watershed. The creek system is also generally bedrock controlled (either shield or limestone plain) or contained within an extensive riparian wetland system. Information was generally lacking on aquatic habitats and communities and local effects of water level/flow changes on stream cross sections. CRCA opted for an approach that emphasized the use of inhouse resources and expertise, to ensure that the chosen methodology could be used by inhouse staff. CRCA adopted a monitoring approach where basic hydrologic, hydraulic and ecological data was collected and synthesized to characterize existing conditions and water management operations and then evaluated the strengths/weaknesses of different instream flow methods, including examining the operational strategies for the water control structures.

The GRCA study considered the entire Grand River watershed of over 6900 km2 including a series of reservoirs linked to a comprehensive water management operations strategy, with a relatively extensive stream flow/precipitation monitoring network that considers multiple objectives. GRCA opted for a stratified evaluation approach and selected a series of 8 segments/reaches typical of small (less than 100 km2), moderate (200 - 400 km2) and large (greater than 1000 km2) drainage areas to investigate instream flow methodologies. In addition, detailed aquatic habitat and fish community data was available for the selected segments. GRCA has good information on existing PTTW that has been summarized by subwatershed area for both surface and ground water takings. Within each segment, detailed geomorphic and stream cross section data was collected to allow hydraulic models to be used in conjunction with hydrologic models. GRCA staff and consultant specialists were utilized to develop an approach requiring a relatively high degree of expertise. GRCA used a combination of hydrologic and hydraulic modelling to compare a broad range of methodologies including more data-intensive, sophisticated methods such as the wetted perimeter, RVA and IHA methods.

The LPRCA considered an intermediate sized watershed (Big Creek) of 750 km2 with a large number of PTTW's (over 1000). Big Creek contains numerous flow and precipitation gauges and has a detailed database of reach specific fish habitat and fluvial geomorphology. Recently the GAWSER hydrologic model was set up, calibrated and validated for the watershed and used to characterize existing and historic (presettlement) conditions. The availability of the GAWSER model provided an excellent opportunity to explore the merits of the RVA hydrologic methodology, since the model was capable of examining a number of different scenarios, including comparing results to historic conditions. Other methods could also be approximated by the model for comparison purposes.

5.2 Summary of Approaches

5.2.1 CRCA

Of the three pilot projects, the CRCA study perhaps has the least amount of historical data that is quantifiable. In other words, there is a considerable amount of data available on Milhaven Creek, however much of the information is more qualitative in nature or focuses on specific issues. This type of information is typical for many watersheds in southern Ontario that have not been the subject of formal watershed/subwatershed studies.

The following types of information were available:

- Stream flow (1gauge), precipitation, snowmelt, air temperature
- Water quality (5 stations, 2 long term)
- Limited historic fish inventory data
- Wetland evaluations and mapping
- Floodplain and topographic mapping
- Hydrologic modelling focuses on determining low flow requirements for assimilative capacity
- Limited hydraulic modelling in association with control structures
- Long term water level records for control structures
- Municipal treatment plant intake and wastewater discharge volumes
- Land use - existing and future
- Water taking permits

CRCA augmented this historical database with detailed field studies over two field seasons. Field work focuses on the following:

- Detailed mapping of stream characteristics along its entire length, primarily stream widths/depths, estimates of flow, velocity, barrier identification, reaches sensitive to low flows and potential fish refuge pools, general habitat characteristics
- At approximately 10-12 sites (depending on type of field study), collection of more detailed information:
  - Stream flows, widths, depths, velocities under a variety of flows
  - Detailed cross sections
  - Habitat mapping following the OSAT procedures
  - Fish inventory and benthic invertebrate collections
  - Continuous temperature recordings
  - Diurnal and seasonal measurements of temperature, conductivity, dissolved oxygen, pH
- Detailed mapping of wetland habitats, focusing on bathymetry and plant community/depth associations
- An assessment of the effect on reservoir storage (water levels) of changing precipitation and evaporation conditions and consequent impacts on stream flow
- Review of historical airphotos to assess historical changes in stream morphology
- Review of water uses, including water taking permits within the watershed

Once this information was compiled, CRCA examined how various environmental parameters associated with detailed stream cross section locations responded to changes in flow. This was done using limited hydrologic/hydraulic modelling, spreadsheet methods and professional judgement/analysis to compare how various water management strategies and various instream flow tools affected these "indicator sites".

5.2.2 GRCA

GRCA selected stream segments/reaches for their pilot study, based in part on specific issues affecting instream flows and in part based on sites with the best available databases. Section 3.3 lists the key issues associated with each site. Table 5.1 provides a summary of information availability at each site. In addition, detailed geomorphic/cross section information and in some cases fish habitat data was collected. The key strengths of the GRCA study are the detailed level of available data, and the availability of hydrologic and hydraulic modelling that allows historic, current and future conditions to be characterized. In addition, this information is available for 8 segments characterizing different watershed scales, land use conditions and issues affecting instream flows.

A key strength of the study is the availability of detailed cross section data, including in some cases sufficient information to construct a Digital Elevation Model (DEM) of the study segment. With this level of detail, a detailed evaluation of aquatic habitat considerations/impacts can be made, even though detailed fish habitat/inventory data may be lacking. Figures 5.1 and 5.2 show examples of the stream segments, highlighting the cross sectional data available/collected as part of the study.

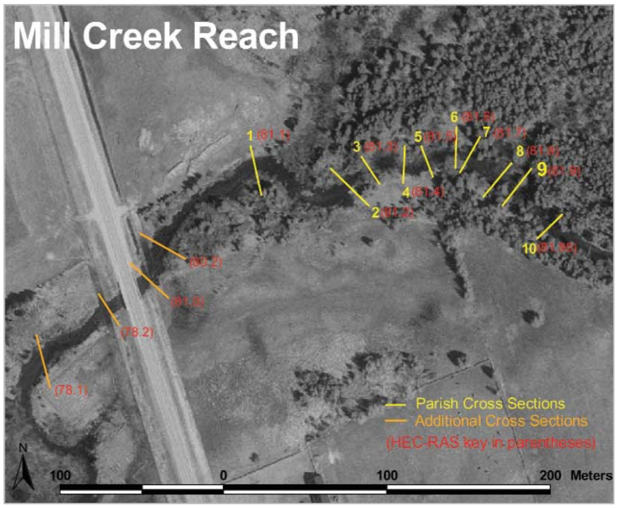


Figure 5.1 Mill Creek pilot reach cross sections and geodetic survey

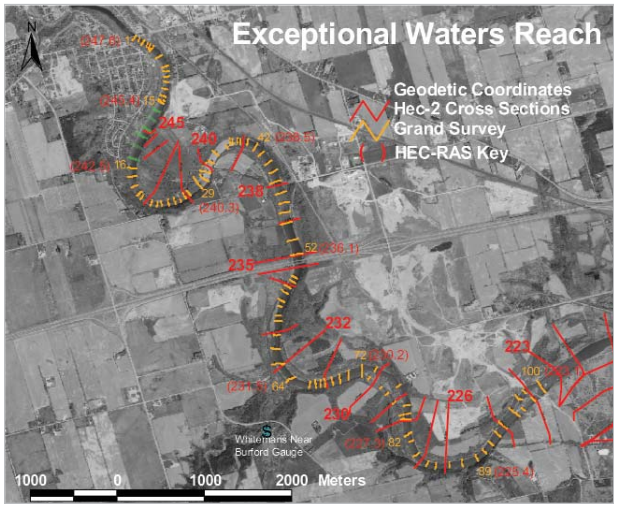


Figure 5.2 Cross section locations for the Exceptional Waters Reach

Table 5.1 Information availability for the pilot study reaches

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

There is also considerable fisheries information available for some sites, in sufficient detail that preliminary relationships between physical habitat conditions and measures of fish productivity (for example, biomass) can be explored. In addition, there is ongoing research looking at other surrogates for fish productivity that may assist in the assessment of effects (Power, 2004).

Once models were set up, calibrated and validated on each study segment, GRCA examined a variety of instream flow tools and their effect for different hydrologic conditions, including assessing the level of protection from current water taking. This included flow based models (for example, Tennant and Tessman), hydraulic/geomorphic methods (for example, IHA, wetted perimeter) and habitat/fish productivity approaches. GRCA focused on the use of IHA and also reviewed the OFAT model.

5.2.3 LPRCA

The LPRCA study uses the Range of Variability Approach (RVA) (Richter et al., 1997), as the most appropriate and ecologically-defensible method currently available, with which to investigate the establishment of instream flow management criteria for the Big Creek watershed, and to provide a benchmark for comparisons with alternative approaches. The RVA approach involves understanding, quantifying and ultimately managing in relation to the "normal" (or reference) range of flow variability in a stream or river system, with the underlying assumption that the ecological character and quality of a stream ultimately depends on the dynamics and variability of its flows. This assumption is extended to the understanding that the river flow regimes, or at least the critical elements of a river's flow regime, must be maintained in order that other dependent and essential ecological elements of a stream - its geomorphology, form, and fluvial aquatic habitat and biological communities - are maintained.

In order to establish a reference condition upon which to base flow management in the Big Creek watershed, it was necessary to understand the existing state of the system, with respect to its hydrology, geomorphology and aquatic ecology (in this case fish community endpoints). At the outset of this study, the best information related to overall ecosystem integrity was established using data on the distribution and abundance of cold water fish species. On this basis, the study test sites were purposely selected to represent good quality coldwater fish habitat in the Big Creek system as a reference condition.

Using these reference sites, a detailed hydrologic model developed for the Big Creek watershed was employed to investigate and compare RVA flow "normals" under three scenarios: (1) existing conditions with known water takers; (2) existing conditions with water takers "turned-off"; and (3) pre-settlement conditions (e.g. 95% forest cover, no water takers, no reservoirs and no sewage treatment plants). The hydrologic modelling software (e.g. GAWSER) was modified so that it would calculate a number of relevant RVA parameters after methods described as Indicators of Hydrological Alteration (IHA) by Richter et al., (1996). Several new IHA type indicators were developed as part of this study, resulting in a total of forty-two IHA parameters calculated for the Big Creek sites. Following model application, software modification and testing on the two reference sites, five other test sites in the Big Creek watershed were modelled and tested using the RVA approach. The other five sites were selected to represent an expanded set of reference sites to permit a more robust evaluation of the RVA method and to facilitate comparison with other techniques. Using the Big Creek hydrologic model, comparisons of results of the 'normal' RVA flows were made with other historic flow methods/parameter results including flow duration curves, Tennant method, 7-day 10-year low flow (7Q10). The wetted perimeter (hydraulic method) was also evaluated using modelled flow and stage cross-section profiles (rating curves) at test locations. Flow rating curves were developed and evaluated for a number of fish habitat metrics and compared to RVA endpoints for all seven test sites.

Existing data available for the Big Creek study site was intermediate between the information available for the CRCA study and the GRCA study. Among the more detailed data sets available were the following:

- Flow gauge, precipitation and other climate data from 22 locations within LPRCA's jurisdiction, including 4 gauges within Big Creek
- An extensive stream dataset of geomorphic and fish community, biomass and habitat measures (using OSAT) based on a PhD thesis
- Data on over 300 PTTW's within the watershed, as well as the Delhi WWTP discharge
- A detailed hydrologic model, GAWSER, as described above. In particular, the model provided for development of rating curves and discharge information for "areas of interest" in the watershed where gauged information was lacking. The model is cabable of generating hourly or daily hydrographs for a 39 year period at any of 240 point locations in the watershed

The use of the IHA/RVA method was augmented with additional detailed studies of hydrologic, hydraulic, geomorphic and aquatic habitat. Additional data collected for the study included the following:

- Detailed cross sectional data at 12 locations
- The development of simple "habitat suitability" variables for cold water species that could be used in the instream flow analyses to measure impacts of different tools and management strategies, including useable wetted area (perimeter)
- A fluvial geomorphic survey and the collection of key input variables to allow an assessment of instream flow requirements to address key geomorphic considerations and to utilize the sediment transport modelling capabilities of GAWSER (Sediment transport was investigated on a small test catchment (Brandy Creek) and the results were then extrapolated to consider watershed scale effects).

6.0 WATER USES AND PTTWS

6.1 Water Taking Permit Process

A new permitting process including a new Water Taking and Transfer Regulation (Ontario Regulation 387/04) and a new PTTW Manual has been recently put into place by the MOE. The new process more rigorously addresses potential impacts of water taking and recognizes that different types of water taking may pose different risks to the environment and other water users.

The PTTW program adheres to 6 principles as described in the PTTW Manual:

- Principle #1: The Ministry will use an ecosystem approach that considers both water takers' reasonable needs for water and the natural functions of the ecosystem.
- Principle #2: Water takings are controlled to prevent unacceptable interference with other uses of water, wherever possible, and to resolve such problems if they do occur.
- Principle #3: The Ministry will employ adaptive management to better respond to evolving environmental conditions.
- Principle #4: The Ministry will consider the cumulative impacts of water takings.
- Principle #5: The Ministry will incorporate risk management principles into the permit application/review process.
- Principle #6: The Ministry will promote public and local agency involvement.

