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A Desk-top Method for Establishing Environmental Flows in Alberta Rivers and Streams

Government of Alberta

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Preface

The enclosed technical report, *A Desk-top Method for Establishing Environmental Flows in Alberta Rivers and Streams,* identifies a method to estimate an ecologically-based flow regime on the basis of reductions from natural flow or the per cent exceedance from natural flow. It also provides background information and a jurisdictional review of current environmental flows (commonly known as instream flow needs) knowledge in North American and international rivers. The method has been peer reviewed by several instream flow specialists from academic and other government jurisdictions. The report was prepared jointly by Alberta Environment and Alberta Sustainable Resource Development in support of the outcomes and goals identified in the provincial *Water for Life* strategy and action plan.

The method provides a technique to estimate flows to meet the objective of full protection of the riverine environment, in the absence of site-specific studies, which are time consuming and costly to undertake. The method was developed primarily for rivers that have natural flows but can also be used to assess the degree of impact on flows in regulated systems or in those situations where a high degree of allocation currently exists.

While not directly linked to water management acts or legislation, the instream flow needs desk-top method can provide valuable information when considering environmental aspects in balancing natural river flows and water demand. The technical report provides a science-based water management tool that can support informed decisions regarding the environmental considerations of flowing rivers and streams of Alberta. In addition to regulatory activities, many organizations within Alberta in an advisory capacity are undertaking reviews of water availability and general planning, and this method provides an efficient way to assess environmental flow options.

While the understanding of river flows and the requirements of aquatic ecosystems will improve over time and the method may need to be updated to reflect new information, the approach identified in this technical report is one way to assess the influence of water flows on aquatic ecosystems without having to carry out site specific studies. In those instances where the method does not address the numerous and complex issues that arise in water management planning or the allocation process, site specific studies should be undertaken. Specific approaches to manage water across river systems and basins will require a suite of options and tools that incorporates the full range of values derived from the water resource.

Executive Summary

Flowing waters in Alberta provide for a rich diversity of plant and animal life. Sufficient water of good quality is among the most essential requirements for sustaining fish and other aquatic life within Alberta's rivers and streams. At the same time, rivers, and streams are a valuable resource for Albertans, as they provide a diverse array of social, cultural and economic benefits to them. Consequently, Albertans face the challenge of maintaining sustainable environmental conditions in rivers and streams while balancing existing and future demands on water resources throughout the province.

Water for Life: Alberta's Strategy for Sustainability acknowledges that there are limits to the available water supply and that, in order for Albertans to live within the capacity of individual watersheds, they need to become leaders at using water more effectively and efficiently. The method described in this document contributes to the achievement of a *Water for Life* action, namely to "…establish science-based methods for determining the ecological requirements for a healthy aquatic environment."

As Alberta's population continues to grow, demand for water will also grow. The following method for protecting rivers and streams demonstrates the commitment of the Government of Alberta to ensure the water resources will be used in an environmentally sustainable manner.

Aquatic Ecosystem Protection

The approach described in this technical document provides a method for setting instream flow requirements for flowing waters in Alberta. Based on a combination of "per cent of natural flow" and "ecosystem base flow" components, the method outlines a science-based recommendation suitable to guide water management decisions in the absence of site-specific instream flow information. The method is a "desktop" approach, as it requires only existing site-specific natural or "naturalized" hydrology data.

While having information from site-specific instream flow needs (IFN) studies is always preferable, there are many instances where management decisions are made where site-specific IFN data do not exist, nor are the resources available to carry out site-specific studies in a timely manner, for example, water licensing and administration. Completing detailed IFN studies for every watercourse in the province is likely cost prohibitive.

This method provides a means of making an instream flow recommendation in lieu of detailed studies. If the need arises to reduce the uncertainty in the IFN recommendation, then site-specific studies must be carried out to provide better information. Should site-specific IFN studies be completed, then the recommendation from the site-specific studies would replace the IFN method recommendation.

Flow Regimes Impact Aquatic Resources

It is widely accepted there is an ecological basis for the management of flow regimes of rivers and streams. River ecosystems entail variable physical, chemical, and biological constituents upon which fish and other aquatic resources exist. Environmental conditions, such as, depth, velocity, substrate, and cover temperature, and resources, such as food and space, are necessary for species survival. In rivers and streams, the suitability of environmental conditions for aquatic resources relate directly to the characteristics of the flow regime. However, measurable biological response has variable lag time depending on life history and other interactions. This method produces an ecologically based flow regime that incorporates the spatial and temporal flow conditions necessary to ensure long-term protection of the aquatic resources. This method for setting instream flows is considered to be the best that can be used to protect the aquatic ecosystem where no site-specific data are available.

Method Uses Canadian and International Findings

The method relies on existing or synthesized hydrology and ecological information, and draws upon the experience from detailed studies carried out in Alberta and elsewhere over the past several decades. Details of relevant Canadian and international studies are included in Appendix C of this publication.

Intent of the Method

This method is intended to provide guidance for the issuance of water licences in unaltered (limited or no extractions) flowing waters where no site-specific environmental data exists and where the objective remains to provide full protection of the aquatic ecosystem. The method can also be used as a course filter in watershed management planning initiatives to assess current flow conditions relative to the natural and method flow values. The method is the basis upon which a flow recommendation can be made without the benefit of site-specific biological, chemical, or physical data or knowledge. At the time that knowledge or data is obtained upon which a more scientifically defensible instream flow recommendation can be made, then the instream flow recommendation would be revised. In rivers and streams, the