The process classifies water takings into three categories based on level of risk in terms of causing adverse environmental impact or interference with other water users. Surface water takings are classified as follows:

- Category 1: typically includes renewals of existing permits or new applications where the environmental effects are readily predictable and minor;
- Category 2 permits include:
    - **Great Lakes** or connecting channels takings less than the Great Lakes Charter threshold
    - **Takings from sources with previous assessments** (i.e. further to a previous study and implementing previously established controls)
    - **River and Streams (3rd order or higher order)** taking <5% of 7Q20
    - **Transitional Permits** where the Director previously required upgrades/modifications to water taking
    - **Takings and Returns** where water is removed for a short time only and water is returned to a nearby point with no significant change to water quantity or quality (i.e. for cooling, hydrostatic testing, hydraulic lake dredging)
    - **Lakes and Ponds** takings 1,000,000L/day twice per week from water bodies >10ha in size that are not on-stream and not part of the headwaters of any watercourse.
- Category 3 permits include all other situations: all surface water takings that do not meet Category 1 or Category 2 criteria and new takings from 1st or 2nd order watercourses, wetlands, intermittent streams, new on-stream reservoirs, impoundments and ponds, groundwater sources that potentially affect surface waters.

The MOE Regulation (O.R. 387/04) considers the relative level of water use by tertiary watershed; for water taking within watersheds classified as moderate or high use watersheds, more stringent information requirements and water taking limitations may apply.

Maps highlighting level of water use described in the Regulation can be found on the following link:

- **http://www.ene.gov.on.ca/envision/gp/4932e.pdf** ; maps on pages 32 Water Use - Summer Low Flow Conditions; and 33 Water Use - Average Annual Flow Conditions

Category 1, 2 and 3 permit applications each have different requirements for addressing instream flow needs and aquatic habitat considerations. This may include simple or complex methods, at the discretion of the Ministry and include a requirement for monitoring. Permits may be granted for different periods of time depending on a water taking's known or predicted level of risk to the environment.

6.2 Study Areas

CRCA has only 6 surface PTTW within the Milhaven Creek watershed, however, it has been noted that there are in fact numerous water takings for agricultural and domestic water use (related to cottage development) within the watershed that do not require a permit.

GRCA does not specify the number of takings, however, Figure 6.3 illustrates in general the number and distribution of takings. Whiteman's Creek has been identified as one subwatershed where water takings may be interfering with instream flow requirements for coldwater fish species. Approximately 800,000 m3/day of surface water takings and a similar volume of groundwater takings are identified upstream of the Exceptional Waters Reach, the most downstream reach in the study.

LPRCA has over 1000 PTTW (surface) within the Big Creek watershed and over 2400 PTTW (surface) in total, **which represents nearly half of the total surface PTTW in the province**. The distribution of PTTW within the LPRCA's jurisdiction is shown in Figure 6.4. Note that Big Creek (highlighted in blue) is located in the center of LPRCA's jurisdiction, generally where the highest density of PTTW's are located.

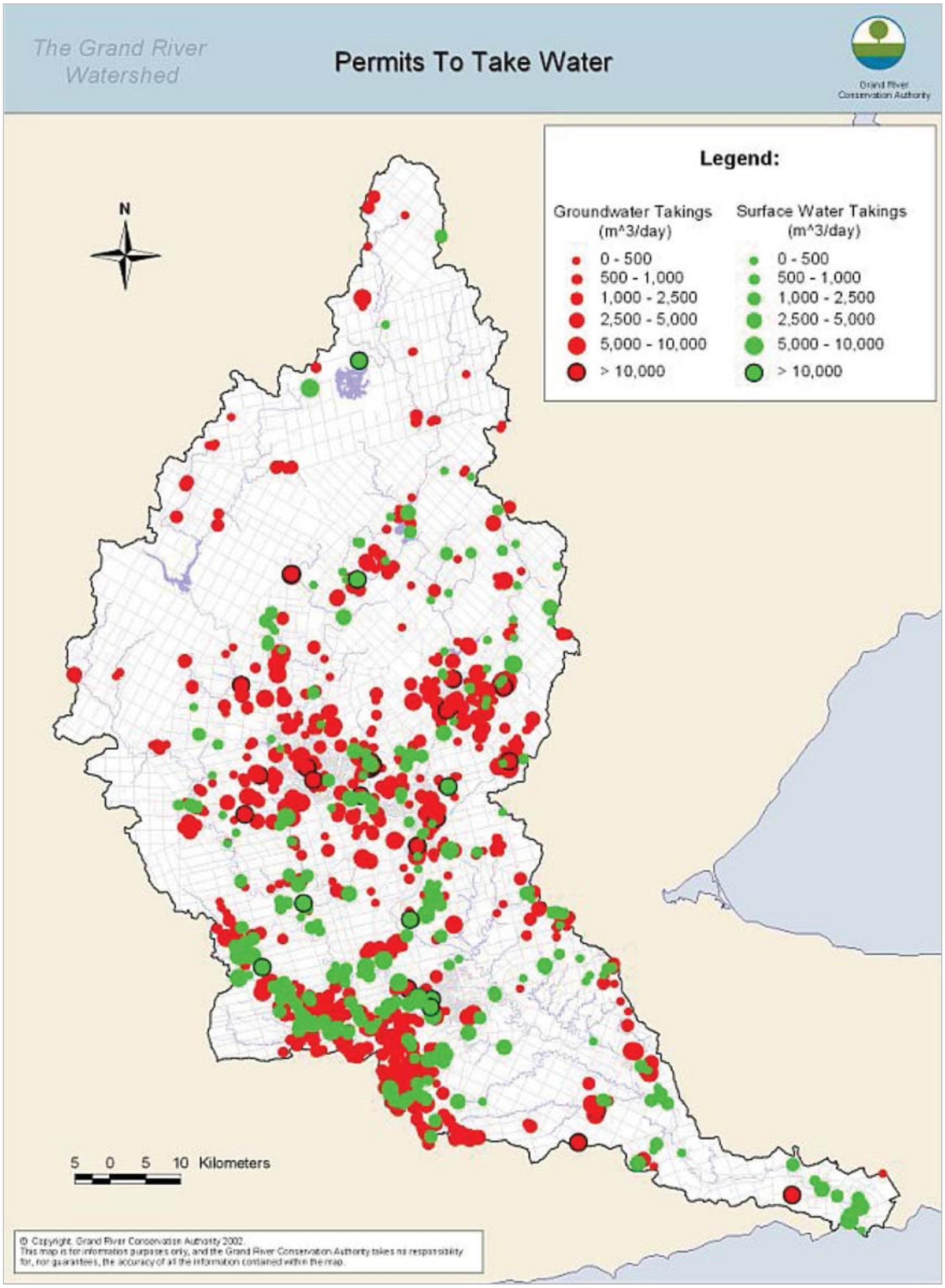


Figure 6.3 GRCA permits to take water

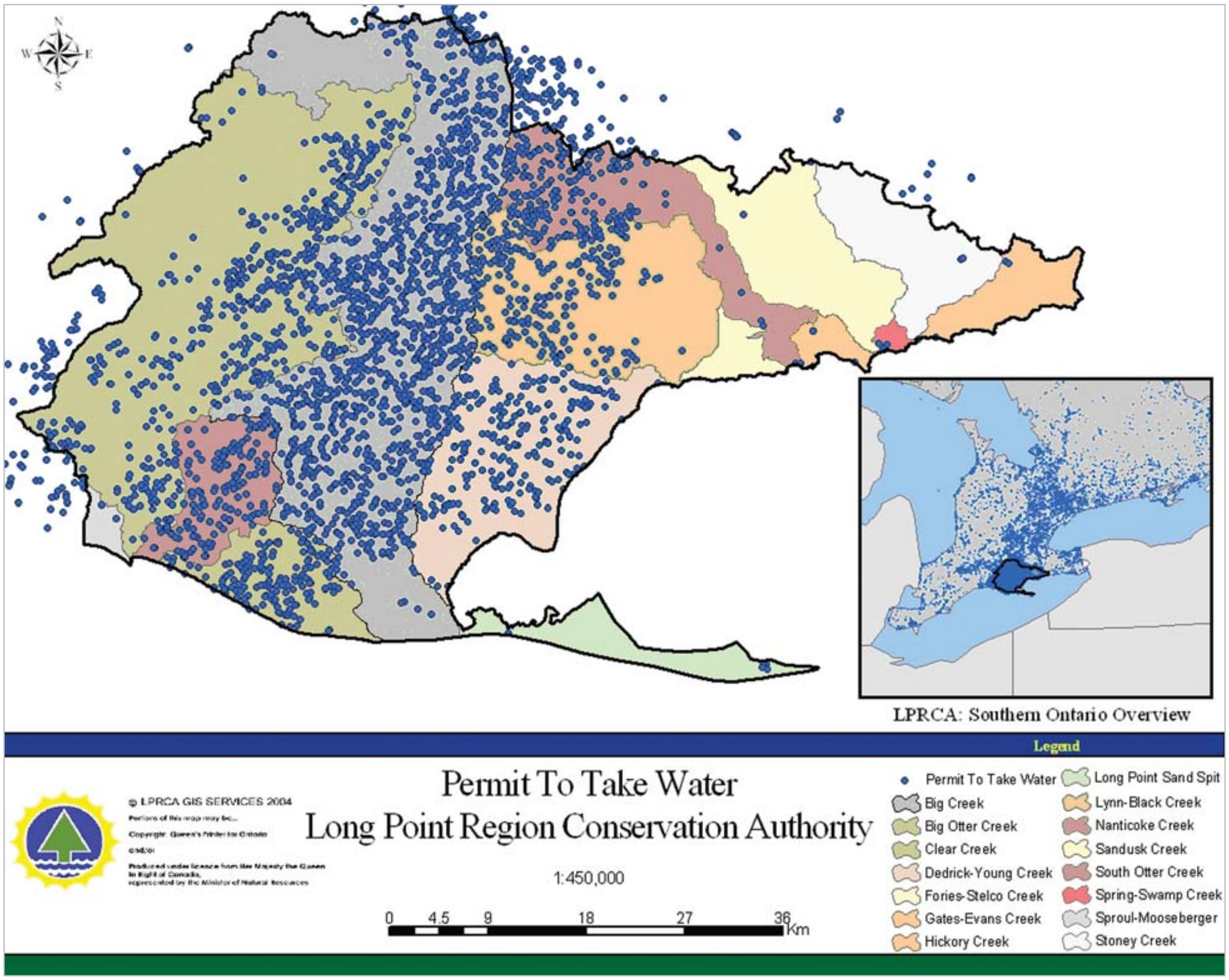


Figure 6.4 LPRCA Permits to take Water (surface)

7.0 DETERMINATION OF ENVIRONMENTAL FLOW REQUIREMENTS

7.1 General

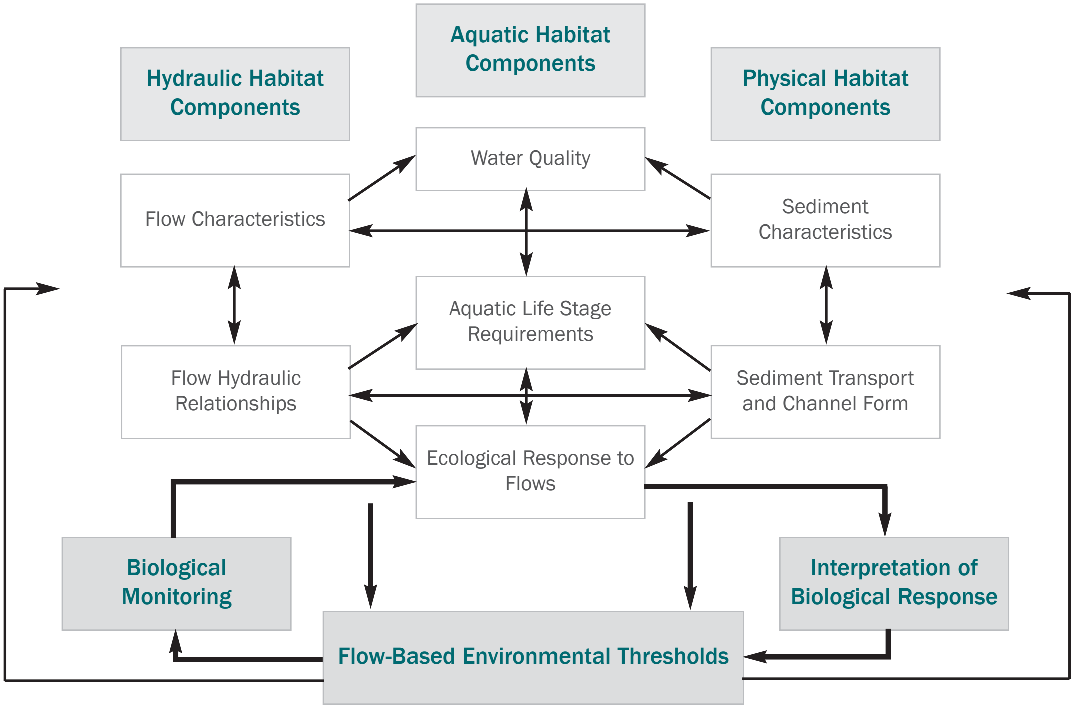
In order to develop effective tools for determining volumes of water that can be withdrawn from a riverine system, without substantial impacts on the aquatic ecosystem, a thorough understanding of the internal and external processes that sustain the system is needed, as well as a model of the system that reasonably characterizes these processes. Once this is accomplished, a set of environmental flow requirements or instream flow thresholds could be established that would limit water takings to levels that fall within the ecosystem's natural resiliency to stress.

An environmental threshold for a given ecosystem variable can be defined as the minimum/maximum level at which the effects of a stress can be absorbed within the ecosystem's inherent ability to absorb the effect, without irreversible consequences.
As noted in Section 4, determining a single, minimum threshold flow, to the exclusion of other ecologically relevant flows, is no longer an accepted approach to instream flow management. It is known for example that the minimum flow determined for one life stage of one species does not ensure adequate habitat protection, even for the species for which the threshold flow was established. Currently, the trend is towards the use of the "natural flow regime" as a basis for determining instream flow needs and it is common to consider flow to be a "master variable" determining the form and function of streams, and in fact, streamflow is strongly correlated with many physico-chemical characteristics such as water temperature, channel geomorphology, and habitat diversity, which are critical to sustaining the ecological integrity of streams and rivers.

The challenge then is establishing the essential or critical components of the "natural flow regime" that are necessary to sustain important biological, hydrologic/hydraulic, fluvial geomorphologic (including sediment regime), water quality, and hydrogeologic components of the aquatic ecosystem. Once these essential components are known, a set of environmental flow thresholds can be established to maintain them.

The establishment of a set of multiple, flow-based, ecological thresholds that define the instream flow requirements for a given watershed is the fundamental objective of this study. This is conceptualized in Figure 7.1 (from GRCA).

Figure 7.1 Flow Diagram adapted from GRCA



There are several key considerations in the development of flow-based environmental thresholds:

- Thresholds may operate at different spatial scales - watershed, reach, site, for example, return frequency flows may be important watershed thresholds, annual and seasonal hydrographs may be important reach thresholds, and flow/depth relationships may be important site thresholds
- Thresholds may operate at different temporal scales - daily, monthly, seasonally, annually; thresholds may also be relevant for only certain time periods, for example during fish migration or during fish spawning - conditions that may depend on other variables (eg temperature) rather than flow for their timing
- Thresholds may change spatially throughout a watershed - changes in flow time series may have greater impacts on small order streams and less impact on large order streams; channel hydraulics in different reaches result in significant differences in flow depth relationships
- Thresholds may change temporally - the minimum monthly flow changes dramatically from year to year, organism sensitivity varies throughout the year;
- Thresholds may vary based on the sensitivity of the ecosystem(s)
- Linkages or correlations between ecologically important functions/characteristics and flow thresholds may be difficult to define - for example, although flow regimes can generally be correlated to aquatic habitat characteristics, effects on physical habitat are poorly linked to effects on fish populations and communities; different life stages of individual fish species often require different stream habitat conditions

As Section 4 indicates, there has been a rapid expansion in the range and complexity of instream flow methods, shifting away from simple "standards" to complex, diagnostic/analytical methods such as IHA/RVA that first characterize the natural flow regime and then provide numerous environmental indicators that can be examined to assess the effects of a change in flow resulting from a water taking or other change in the watershed. The application of an Adaptive Environmental Management Approach (See Section 8) to the assessment, evaluation and monitoring of water taking permits is considered to be a fundamental requirement to lead to a better understanding of environmental flow requirements and methods of assessing them.

7.2 Approach to Defining Thresholds

The selection of an approach to defining ecological thresholds depends upon a number of considerations:

- present state of the aquatic ecosystem;
- nature and complexity of the management issue(s);
- level of controversy of a particular project or purpose;
- habitat homogeneity at various scales;
- sensitivity of fish communities and fluvial geomorphological conditions
- data requirements of models;
- existing management plans, goals and objectives;
- cost; and
- expertise of the personnel.

The process followed by each CA in selecting a appropriate model can be summarized as follows:

- identify/review the management objectives within the watershed or tributary
- characterize the type of system in terms of surficial geology, land use, regulated vs. unregulated, static vs. changing land use, fish community type (cold/warm, sensitive/tolerant), etc.
- characterize water use requirements/characteristics: instream features (fish communities, wetlands), recreation, water takings, assimilative capacity requirements, sediment regime, ice management, etc.
- identify range of applicable methods
- identify/review existing data
- screen models based on cost, reliability, expertise required, data and time requirements and watershed/water use characteristics (noted above)
- select model and apply

7.2.1 Milhaven Creek (CRCA)

CRCA selected a "standard setting" approach (as defined in Table 4.1), focused on collecting data at key times of the year when flow conditions may impact on critical components of the aquatic system. This approach was selected for the following reasons:

- Data requirements were compatible with data availability for Millhaven Creek, and
- The standard setting methods can be applied with a moderate level of expertise and allowed the CA to utilize in-house staff resources.

The uniqueness of the watershed provided a forum for testing the viability of the methods in these conditions:

- Millhaven Creek is a highly regulated system, characterized by (relatively) large lake environments connected by small stream systems,
- The creek channel is primarily bedrock based,
- Land use is static and the overall system is very stable, with little evidence of any recent changes,
- Water taking is relatively minor, except for the two water storage dams, and
- While sensitive fisheries and wetland habitats exist in the lake environments, the stream environments support tolerant species that are adapted to the existing long term flow regime.

The CRCA monitored field conditions, examining the flows required for various ecological functions/processes, the general health of the ecosystem and whether changes in flow regime would be necessary/beneficial or possible. In this approach, basic hydrologic, hydraulic and ecological data were collected (historical data supplemented with field work) and synthesized to characterize existing conditions. Then the "standard setting" techniques were applied to the historic and field data to determine whether they applied to the watershed.

CRCA identified the following general ecological considerations:

- Fish Habitat
  - spawning - maintain water levels to adequately cover spawning beds, maintain flows for fish passage and attraction, maintain flows to minimize sediment deposit over incubating eggs
  - rearing - maintain flows (not too high) for young to find food, provide water levels for cover of young fish, provide nutrients (benthic habitat) to produce food
  - oxygen - maintain flows over riffles to keep minimum oxygen in the water
  - flushing - maintain flows to provide flushing of wastes out of pools, and flushing nutrients in
- Benthics
  - provide habitat to continue production for food values, i.e. cover over riffles

- Wetlands
    - adequate water depth in spring time for spawning beds (northern pike)
    - seasonal variation in water levels for different plant species
    - flushing of nutrients/sediments to downstream areas for use by aquatic plants and other organisms
    - base flow maintenance for downstream stream habitat maintenance
- Channel
    - channel forming flows, erosion/sedimentation, meanders, plant species movement, growth
    - quantity of sediment movement to form bars, pools, etc. without excessive sediment build up or sediment deficiency
- Flushing
    - moving sediment, nutrients, etc. onto floodplain, off floodplain
- Water Quality
    - seasonal variations in nutrient runoff
    - summer time - less flow, but more fertilizer, pesticide, herbicide, therefore higher concentrations, greater impact
    - winter time - more flow, less nutrients/contaminants, less of an impact
- Users
    - summer time - lawn watering, vegetable gardens, livestock, irrigation, swimming, boating, fishing
    - winter time - ice cover, ice flushing, fishing, on ice uses
    - all year - municipal supply, sewage dilution, aesthetics

In addition, there currently is a minimum flow objective of 0.12 m3/s based on water supply and waste assimilation considerations. Furthermore, there is a rule curve established for each of the two dams that are managed for flood control, recreational use and low flow augmentation. It is important to note that the current water management strategy of maintaining significant water storage in these reservoirs for release downstream during periods of insufficient base flow artificially increases base flows in Milhaven Creek above their natural levels. This low flow augmentation strategy also provides a significant benefit in terms of maintaining stream habitats that under natural conditions may not be sustained.

CRCA employed field methods, simple hydraulic analyses and qualitative assessments to assess the effect of current operations on key ecological considerations. Based on their field studies, they concluded that the current water management regime was optimal for meeting the instream ecological requirements of the Milhaven Creek Watershed. There were several key considerations in arriving at this conclusion:

- The existence of the lake and reservoir system meant balancing water level needs in the reservoirs with instream flow needs downstream. In this regard, maintenance of water levels was important to maintain PSW's, provide recreational uses and sustain lake resident fish populations (which were considered to be the most important. fishery in the watershed). Maintenance of targeted low flows was generally achievable, but not in all years. However, even at higher "flow minimums" many of the stream reaches are reduced to partially isolated pool systems. The tolerant warmwater fish community in the stream environments appears to have adapted to this type of environment. Based on these management objectives, there would appear to be little benefit of increasing the minimum flow target.
- Maintenance of targeted low flows was considered to be very important during the winter months to prevent frazile ice formation that could lead to ice-jamming problems and result in stress on aquatic habitats.
- While the lake and reservoir systems have significant influence on so called "flushing flows" and perhaps on lower, "channel forming" flows, these thresholds were not considered to be important since the channels are primarily bedrock controlled and show little evidence of movement historically.

Hence the CRCA concluded that their current water management strategy was generally optimal. CRCA identified the need to continue to monitor instream conditions to ensure that no unforeseen changes occurred.

In general, the field method approach in this case was effective, requiring limited historical data.

7.2.2 Grand River (GRCA)

GRCA selected a detailed analytical/diagnostic approach to instream flow assessment using the RVA/IHA diagnostic method and selected 8 pilot reaches representing different watershed scales and conditions. This is a detailed approach requiring statistical analyses of long term gauge records and detailed field studies to build hydraulic models suited to assessing flow, fluvial geomorphologic and aquatic habitat variables. This approach was selected, for the following reasons:

- ○ With a very large watershed, a targeted or layered approach was necessary to complete the project within time and cost constraints;
- ○ The watershed is highly complex with both regulated and unregulated systems and a moderate to high number of water takings;
- ○ Instream resources, primarily coldwater fish communities, were considered highly sensitive to hydrologic impacts; and
- ○ GRCA has both staff and consulting resources with a high level of expertise to implement the study.

An approach utilizing a statistical analysis of existing long term stream gauge information was chosen for the following reasons:

- ○ Gauged data provides a real-time historical account of actual stream flows;
- ○ Gauged data reflects the cumulative effects of any water taking that has occurred;
- ○ Gauged data does not rely on estimates of runoff/groundwater discharge based on land use, topography, physiography, etc. to estimate flow; and
- ○ Gauged data may provide more accurate information on flow extremes, such as very low and high flows.

GRCA developed eight detailed hydrologic/hydraulic models for stream segments within the watershed to characterize existing conditions. They used this information to apply the RVA/IHA methodology that provides numerous hydrologic indicator parameters in 5 broad categories(Table 7.1).

Table 7.1 Description of *Indicators of Hydrologic Alteration* parameter groups

Group	Description	Number of Parameters
1	Magnitude of monthly water conditions	12
2	Magnitude and Duration of Annual Extremes	12
3	Timing of Annual Extremes	2
4	Frequency and Duration of High and Low Pulses	4
5	Rate and Frequency of Change in Conditions	3

The IHA includes many hydrologic parameters that are associated with ecological conditions.

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

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

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

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

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

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

A standardized process for assessing hydrologic impacts is included within the IHA software. The Range of Variability Method (RVA) is another analysis frame in which to assess change in a structured manner. This method of determining hydrologic alteration is based on the theory that there is natural variability in streamflow. The RVA software would plot and determine whether an activity, such as a water taking, would alter the streamflow outside this normal variability. Significant alteration would occur if the streamflow regime is altered more than one standard deviation from the natural variability, which may have ecological consequences.

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

Several important fluvial geomorphological and habitat parameters were also identified (Table 7.2).

Table 7.3 Summary of hydraulic parameters used to interpret hydraulic results

Hydraulic Parameter	Definition	Significance
Flow Depth (m)	Maximum depth of water in cross section	Could be used to determine at which flow, channel connectivity is lost. Personal communication with Jack Imhof (2004) suggests 20 cm of depth needed for connectivity in the Eramosa River Study Reach
Flow Area (m2)	Area of channel cross section that conveys flow	Infers the space available to aquatic life at various flows
Wetted Perimeter (m)	Perimeter of channel cross section that conveys flow	Determines the amount of submerged channel substrate available
Flow Velocity (m/s)	Velocity of flow in main channel	May be used to assess the limitation for species migration. Movement of specific species is limited at specific velocity thresholds
Froude Number	Criterion of the type of flow present. As Froude number approaches 0, the flow is more tranquil and slower. As it approaches 1, flow is characterized by shallow and fast motion	Identifies pools versus riffles. May be used to identify at which flow, riffles are overcome by a pool, or vice versa. Important for aeration, invertebrate production
Topwidth (m)	Top width of cross section that conveys flow	Useful parameter to identify changes in hydraulic characteristics, can often be used to identify persistent hydraulic conditions
Width to Depth Ratio	Dimensionless ratio calculated by dividing channel width by maximum depth at a given flow	Used in geomorphic calculations and to infer large changes in the hydraulic regime, for example flow becomes confined to the thalweg

Geomorphological investigations also identified four geomorphic thresholds for consideration. These include:

○ Bed Mobilizing D_{50} Flow

○ Bankfull Flow

○ Flushing Flow

○ Residual Pool Threshold Flow

GRCA also investigated several thresholds that attempted to relate hydrologic/ hydraulic/ habitat parameters to measures of fish productivity (Biomass, Density, Stable Isotope Method), however no good correlations could be made. It was concluded that further research was needed before these productivity related measures could be realistically used as instream thresholds.
A common approach was then used for each study segment to analyse streamflows and water takings. This analysis examines taking strategies and their potential impact on the natural environment's flow requirements. The approach taken to analyze selected reaches includes the following:

1. Summarize existing water takings above the study reach.
2. Where appropriate and feasible, adjust existing streamflow data to reflect a naturalized condition.
3. Prepare a daily percentile flow plot to include the Tessmann Instream flow requirements (see Section 4.4).
4. Create a synthesized streamflow series by adding water takings back to the river.
5. Apply the Indicators of Hydrologic Alteration model and Range of Variability Approach (RVA) to interpret how takings are affecting streamflow.
6. Compare RVA summary to expected ecological impacts as suggested by IHA papers, other instream tools and other threshold values (for example Table 7.4).
7. Compare expected change to geomorphic requirements.
8. Where necessary, quantify hydraulic habitat impacts by applying flow hydraulic relationships established by detailed reach hydraulic models.
9. Compare expected hydrologic alteration to fishery requirements in each reach to anticipate expected impacts.
10. Make recommendations of how the permitted takings could be modified to better support the natural environment's ecological flow needs.

The RVA/IHA approach was then overlain against other instream methods to evaluate their strengths and weaknesses. Generally, the modified Tessman method (see Section 4.4) was considered to be the only "standard" method with some potential for establishing environmental flow requirements.

Figure 7.2 shows a sample output of the RVA/IHA approach with the modified Tessman Method overlaid. When the RVA/IHA analsis was completed for the Eramosa River with and without water taking, the 7 Day minimum flow statistic was observed to show a potentially significant result as shown in Figure 7.3 (the IHA literature suggests that a change is significant if it is varies from the original by more than one standard deviation). The RVA/IHA method allows this type of diagnostic analysis to be completed, but leaves the decision as to whether the effect is significant up to the decision-maker.

Figure 7.2 also overlays the Tessman Method against the daily flow percentiles generated for the Eramosa River. This figure illustrates how the Tessman method relates to the natural flow variability. When this was done for each of the 8 pilot study areas, the Tessman method generally produced favourable results, however, in several cases the Tessman method was found to under or over-estimate seasonal flow conditions, when detailed comparisons were made with the hydraulic and geomorphic indicators. These under /over estimates appeared to be the result of the degree of flow regulation, changing land use, and fluvially active vs. inactive channels and illustrate the need for careful assessment of methods such as Tessman before they are applied.

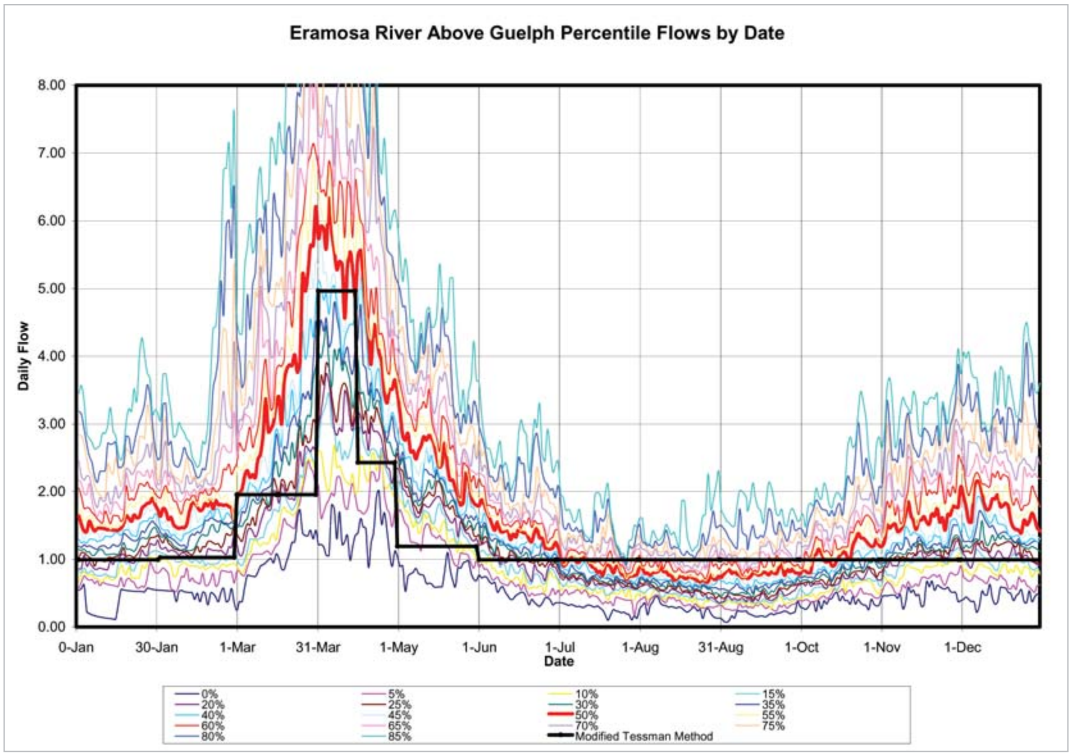


Figure 7.2 Daily flow percentile plot for Eramosa Reach with Tessman Method overlaid

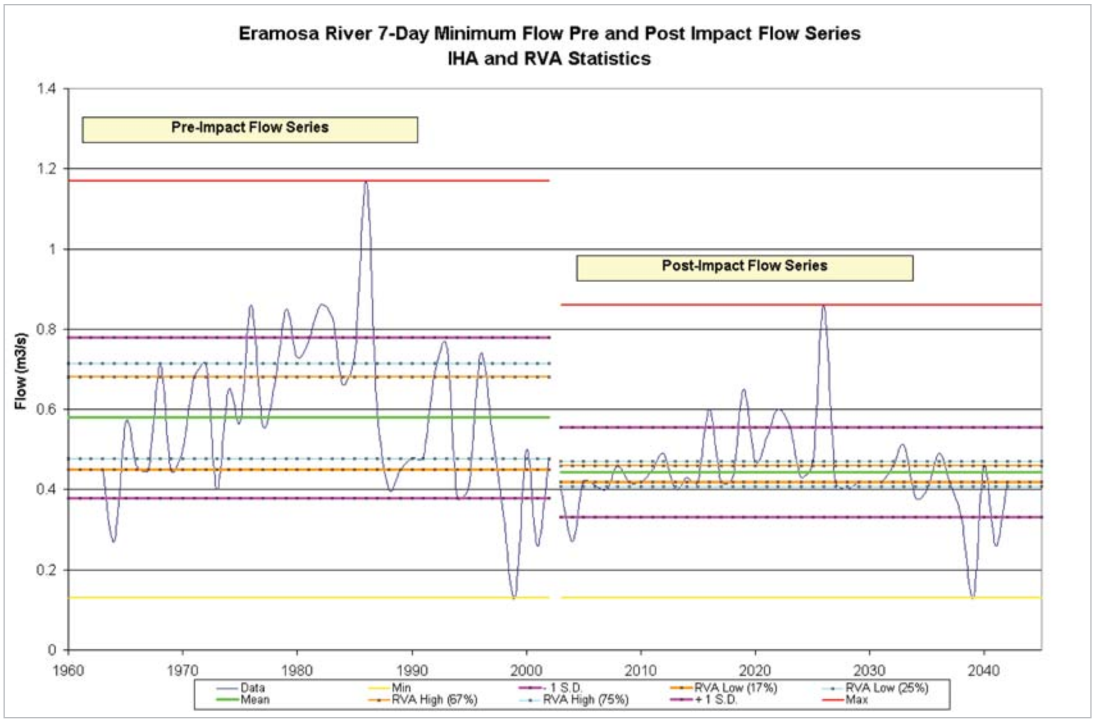


Figure 7.3 Eramosa Case Study Pre and Post 7-Day Minimum Flow Statistics from IHA and RVA

Figure 7.3 provides an example comparison of the IHA and RVA results for flow. Using the hydraulic models developed for each of the study reaches, variation in hydraulic parameters, such as those in Table 7.3, can also be generated. This provides a useful indicator of, for example, wetted perimeter pre- and post- water taking.

The RVA/IHA approach requires a significant amount of historical flow data and some intensive field work (to establish hydraulic cross sections and obtain fluvial geomorphological data) to use. In addition, while it does an excellent job of identifying where potential impacts on the "natural hydrologic regime" occur, it leaves determining the significance of the effect to the decision-maker. The interpretation of results also requires a fairly sophisticated level of knowledge. A significant benefit of the RVA/IHA method is that it can be used to improve the performance of simpler tools, for example the modified Tessman method by allowing the seasonal "standards" to be adjusted to better reflect local conditions.

In addition, by reviewing the various RVA/IHA metrics in relation to detailed hydraulic, geomorphic and aquatic habitat data for study reaches, it may be possible to develop empirical relations between hydrologic parameters and key habitat variables that would be more protective of instream habitats than other currently available methods. LPRCA also investigated the potential for establishing these empirical relations.

7.2.3 Big Creek (LPRCA)

LPRCA selected a modeling approach to instream flow assessment using the RVA/IHA diagnostic method and the GAWSER hydrologic model that had recently been set up and calibrated on Big Creek. This enabled the CA to define and examine hydrologic conditions at any point in the watershed which were augmented by detailed field studies at selected locations to build hydraulic components suited to assessing flow, fluvial geomorphologic and aquatic habitat variables. This approach was selected, for the following reasons:

- ○ The availability of the Big Creek hydrologic simulation (GAWSER-based) model provided an excellent tool that could be used to evaluate instream flow requirements in detail;
- ○ The watershed is moderately complex with a very high number of water takings;
- ○ A primary objective of the project was to develop and assess tools capable of linking flow management with existing fish habitat management objectives/concerns to facilitate protection of fish communities (cold and warm water) from potential impacts of hydrologic alteration; and
- ○ LPRCA has both staff and consulting resources with a high level of expertise to implement the study.

LPRCA also used the RVA/IHA approach to assess instream flow thresholds, however they applied the approach to the entire Big Creek using the hydrologic simulation model. In addition to the ecological thresholds identified in the GRCA study (Section 7.2.2), they added some additional hydrologic/hydraulic parameters to the IHA approach as well as adding some aquatic habitat parameters as follows:

1. Useable (wetted) area (=metric for total potential useable habitat area in a stream site).
2. Maximum water depth (=general habitat size metric).
3. Percentage of low flow habitat area as all types (pools, riffles, glides) > 150 mm water depth (=metric for adult trout habitat).
4. Percentage of low flow habitat area as pool habitat (hydraulic head < 5), pool depth > 150 mm (=metric for preferred adult brook trout habitat).
5. In addition they examined the availability of deep pool habitats (> 300 mm, and > 600 mm depths) as possible indication of deep pools suitable for big fish.
6. In some of the small nursery streams (e.g., Brandy Creek) there is very little habitat > 150 mm in depth under normal low flow conditions, thus they adjusted measures (habitat >100 mm) to reflect these smaller environs which are well suited to young-of-the-year (YOY) salmonids.

Table 7.4 Comparison of Flow Indices determined using various Instream Flow Methods for Big Creek at Station XBC4 (at Dalton Gauge near Delhi)

Sorted Flow Indices (Ascending Order)	
Hydrologic Endpoints & Flow Target	FLOW (cms)
7Q50	0.27
RVA 1-day Low Flow Target	0.29
Hydraulic Geometry: Wetted Perimeter (1st Inflection)	0.3
Hydraulic Geometry: Top Width	0.3
RVA 3-day Low Flow Target	0.32
7Q20	0.33
RVA 7-day Low Flow Target	0.36
Tenant Summer Poor	0.372
Tessman (July - Sept) Poor	0.372
7Q10	0.4
Lowest Average Summer Month (September) Flow Low RVA Target	0.43
RVA 30 day Low Flow Target	0.46
7Q5	0.5
50 % Loss of Total Microhabitat Space >150 mm depth	0.54
Ontario Low Water Level 3	0.543
Tessman (July - Sept) Fair	0.744
7Q2	0.77
Ontario Low Water Level 2	0.905
Tenant Summer Fair	1.116
Tessman (July - Sept) Good	1.116
RVA 90 day Mean Flow	1.15
50 % Loss of Pool Microhabitat Space > 300 mm depth	1.15
7Q1.25	1.18
50 % Loss of Pool Microhabitat Space > 150 mm depth	1.25
Ontario Low Water Level 1	1.267
Baseflow (Model Balance)	1.3
Summer baseflow	1.3
Tenant Summer Good	1.488
Tessman (July - Sept) Excellent	1.488
50 % Loss of Pool Microhabitat Space > 600 mm depth	1.7
Ontario Water Normal	1.81
Tenant Summer Excellent	1.86
Baseflow (total annual basis)	2.39
Hydraulic Geometry: Wetted Perimeter (2nd Inflection)	2.8
Hydraulic Geometry: Top Width	2.8
D50 (=5.5 mm) Bed Mobilizing Flow	3.81
Mean Annual Flow	4.05
Tenant/Tessman Flushing Flow	7.44
80% Annual SS Load Cumulative Flow Threshold Estimate	7.59
1.25 year	19.8
D50 Substrate Mobilizing Flow (Annable Data)	26.7
Hydraulic Geometry: Wetted Perimeter	29.5
Hydraulic Geometry: Top Width	29.5
Bankfull Flow (Annable estimate)	29.73
2 year	32.2
5 year	58.8
10 year	73.2
20 year	91.7
50 year	118
100 year	140

In addition, LPRCA related many of the IHA variables to more commonly used hydrologic variables. Table 7.4 shows the flow variables considered in the IHA approach used by LPRCA.

LPRCA ran several different scenarios using the RVA/IHA approach modeled with GAWSER. A key benefit was the ability to characterize pre-settlement conditions with the model and compare these pre-settlement conditions with the others, which were:

- Existing conditions with no water taking
- Existing conditions with water taking

Figure 7.4 shows the scenario results. The graph also plots the OLWR standards and the RVA confidence limits. Based on these results, and the aquatic studies completed in Big Creek, LPRCA concluded that current water takings are not having adverse effects on the watershed resources. This conclusion was reached based on the observation that of the 32 variables plus the additional variables developed through the modeling efforts (Table 7.4), all of the key variables were within 1 standard deviation of the existing conditions without water taking (see example in Figure 7.4).

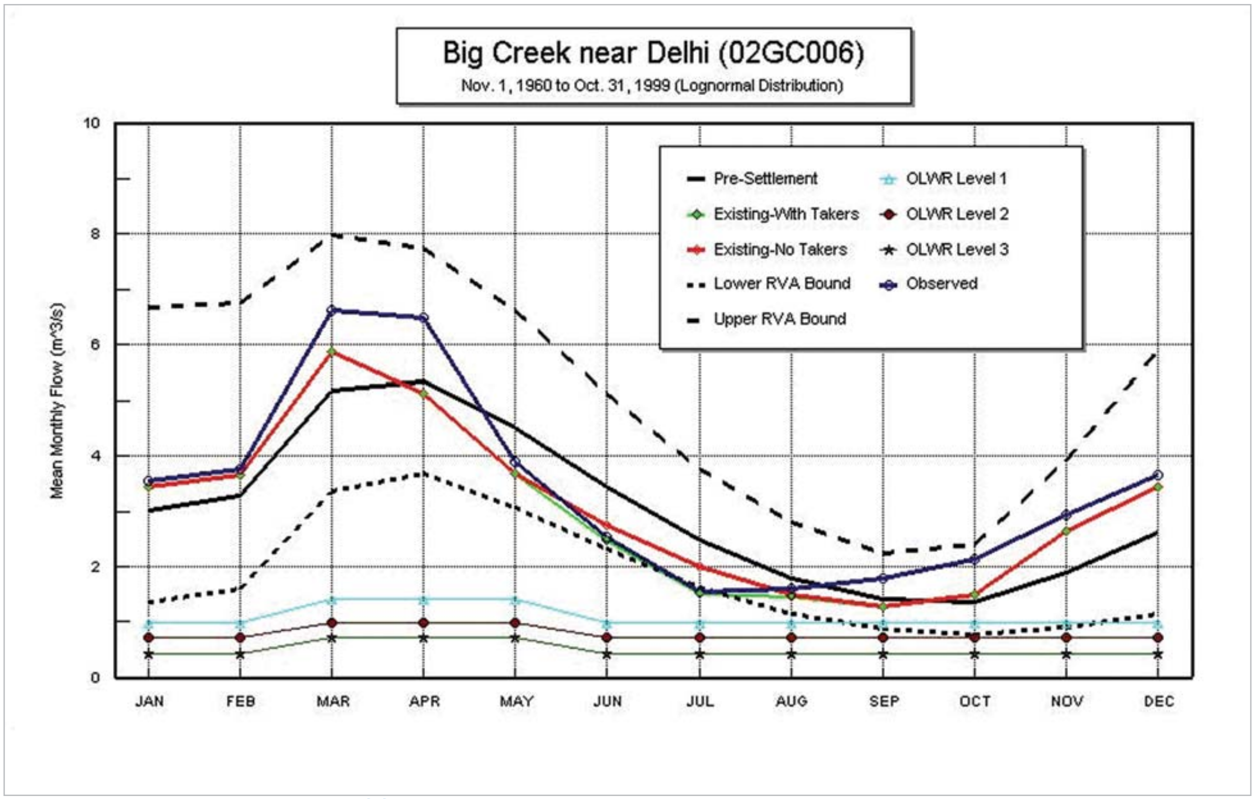


Figure 7.4 Monthly variation of flows at the Big Creek near Delhi for each scenario. (assuming lognormal distributions)

As noted with the GRCA and LPRCA study, the RVA/IHA approach requires a long term historical flow data-set, or a hydrologic model in order to run the statistics. In both studies, some intensive field work (to establish hydraulic cross sections, gather aquatic habitat data and obtain fluvial geomorphological data) was used to strengthen the analyses and improve the correlation between the observed statistics (metrics) of the IHA and instream parameters of concern. The method does an excellent job of identifying where potential impacts on the "natural hydrologic regime" occur, although it leaves determining the significance of the effect to the decision-maker, who may require specialized training in order to interpret results. A significant benefit of the RVA/IHA method is that it can be used to improve the performance of simpler tools, for example the modified Tessman method by allowing the seasonal "standards" to be adjusted to better reflect local conditions. Overall the RVA/IHA method was considered to be a preferred approach, in order to first characterize and understand the limitations of the natural flow regime and second to select from the suite of parameters, a subset of parameters that best reflects the areas of concern that may be most impacted by water taking. **It should be noted that that IHAs (Indicators of Hydrologic Alteration) provide the 'statistics' to characterize a particular streamflow response or time-series, and the RVA (Range of Variable Approach) is the practical application of those statistics for water management purposes (e.g. assigning a PTTW, or discharge from a STP, or the response from a new urban development).**

Moreover, the RVA method is completely adaptive, as the RVA targets can be computed using other criteria, and can vary depending on the application. For example, it may be that the one standard deviation criterion is appropriate for the protection of fish habitat and geomorphological concerns, but it could be different, say three quarters or half a standard deviation for dissolved oxygen or temperature considerations. With further field work and reported practical applications, we can determine whether the one standard deviation criterion is appropriate for all locations within Ontario.

7.3 Suitability and Cost

All studies concluded that in order to establish instream flow requirements, several factors were important:

○ The complete flow regime, not just one aspect of it needs to be reviewed and assessed in order to establish instream flows to protect aquatic systems.

○ An integrated field collection program including collection of hydrologic, fluvial geomorphologic and aquatic habitat data are needed.

○ Assessment of instream flow methods and interpretation of results should include a multidisciplinary team with expertise in hydrology, fluvial geomorphology and aquatic biology.

The **modified Tessman** methodology (see Section 4.4) showed promise and was considered to provide good results at a screening level of analyses. The methodology did not work in all cases; highly regulated systems and systems with significant groundwater flows were not accurately characterized. Additional work would improve the application of this method by testing it in watersheds with different surficial geology and levels of regulation.

The **OLWR** were also found to provide some generally consistent results, however they only provide information for one hydrologic condition (ie low flow conditions).

The **RVA/IHA method**, when combined with hydrologic models such as GAWSER or a statistical analysis of gauge records, was considered to provide the best diagnostic tool for assessing instream flow requirements. When integrated with aquatic habitat and fluvial geomorphology/hydraulic data, the method can be used to identify impacts from water taking by examining the various parameters calculated by the method. Each parmeter can be examined in more detail and potentially linked to a hydrologic, fluvial geomorphologic or aquatic habitat effect that can then be used to decide how the water taking may be modified to lessen the impact.

OFAT was also considered as a tool in support of defining instream flow requirements in ungauged watersheds. Comparison of results from the OFAT method compared to actual gauged systems indicated that the approach could be inaccurate for some types of watersheds. It can be more effective when used in combination with gauged information. Further work is required to improve its accuracy (See Page 71).

Useable Wetted Perimeter was also assessed by GRCA and LPRCA. In both studies, this method was shown to be a sensitive measure of total habitat availability. Using a hydraulic analysis, the minimum flows required to maintain different habitat conditions, such as maintaining connectivity between pools, achieving minimum pool and riffle depths, and examining the distribution of habitats using Froude number could be examined. Based on these studies, there is evidence that a hydraulic analysis combined with habitat data and fluvial geomorphological data can be used to establish instream flow characteristics provided that the hydrologic regime can be established based on either nearby gauges, installation of short-term gauges or OFAT methods. This approach requires further assessment to confirm its accuracy and applicability in different types of channels.

In general, costs to implement each of the approaches used in the three studies ranged in the order of $80,000 - $100,000 over four seasons. These costs did not include some upfront costs, for example, this did not include setting up the GAWSER hydrologic model for LPRCA, nor completing some of the hydraulic field and model calibration studies for GRCA. As a general indication, the following provides an approximate cost breakdown for individual study components on a reach basis:

Component	Smaller Stream	Larger River
Watershed characterization upstream of reach*	$1,000	$1,000
Flow data assembly and analyses*	$2,500	$2,500
Geomorphic field collection, analyses and threshold development	$5,000	$10,000
Detailed hydraulic model construction and calibration*	$5,000	$5,000
PTTW analyses*	$1,000	$1,000
Threshold development and RVA/IHA Analyses	$2,500	$2,500
Biological Assessment of Reach*	$6,000	$12,000
Interpretation of Biological information*	$2,500	$2,500
Reporting and documentation	$2,500	$2,500

* Note: these tasks may be completed by internal CA staff, while other tasks likely require external experts

7.4 Summary

Each of the three pilot studies utilized a different approach to determining environmental flow requirements. The choice of approach was dependent on a number of considerations:

a. present state of the aquatic ecosystem;
b. nature and complexity of the management issue(s);
c. the relative scale of the total water taking in the watershed relative to instream flows;
d. level of controversy of a particular project or purpose;
e. habitat homogeneity at various scales;
f. sensitivity of fish communities and fluvial geomorphological conditions
g. data requirements of models;
h. cost; and
i. expertise of the personnel.

CRCA chose a "standard setting" approach, field-verified based on aquatic habitat, hydrologic, hydraulic and aquatic community data. Standards were established based on critical time periods that coincide with key management objectives, such as maintaining minimum summer flows, meeting assimilative capacity requirements, preventing frazil ice formation, and sustaining important wetland habitats. This less sophisticated approach was feasible, in part because the watershed is dominated by several large reservoirs (relatively speaking), the stream network consists primarily of bedrock controlled cross sections and morphologically simple habitats and the most sensitive natural resources (fish communities and wetlands) are primarily dependent on the reservoirs rather than the connecting stream reaches. Under these circumstances, "standards" that are directly linked to observed conditions were found to be more reliable than more generic standards such as Tennant, Tessman and the OLWR.

GRCA selected an analytical/diagnostic approach and examined 8 study reaches within the watershed, each with different characteristics of water use, degree of flow regulation, geomorphic and aquatic habitat conditions. GRCA used the IHA/RVA approach to complete a statistical analysis of existing stream flow records for each study reach. The IHA/RVA approach provides a multitude of "metrics" or measures of the historic flow regime for a given site that can be interpreted to identify environmental flow requirements. GRCA also compiled detailed hydraulic and geomorphic analyses at each site, and related these detailed channel characteristics to the IHA analysis to help identify which of the various IHA/RVA parameters provided the best diagnostic indicators of environmental flow requirements. GRCA also examined several methods, including Tessman and the OLWR, and assessed their performance against the IHA parameters and the hydraulic/geomorphic detailed assessments.

LPRCA utilized a similar approach to GRCA, using the IHA/RVA methodology, augmented by detailed hydraulic, geomorphic and aquatic habitat field data. Unlike GRCA, LPRCA chose to utilize a hydrologic model (GAWSER) to generate the necessary statistics for the IHA/RVA analysis rather than stream flow records. A modeling approach was taken, for the following reasons:

- a number of weaknesses were identified with respect to using the historical gauge records:
    - the historic record for the gauges was not always long enough to reflect historic land uses and water taking practices
    - the historic records had deficiencies with respect to accuracy of rating curves, inaccurate or missing records
    - the gauges were not located in the vicinity of stream reaches of concern
- modeling provided a number of advantages over historical analyses of stream gauges, including:
    - data could be generated for missing data from gauge records and ungauged tributaries
    - the model could be used to examine "scenarios" including predicting stream hydrology in the absence of water taking permits, under pre-settlement conditions, and assuming increases in water taking
    - the model could also be used to examine/develop relationships between watershed conditions and various parameters of the IHA/RVA methodology, as well as other geomorphic and aquatic habitat parameters in order to transfer or infer how other, similar watersheds may respond to water taking

On the other hand, statistical analyses of long term gauge records can have the following advantages over the use of models:

- Gauged data provides a real-time historical account of actual stream flows;
- Gauged data reflects the cumulative effects of any water taking that has occurred;
- Gauged data does not rely on estimates of runoff/groundwater discharge based on land use, topography, physiography, etc. to estimate flow; and
- Gauged data may provide more accurate information on flow extremes, such as very low and high flows.

LPRCA also used the IHA/RVA methodology to examine and compare the performance of other methodologies, such as Tennant, Tessman and the OLWR.

All studies concluded that in order to establish instream flow requirements, several factors were important:

- The natural flow regime, not just one aspect of it needs to be reviewed and assessed in order to establish instream flows to protect aquatic systems;
- An integrated field collection program including collection of hydrologic, fluvial geomorphologic and aquatic habitat data is needed; and
- Assessment of instream flow methods and interpretation of results should include a multidisciplinary team with expertise in hydrology, fluvial geomorphology and aquatic biology.

Based on both the LPRCA and GRCA studies, it was evident that the amount of data to be collected is dependent on available data. In general the development of environmental flow requirements can be accomplished using one year of hydrologic, hydraulic and fluvial geomorphologic data, provided that there is a stream flow gauge within the watershed that can be used to establish historical flow conditions and to calibrate hydraulic models. In addition, however, a comprehensive monitoring and reporting program would be required in order to better characterize effects and to refine water taking limits. In the absence of an existing gauge, more than one year data would be required to confirm hydrologic conditions. This would be further facilitated by using the OFAT techniques (subject to the limitations described on page 71) or through a modeling approach, similar to the one used by LPRCA. For example, LPRCA found that there were strong similarities between gauged and ungauged watersheds exhibiting similar physiography, topography and fish communities. On the other hand, it was generally concluded that more that one year of biological data is necessary.

8.0 TRANSFERABILITY AND IMPLICATIONS FOR WATERSHED-WIDE INSTREAM FLOW REQUIREMENTS

8.1 General

The goal of study B was to develop a process or framework to estimate environmental flow requirements within a given watershed to avoid adverse ecological impacts while trying to accommodate water users. The objective was to investigate the transferability of methods assessed in study A to characterize the environmental flow requirements within other watersheds in Ontario.

During the course of study B investigations, it also became apparent that, while no single method was appropriate for use in all watersheds or all water taking permit situations, a standardized approach was needed to assess the watershed's sensitivity to water taking, select the appropriate method for determining environmental flow requirements and complete the necessary studies and analyses. A Decision Support System (DSS) that outlines an approach for scoping methods based on watershed sensitivities was also identified in study B.

Section 8.2 summarizes the pilot study findings with respect to the transferability of methods to other watersheds and Section 8.3 outlines a proposed DSS based on the Adaptive Environmental Management Approach.

8.2 Transferability to watershed scale and to other watersheds

This section discusses the findings of the pilot studies for Part B of the project. Part B of the pilot studies required an assessment of the transferability of the approaches used in Part A. This involves looking at the issue of scaling up existing studies to a watershed scale, as well as transferring results to other watersheds. Each study addressed the following:

○ Define transferability in terms of each CA's approach

○ Outline the general approach to scaling up or transferring the approach

○ Evaluate the approach and discuss its applicability, strengths and weaknesses

○ Provide recommendations for use in other watersheds

Transferability refers to either scaling up/extrapolating the results of each approach to address issues in other parts of the watershed or transposing/extrapolating the results of each approach to other watersheds that may or may not have existing stream gauge stations. Transferability of each instream approach, in large part depends on the sensitivity of the system, the availability of historic data and the type and magnitude of water taking.

The sensitivity of the system, and its sensitivity to change in terms of the hydrologic changes associated with water taking depends on many factors, including:

○ Surficial geology

○ Stream order

○ Fish community type

○ Presence of Species At Risk

○ Other sensitive resources, such as wetlands, ESA's, etc

○ Other water uses, such as assimilative capacity, recreation, sediment regime, ice management, navigation, number/volume of water takings, irrigation uses, etc.

Transferring instream flow requirements or flow information to ungauged locations requires careful consideration of the underlying physical characteristics that influence flow and sediment transport in a given area.

A summary of key factors affecting water taking sensitivity are shown in Figure 8.1.

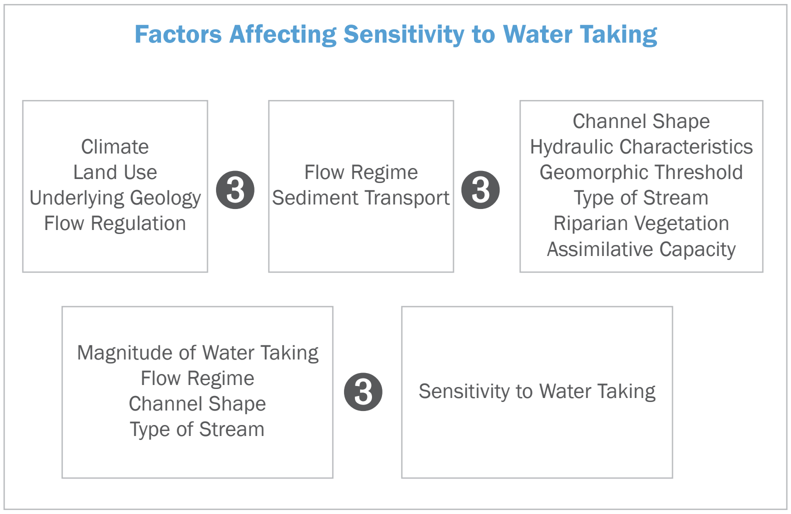


Figure 8.1 Factors Affecting Water Taking Sensitivity

The above factors can be used to determine whether two watersheds or tributaries are sufficiently similar in nature to allow instream flow requirements to be transferred from one watershed to another. This type of analysis in combination with the OFAT tools may provide a good means of determining when instream flow requirements may be transferable.

In the case of relatively simple systems, such as Millhaven Creek (CRCA), which is a highly regulated system with a fish community that is adapted to the current hydrologic conditions, methods may be relatively easily transferred. Millhaven Creek also has few water takings, most of which relate to dams.

In the case of complex and sensitive watersheds, with cold water fish communities, for example Big Creek (LPRCA) and the Grand River (GRCA) transferring methodologies typically requires considerable effort, essentially repeating the methodology. These watersheds also have a large number, volume and variety of water taking permits that requires a more detailed approach to instream flow assessment. For the Big Creek example, however, LPRCA was able to derive generalizations (albeit initial ones that should be subjected to continued assessment and refinement) to permit extrapolations within and between watersheds supporting cold water fish communities. This was accomplished because the watersheds exhibited many similarities in terms of baseflow, physiography and geomorphology.

Three general approaches to transferring methodologies to other watersheds were identified:

- A Modeling approach (8.2.1) where a hydrologic model, for example GAWSER, is set up based on existing long term flow gauge records, complemented by detailed fluvial geomorphic and aquatic habitat studies (e.g., LPRCA)
- A Scoped or Layered approach (8.2.2), using different levels of detailed assessment, including the use of OFAT to develop instream flow requirements. This also includes the use of empirically derived geophysical relationships (eg hydrologic to drainage area) (e.g., LPRCA), and methods such as Tessman, and detailed methods such as the IHA/RVA (e.g., GRCA, LPRCA)
- Use of the Ontario Flow Assessment Techniques (OFAT) (8.2.3), which may be applied in ungauged watersheds to characterize hydrologic conditions (e.g., CRCA)

These general approaches provide direction on how to select an appropriate approach and also describe what tasks need to be undertaken to complete an assessment of instream stream flow requirements for a reach, tributary or watershed scale study. The studies were also unanimous in recommending the need to use an **Adaptive Environmental Management Approach** as a DSS for developing instream flow requirements/thresholds and for assessing the impacts of a PTTW on these thresholds. This is presented in Section 8.3.

8.2.1 Modeling Approach

The Modeling approach used by LPRCA applied the RVA/IHA approach. The LPRCA, made use of a fully validated GAWSER-based hydrologic model to determine "natural" variation in flows for a particular watershed. This specific methodology can be easily transferred to other areas, expecially in places where hydrologic models have already been set-up for water management purposes through watershed and subwatershed studies and real-time flow forecasting. The RVA approach in general is transferable to any watershed with a long-term stream flow / precipitation record, using any suitable hydrologic model.

LPRCA ran several different scenarios using the RVA/IHA approach modeled with GAWSER. A key benefit was the ability to characterize pre-settlement conditions with the model and compare these pre-settlement conditions with the others, which were:

○ Existing conditions with no water taking

○ Existing conditions with water taking

LPRCA was also able to derive generalizations (albeit initial ones that should be subjected to continued assessment and refinement) to permit extrapolations within and between watersheds supporting cold water fish communities (Low Flow Stability Index). This was accomplished because the watersheds exhibited many similarities in terms of baseflow, physiography and geomorphology.

Selection of suitable management endpoints may vary depending on the nature of flow regime, nature and timing of demand for water taking and consideration of fish habitat/fluvial geomorphological sensitivities in other systems. Use of the RVA flow regime characterization, combined with hydrological simulation modeling, fluvial geomorphological and ecological data sets over a large number of stream habitats within and across watersheds and including a range of ecological conditions (e.g., thermal regimes, fish communities, degraded habitats, etc) will permit the development of flow management guidelines based on an understanding of relationships between flow regime and stream ecology. The power of this approach for developing ecologically-defensible instream flow targets will increase as the number of objective evaluations using this approach are completed.

8.2.2 Scoped or Layered Approach

The Scoped or Layered Approach was proposed by GRCA. The RVA/IHA approach can be applied to any watershed with a long-term gauge station, using either the GAWSER model (LPRCA) or a combination of hydrologic/hydraulic modeling (GRCA). Additional field-based information is needed to include fluvial geomorphologic and aquatic habitat variables, depending on the size of the watershed.

GRCA identified a scoped approach to transferring or scaling up results of the pilot studies to the entire watershed or to other watersheds as described below.

Items to consider for a Watershed Study:

○ Full studies are impossible for larger watersheds at every area of concern, thus we need to scope other potential reaches for study and determine if there is enough concern to warrant a full study on that reach.

○ Using modeling and the techniques used in this report, several other gauged sites were considered in a scoping exercise to scale up the EFR issues into a full Grand River watershed study.

○ OFAT was one of the models used to quickly determine some subwatershed parameters.

○ Comparison of the OFAT parameters were done with monthly mean flow data obtained from the Water Survey of Canada archived hydrometric data.

The expansion of the Instream Flows Project to a watershed scale requires the selection of a number of other reaches across the watershed. Sites that may have potential issues with regard to water takings and the subsequent degradation of the ecological habitats within those reaches are subject to various levels of study. Three stages of study are proposed: to determine whether a serious issue exists in the selected reach, to characterize the water uses, and if human extractions are seen to pose a serious threat to the ecological integrity of the reach, to determine the ecological flow requirements.

The levels for the study are thus a screening stage, a detailed evaluation stage and a full study. Each level of the assessment is detailed below.

Level / Stage 1: Screening

The first stage of the process is an initial screening to determine where potential water takings may exceed the ecological threshold for that reach. Screening is a basic assessment of the water available and the water currently being taken and the characterization of the prospects for future takings. This step focuses on finding several reaches within the watershed that may have potential water management issues.
At this stage, a general characterization of the watershed and flow regimes in different parts of the watershed should be completed. These tasks may already have been completed by a CA, and the purpose of this exercise is to sort out takings that are expected to have little or no consequences versus those that require closer scrutiny.
Tasks in the Scoping stage include:

1. Organizing and characterizing water use from unadjusted Permit To Take Water information
2. Organizing summary flow information using OFAT
3. Comparing water use to flow instream, using a few parameters such as mean annual or average summer flows

The first task in the Scoping stage involves obtaining PTTW database information from the OMOE. The database provides information on the maximum permitted water takings in a region or subwatershed. The second task utilizes OFAT modeling software (note limitations on page 71) to provide a base for generating summary flow statistics in a subwatershed (see Section 8.2.3). The PTTW and OFAT information can then be compared to determine the demand (PTTW information) and supply (OFAT results) within a watershed.

The goal of these tasks is to determine whether an issue exists in this reach. The tasks try to establish if the water takings exceed the available water in the reach, and if the takings are above a certain threshold value. This threshold value could be a percentage (i.e. 10%) of the mean annual flow, or perhaps on a seasonal basis for summer flow parameters or low-flow parameters.

If no significant difference or exceedance is found between the "surplus" water (defined as a percentage of 7Q20 flows, for example) and the water takings in the reach, then the study can be completed here and no further work needs to be completed at this point. There is no threat to the ecological integrity of this reach from a water taking perspective. There is enough water in the reach to fulfill the needs of both human and ecological needs.

If, however, the water takings begin to exceed the available "surplus" water (based for example on a percentage of a low flow criteria such as the 7Q20), then the study needs to move to the next stage of the process, to Stage 2: Detailed Evaluation. There is a potential issue of the degradation of the ecology of the reach based on current water takings.

It is important to note that both the GRCA and LPRCA identified the modified Tessman method as still showing promise as a scoping-level tool, based on an assessment of its strengths/weaknesses using the RVA/IHA approach. In addition the OFAT tools for estimating flow in ungauged watersheds also shows promise at least in unregulated systems. With some additional calibration, based on the results of the GRCA and LPRCA studies, the Tessman method in conjunction with OFAT, would appear to provide a scoping level tool. This could be combined with some detailed field studies to confirm instream responses to varying flow conditions, similar to the approach of CRCA. It would be more beneficial if these field studies placed greater emphasis on developing detailed cross sectional data that could then be used in a hydraulic modeling exercise.

In addition, LPRCA developed an empirical relationship between low flow characteristics, specifically the IHA/RVA 30 day minimum flow target and drainage area for all watersheds within their jurisdiction with similar fish communities, physiography and broad fluvial geomorphic characteristics. This Low Flow Stability Index indicated a very stable stream flow environment and showed a strong correlation to streams and stream reaches with good quality salmon and trout habitats. This information was considered to have sufficient merit to develop generic interim low flow limits to protect different stream habitat types in the absence of detailed RVA information within the LPRCA jurisdiction. Based on this analysis, a low flow target of 20% of MAF could be used as a simple interim low flow limit for protecting trout streams in the Long Point Region. Additional work would be necessary to address other hydrologic, fluvial geomorphic and hydraulic environmental flow requirements, if the proposed water taking was determined to have potential effects on these other hydrologic parameters. Further work with the method advanced by LPRCA on these other parameters could also identify some empirical relations.

Where scoping studies indicate that proposed water takings are relatively minor, these empirical relationships, as well as the Tessman method, should provide a conservative level of protection, provided that a monitoring and reporting program is established consistent with the Adaptive Environmental Management Approach.

Level / Stage 2: Detailed Evaluation

The second stage of the process further refines the values calculated in Stage 1 for a more detailed scoping of the water use and availability in the reach. The goal of this stage is to get a better, more realistic estimate of the actual water takings, to determine whether an issue will arise with the degradation of the river ecology due to over-takings and to better define the linkages between takings and the natural environment.

Tasks in the Detailed Evaluation stage include:

1. Organizing or characterizing the water use by adjusting the PTTW information to better reflect actual takings
2. Organizing summary flow information
3. Comparing water use to flow instream
4. Simulation modelling

As the existing PTTW information from the database is fairly crude, further research is needed to detail the actual water takings and assess the takings more accurately. In future, information on actual water takings will be more readily available because of requirements in the Water Taking and Transfer Regulation for permit holders to record data on the volume of water taken daily and report those data to the Ministry on an annual basis (note that the current PTTW database and PTTW reporting requirements have been revised under the new PTTW process which will be fully phased in by 2008). This may include looking at seasonality, calling municipalities for actual water takings and researching other water users for metering or reporting of actual water extraction from groundwater and surface water sources. Information on flow could be gathered from any WSC or other stream gauges in place to characterize the long-term flow record. Further modelling could be completed with other tools where the data permits. Once these tasks are completed, the decision needs to be made whether an issue of overtaking exists in the reach.

If there is a significant exceedance of water takings when compared to the instream flow, based on critical threshold values, then there is a potential threat to the ecological integrity of the reach. The water takings could pose a threat to the ecological needs of the reach, and so the reach is declared a high-use or sensitive area to consider for establishing a detailed instream flow program.

Note that there is reason to distinguish between high use areas and sensitive areas. For example, a water taking may be proposed close to a spring that has a direct linkage to the natural environment, possibly a coldwater stream. The total use in the given area may not be high, however the ecology of the coldwater stream system may be sensitive, and therefore a more detailed study may be warranted.

The use of a hydrologic model, as proposed by LPRCA would also be applicable at this scale of assessment. This would be used to generate long term hydrologic statistics for the reach/segment of concern, supplemented by detailed aquatic and fluvial geomophological field studies sufficient to apply the RVA/IHA approach.

Examples of additional tasks for follow-up for the Detailed Evaluation Stage could include:

- ○ Developing detailed reach instream flow estimates
- ○ Implementation of staff gauges in the reach to monitor local conditions
- ○ Implementing rules for water takings, based on staff gauge heights for example
- ○ Applying conservation measures along the reach based on levels of water

Level / Stage 3: Full Ecological Flow Assessment Study

The final stage of the process would be the implementation of a full assessment of the reach to determine instream flow requirements. This stage would determine how much can be taken and what needs to remain instream for the maintenance of ecological flow needs.

To define how much can be taken, the IHA/RVA software would be run to determine the point at which a standard deviation of change had occurred. This would be simulated by continuously removing a unit of water and observing the change in the parameters until a standard deviation of change (either positive or negative) from the original values has been reached.

The full assessment, including fieldwork, data analysis and interpretation would be completed for this stage to determine the ecological flow requirements for this reach. A series of steps are presented in Section 8.3 for establishing instream flow requirements where stream gauges are present on a reach.

The use of GAWSER or other watershed hydrologic model, as proposed by LPRCA would also be applicable at this scale of assessment. This would be used to generate long term hydrologic statistics for the reach/segment of concern, supplemented by detailed aquatic and fluvial geomophological field studies sufficient to apply the RVA/IHA approach.

GRCA also described a series of 13 tasks to be completed as part of a Full Ecological Assessment level of study:

1. Assessment of the current water takings, such as locating areas of concern and looking at the discrete and cumulative impacts over time and space.
2. Streamflow Analysis including a comprehensive analysis and development of low-flow statistics, high flow statistics and percentile statistics. Percentile statistics are important to reflect the variability of the source when developing or assessing a taking strategy.
3. Geomorphic Survey with cross sections and information sufficient to construct and calibrate a HEC-RAS model and estimate geomorphic thresholds.
4. Detailed hydraulics model of reach based on HEC-RAS modeling.
5. Development of geomorphic thresholds for reach such as bankfull flows, flushing flows, bed mobilizing flows and residual pool flows.
6. Assemble and rank flow indices, hydraulic indices, biological indices and geomorphic indices.
7. Development of a naturalized flow series reflecting pre-development conditions and of a post-development condition with takings both cumulative and discrete included.
8. Application of the IHA and RVA software to analyze the implications of the water takings on specific aspects of the flow regime.
9. Expected impacts to physical hydraulic habitat estimated by relating the results from the IHA and RVA analysis with hydraulic modeling results.

10. Expected impacts to sediment transport and channel morphology estimated by relating change in flows to exceedance of geomorphic thresholds.
11. Establishment of hydraulic threshold such as flows needed to maintain connectivity.
12. Qualitative assessment of potential impacts based on life cycle requirements of specific species.
13. Assessment of above information to formulate a water taking strategy.

8.2.3 Use of OFAT: Transferring Instream Flow Requirement to Ungauged Locations

The Ontario Flow Assessment Techniques (OFAT), currently being developed by the Northeast Science & Information of the Ontario Ministry of Natural Resources (MNR), is a tool to automatically estimate flow information for watersheds in Ontario. OFAT is a user-friendly, interactive Geographic Information System (GIS)-based software with accompanying databases used to estimate various flow regimes.

These flow regimes include low flows, flood flows, mean annual flows, minimum instream flow requirements, and bankfull flows. OFAT has been created by automating a number of existing regional hydrologic models for Ontario, with the support of GIS to provide various physiographic and climatic inputs to the models. OFAT is a useful tool that effectively and efficiently manages spatial watershed databases and performs hydrologic analyses to support decisions related to water resources planning and management in Ontario.

The streamflow statistics would be used to complete a desktop scoping of the available flow in given areas, with Tessmann being the expected method to be used at this level of scoping to estimate the instream flow needs and the amount of water that may be available. Monthly normalized statistics will be needed to support this effort. Depending on the extent of single taking or cumulative use in a given area the level of detail for further investigations would be scoped. In high use areas, it is expected that detailed hydraulic surveys would be completed to estimate thresholds to partition flows needed for the environment and flows available for human use. Staff gauges could be located on these reaches to assist takers; monitors could be established at staff gauges (Solist Loggers) to monitor compliance/effectiveness of the water taking strategy.

Caution must be used when applying the OFAT program to generate flow statistics. Regionally based empirical flow statistics may vary by orders of magnitude from actual observed statistics. Several of the regional models were developed prior to the availability of GIS and the information layers currently available and need to be revisited. Regional empirical models may also neglect the effects of regulation by large reservoirs. The OFAT tools appear to be able to estimate mean annual flow with some degree of accuracy, however this would have to be confirmed for different areas.

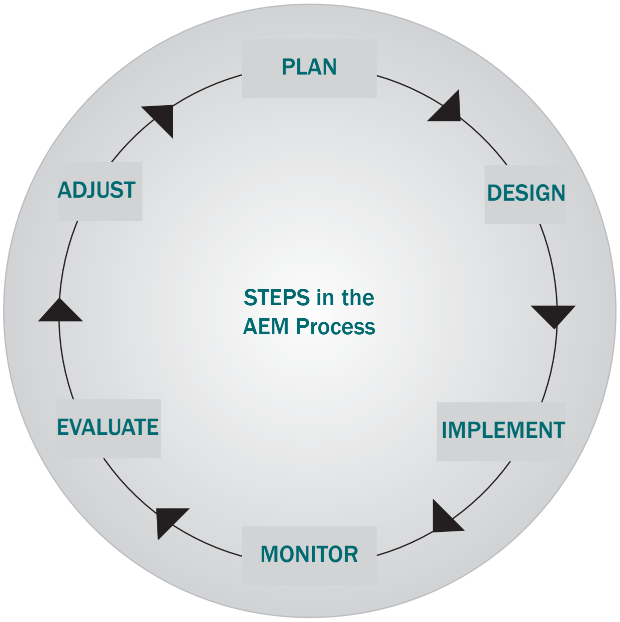
It is suggested that a more reliable approach be used where the indicator gauges selected represent different areas of the watershed in combination with OFAT to estimate physical watershed characteristics at the indicator gauge and the ungauged location. Information at the indicator gauge site could be transposed to the ungauged site using drainage area or a combination of drainage area and other physical characteristics to prorate information between the indicator site and the prorated site.

8.3 An Adaptive Management Approach

As part of a recent initiative to implement a natural channel design approach to address the effects of land use and other impacts on stream processes, functions and channel characteristics, a DSS using the Adaptive Management approach was developed to guide proponents responsible for managing Ontario's stream and river systems (MNR et al 2003). Adaptive Environmental Management may be defined as:

○ Adaptive Management is "learn by doing" management. It accepts that management actions may be implemented based on incomplete knowledge (based on conservative assumptions), provided that the consequences of the action are closely monitored with a feedback (reporting) mechanism that allows the management action to be modified if predicted effects are not being realized. This "loop" of implement, monitor, feedback, modify and re-implement is adaptive management. This approach avoids the trap of using lack of knowledge as a reason for inaction until undesirable consequences are irreversible.

The following figure from MNR et al 2003 illustrates the AEM approach:



It is recommended that a DSS using the AEM approach be utilized to determine the appropriate method and level of study to be applied in other watersheds. This is based on the Scoped or Layered Approach described in Section 8.2.2. A decision-making approach would be followed using a nested approach as follows.

In Table 8.1, the 3 Scoping levels are shown in the left column with the recommended methods for each shown in the second column. For a proposed water taking, a Level 1 (Screening) assessment would be made by considering the Scale of Effect, Watershed Sensitivity and Magnitude of Water Taking (columns 1, 2 and 3 respectively). As noted in Section 8.2.1, if the screening analysis indicates a low potential for impact, then the permit can be approved. On the other hand, if a moderate or high potential for impact is identified, then a Level 2 (Detailed Assessment) assessment would be undertaken. Based on the results of the Level 2 assessment, the permit would be approved or a Level 3 (Full Ecological Assessment) assessment would be undertaken.

Table 8.1 Decision Support System Framework

AEM Decision Hierarchy	Recommended Method	Column 1	Column 2	Column 3
		Scale of Effect	Watershed Sensitivity	Magnitude of Water Taking
Level 1: Screening	1. OFAT 2. Tessman	Watershed	Low	Low
Level 2: Detailed Assessment	1. Tessman 2. IHA/RVA	Subwatershed / Tributary	Moderate	Moderate
Level 3: Full Ecological Assessment	1. IHA/RVA 2. Detailed field studies	River Segment / Reach	High	High

This iterative or nested decision-making process would be used, following the tasks outlined in Sections 8.2.1 - 8.2.3. The same process could be illustrated by means of a "look up" table that proponents could use as a guide to determining what level of assessment may be required. For example, the following Table illustrates how two criteria: watershed sensitivity and magnitude of water taking could be used to create a look up table for determining which of the three assessment levels are required where:

○ Level 1. Screening;
○ Level 2. Detailed Evaluation;
○ Level 3. Full Ecological Assessment

MAGNITUDE OF WATER TAKING	WATERSHED SENSITIVITY		
	High	**Medium**	**Low**
High	3	3	2
Medium	3	2	1
Low	2	1	1

Note that regardless of the level of scoping, the remaining stages of the AEM process would be followed:

○ Implement
○ Monitor
○ Report and Evaluate
○ Adjust

These remaining steps in the AEM process are critical, regardless of the level of scoping completed, in order to confirm that the assessment is accurate and that the level of water taking is consistent with what was proposed. **Of all steps in the process, a commitment to monitoring and feedback to improve that evaluation process is the most important and often neglected step. It is critical that this monitoring occur, if the science of establishing environmental flow requirements is to continue to evolve.**

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

1. There are three basic steps to the process for defining environmental flow requirements for a selected area:
    - review the alternative assessment tools and select the appropriate one;
    - use historical information and augment where appropriate with field work,
    - define threshold based on hydrologic, biologic and geomorphic considerations.
2. Geomorphic, aquatic and hydrologic information/assessments were used to establish thresholds in the three areas. The need to establish thresholds for each of these components of the stream environment, and to ensure the interpretation of this data by specialists in these disciplines, was considered to be a fundamental requirement for each study. Field collected data was invaluable in identifying the proper "threshold" value or environmental flow requirement for a given hydrologic parameter using the IHA analyses. The GRCA and LPRCA studies were essentially able to "calibrate" the various hydrologic parameters and fine-tune the Tessman method (i.e. modified Tessman) to more accurately reflect limits of natural flow variability with this field data.
3. Determining a single, minimum threshold flow, to the exclusion of other ecologically relevant flows, is no longer an accepted approach to instream flow management. Each of the studies examined a number of diagnostic tools, field data collection methods, and a range of instream methods to assess water taking effects and to define instream flow thresholds.
4. A Decision Support System approach (see Recommendation 8) is recommended for establishing the appropriate level of investigation and instream flow method for other watersheds (including ungauged systems). Prior to initiating the scoping exercise, it is important to first define Watershed Management Objectives/Principles in terms of general instream targets, such as a restored fish community, a stabilized channel cross section, wetland protection. These management objectives are key to determining the sensitivity of the system to water takings. Scoping requires a staged assessment of watershed conditions, watershed vulnerability to stress and size of current/anticipated water taking, as follows:
    - Level 1 - Screening: assessing the potential that water takings may exceed ecological thresholds
    - Level 2 - Detailed Evaluation: undertaking limited field investigations and possibly simulation modeling to further refine ecological thresholds and confirm water taking effects
    - Level 3 - Full Ecological Flow Assessment: a detailed analysis of the full range of ecological flow requirements and a sensitivity analyses to confirm the relationship of key variables to different levels of water taking
5. The question "Is one year of data enough to establish instream thresholds?" was assessed in each of the pilot studies. Based on both the LPRCA and GRCA studies, it was evident that the amount of data to be collected is dependent on available, existing data. In general the development of environmental flow requirements can be accomplished using one year of hydrologic, hydraulic and fluvial geomorphologic data, provided that there is a stream flow gauge within the watershed that can be used to establish historical flow conditions and to calibrate hydraulic models. **In addition, however, a comprehensive monitoring and reporting program would be required in order to better characterize effects and to refine water taking limits.** In the absence of an existing gauge, more than one year data would be required to confirm hydrologic conditions. This would be further facilitated by using the OFAT techniques (subject to addressing the limitations noted on page 71) or through a modeling approach, similar to the one used by LPRCA. For example, LPRCA found that there were strong similarities between gauged and ungauged watersheds exhibiting similar physiography, topography and fish communities. On the other hand, it was generally concluded that more that one year of biological data is necessary.

6. All of the pilot studies were completed in watersheds that could be generally classified as "static" systems; in other words, land use conditions and therefore hydrologic conditions have been relatively stable (or buffered by regulation). The establishment of instream thresholds in systems that are adapting to change, for example urban or urbanizing watersheds, was not examined. The use of a hydrologic model in conjunction with the IHA/RVA method would appear to be the most appropriate method to be applied where land use is actively changing. It would be equally critical to back up the model findings with field hydraulic, geomorphic and aquatic habitat data to confirm the "equilibrium state" of the watercourses - are they stable, in adjustment or unstable?
7. Transferability to ungauged watersheds depends on a number of factors:
   - Type/characteristics of the system
   - Water use requirements
   - Instream flow method

   A sensitivity analysis and scoping exercise has been suggested as a means of determining the level of investigation required, which dictates the data requirements. In any case, however, monitoring should be used as a tool to verify whether established thresholds are providing sufficient protection. LPRCA was able to develop some empirically-based relationships between their pilot watershed (Big Creek) and other watersheds in their jurisdiction that could be used to establish interim environmental flow requirements for "like" watersheds.
8. The question of transferability was assessed in each study. The RVA/IHA diagnostic approach was used to define ecological thresholds and based on this work, a scoped approach (see Conclusion 7) was proposed that uses OFAT, modeling, historical analysis of gauges, empirical relationships,etc. The potential to transfer approaches across watersheds is enhanced where common characteristics can be identified, such as physiography, stream order, groundwater characteristics, regulated versus unregulated flows, availability of historic information, cold water fish communities
9. There are a variety of alternative assessment tools, each with their own strengths and weaknesses. While a single value approach is inadequate to address the temporal and spatial range of flow requirements to meet instream ecological needs, the pilot studies illustrated that some desktop methods, such as Tessman can be useful for a scoping or screening level assessment.
10. Different approaches were used in each of the three pilot projects. These included a "standard setting" approach (CRCA), the RVA/IHA analytical/diagnostic approach using a watershed hydrologic/hydraulic model (LPRCA) and the RVA/IHA approach using a hydraulic model and a statistical analysis of stream gauge records (GRCA).
11. All of the recommended approaches were more rigorously based than single threshold standards such as the OLWR. The OLWR and even some multi-level standards such as Tessman were shown to be ineffective under some conditions, but acceptable under others.

9.2 Recommendations and Next Steps

General

1. The MOE should consider specifying variable water taking limits linked to both the availability of supply and variability of the natural environment's flow requirements. A range of flows and thresholds over the complete flow regime is needed to properly describe aquatic system needs, such as those for fish cycle requirements, stream morphology, flood plain and riparian zone maintenance, etc. Limits to water takings may need to vary seasonally to respond to the variability of supply and the associated variability of flows required by biota to complete their life cycles in affected streams and rivers. An integrated approach using geomorphic, hydraulic, biologic and hydrologic indicators is key.
2. Although the need to better manage water takings was the impetus for this project, the determination of environmental flow requirements may be vital to a number of other water resources management activities. For example, the knowledge of environmental flow requirements could be used to establish stormwater management criteria or post-development flow targets for developing subwatersheds. Likewise, the establishment of environmental flow requirements may be fundamental for the protection of headwater streams through a source water protection plan or watershed study. Consequently, it is recommended that the proposed approach for establishing environmental flow requirements be promoted through the various planning processes identified above through a multidisciplinary group of practitioners and with participation from various stakeholders. The promotion of this approach should be pursued as a joint initiative of agencies and non government groups, similarly to the promotion of the Natural Channel Design Guidelines.
3. Specifying minimum flows for a reach requires a nested approach. This approach should include the following:
    - A check with high-level scoping or for orders of magnitude difference should constitute the initial assessment step, with specific emphasis placed on the completion of a cumulative takings assessment.
    - When observed streamflow is not available everywhere; pro-rating streamflow based on common physiographic units is one level of verification. This level of verification should include a characterization of the flow regime and flow characteristics in the area of the proposed taking (i.e. is it a baseflow driven system, runoff driven system or other flow regime).
    - The taking should be related to the flow regime and how the taking is expected to affect the flow regime (considerations include baseflow period, high flow period, intermediate flow period). The taking should also be related to knowledge of the flow requirements of resident biota where such knowledge, at a minimum, should include minimum depths required to maintain habitat connectivity and flows required to maintain non-stressing thermal regimes and sufficient redd oxygenation.
    - Reach-level investigations should be an expectation based on the magnitude of the taking, with respect to the source and cumulative nature of takings in a given reach.
    - Where a large number of takings exist in a given reach, there may be economies of scale to consider when having the reach level investigation completed.
    - Where there are a large number of takings, the cumulative biological effect of those takings should be assessed on an ongoing basis to ensure the maintenance of aquatic ecosystem integrity.
4. Further testing of the Tessman approach in different southern Ontario watersheds should be undertaken. When considering test sites for these methods, they should ideally be sited in distinct physiographic areas and possibly stratified by stream order with the view to potentially regionalize these methods.

5. The question of transferability was addressed in the studies and would be enhanced through the establishment of additional flow stations; the integration of flow, fluvial geomorphic and aquatic habitat data; and further assessment/improvement of OFAT and ORSECT.
6. The OFAT system shows promise as a method of transferring approaches to ungauged systems, and an additional module is under development that would provide linkages to aquatic habitat requirements. Caution must be used when applying the OFAT program to generate flow statistics (see page 71). Regionally based empirical flow statistics may vary by orders of magnitude from actual observed statistics. A more reliable approach would be to use the indicator gauges selected to represent different areas of the watershed in combination with OFAT to estimate physical watershed characteristics at the indicator gauge and the ungauged location. Additional work is required to improve the system to increase the level of confidence/accuracy of the approach. The completion of the ORSECT tool should also be pursued.
7. The RVA/IHA diagnostic approach provides an opportunity to evaluate and fine tune or improve many different instream flow methodologies, including identifying some "made in Ontario" approaches that could improve the effectiveness of hydrologically/based instream flow methods in protecting instream uses. The existing projects should be examined in more detail to "fine tune" some of these methods.
8. The abilities of the IHA software should be utilized in other instream flow studies as a diagnostic tool. The MOE should consider holding a workshop to demonstrate the IHA software and RVA method to interested parties.
9. A Pilot Study should be implemented in another Ontario watershed to test and further develop the DSS process using the scoping approach.
10. An **Adaptive Environmental Management approach** for establishing instream flow requirements should be used to provide the **framework and decision-making process** for the proposed scoping analysis. **This would incorporate a monitoring program with regular reporting into the scoping exercise to provide feedback on the effectiveness of the selected methodology in meeting the instream flow objectives**. The hierarchical/scoping approach (see Conclusion #7) for determining ecological thresholds based on stream sensitivity, type of permit, etc is recommended for ungauged systems. This approach has broader implications/possible applications than just dealing with PTTW's (see Recommendation 3).

Specific Recommendations

1. Additional geomorphic analysis at selected stream gauge sites throughout Ontario should be completed with the goal to investigate regionalizing geomorphic thresholds for unique physiographic areas throughout the province. This should be done through the MOE and discussions with the MNR and Environment Canada.
2. There is a need to establish more integrated flow/fluvial geomorphology/fish habitat reference stations including some new gauging locations. A centralized catalog of detailed assessments should be created to provide a reference source.
3. The three pilot projects provide a foundation for establishing instream flow needs, however other areas may need to be studied to complement existing findings, for example urban/urbanizing scenarios or flow regulation scenarios characteristic of watersheds undergoing change.
4. The conditions and temporal aspect of the Permits to Take Water for the Guelph Arkell and Region of Waterloo permits provided in the GRCA Pilot Study should be used as models to set conditions for future PTTW applications. Consideration should be made to the timing and seasonal requirements of the aquatic ecosystem when issuing permits.
5. The MOE should consider holding workshops or training sessions on the topic of instream flow needs and its related components. This would facilitate the incorporation of instream flow needs into subwatershed studies and other surfacewater management studies for a complete assessment of the ecological effects from water takings.

6. Further work should be undertaken to investigate ecogeographic-flow relationships found in the Long Point Region Pilot Study and determine if and how similar useful instream flow indices could be developed in other jurisdictions of the province. For example, to what extent can the drainage area to MAF equation from the LPRCA study be applied throughout the province to derive specific flow indices such as the 30-day low flow stability index. This may involve the development of hydroclimatological stream flow regions in the province (may be able to develop based on / or similar to work completed by Moin and Shaw, 1985).
7. Both fish habitat-based (e.g., Wetted perimeter, HIS), and fish production-based (e.g., Biomass, stable isotope) approaches were examined for use in establishing environmental flow requirements / instream flow thresholds. At this point in time, habitat-based approaches are the most practical and reliable methods for establishing integrated instream flow needs. Research efforts to link fish production-based methods to instream flow requirements should be supported in an effort to link true measures of fish production to instream flow needs.
8. The MOE and MNR should hold discussions to investigate integrating instream flow requirements into the Ontario Low Water Response Program. The OLWRP could fulfill the communication role so that Ontario Low Water levels, PTTW conditions and instream flow requirements are considered in an integrated fashion.
9. A process or guidelines are needed for high use areas, indicating the components of detailed local instream flow studies and the process for establishing minimum flows that must be maintained. Where current conditions are degraded, a study may be necessary to assess options that may be used to raise the minimum objectives over time, while balancing the social and economic considerations.
10. Studies of a wider range of stream habitats to investigate relationships between stream habitat type/quality and specific IHA responses should be undertaken to improve the diagnostic power and scientific basis for setting ecologically protective instream flow targets.

10.0 GLOSSARY

alluvial : Deposited by running water.

aquifer : An underground water-bearing geological formation that is capable of transmitting water in sufficient quantities to serve as a source of groundwater supply.

bankfull flow : The condition where streamflow fills a stream channel to the top of the bank and at a point where the water begins to overflow onto a floodplain.

cobble : Substrate particles that are smaller than boulders and larger than gravels, and are generally 64-256 mm in diameter. Can be further classified as small and large cobble.

fluvial : Migrating between main rivers and tributaries. Of or pertaining to streams or rivers.

geomorphology : A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.

groundwater : The water below the ground surface, and typically below the groundwater table.

hydrologic cycle : Also called the water cycle, this is the process of water evaporating, condensing, falling to the ground as precipitation, and returning to the ocean as run-off.

natural flow : The flow past a specified point on a natural stream that is unaffected by stream diversion, storage, import, export, return flow, or change in use caused by modifications in land use.

Provincially Significant Wetland : As defined in the Provincial Policy Statement, 1996, wetlands are lands that are seasonally or permanently covered by shallow water, as well as lands where the water table is close to or at the surface. The four major types of wetlands are swamps, marshes, bogs and fens. A wetland is identified as provincially significant by the Ministry of Natural Resources using evaluation procedures established by the province, as amended from time to time.

riffle : A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.

riparian : A relatively narrow strip of land that borders a stream or river, often coincides with the maximum water surface elevation of the 100 year storm.

stream order : A hydrologic system of stream classification. Each small unbranched tributary is a first-order stream. Two first-order streams join to make a second-order stream. A third-order stream has only first- and second-order tributaries, and so forth.

subwatershed : A watershed is an area of land defined by the characteristic that all runoff drains to a common main river (or lake, or chain of lakes) via a series of tributaries. Each of the tributaries of the main river or lake system has its own drainage area, known as a subwatershed.

watershed : The topographic boundary within which water drains into a particular river, stream, wetland, or body of water.

11.0 LIST OF ACRONYMNS

CA	Conservation Authority
CO	Conservation Ontario
MNR	Ministry of Natural Resources
DFO	Fisheries and Oceans Canada
MOE	Ministry of Environment
PTTW	Permit To Take Water
CVC	Credit Valley Conservation
LPRCA	Long Point Region Conservation Authority
CRCA	Cataraqui Region Conservation Authority
GRCA	Grand River Conservation Authority
DO	Dissolved oxygen
YOY	Young-of-the-year
MAF	Mean annual flow
MMF	Mean monthly flow
IHA	Indicators of Hydrologic Alteration
RVA	Range of Variability Approach
DSS	Decision Support System
ORSECT	Ontario River/Stream Ecological Classification Techniques

12.0 REFERENCE LIST

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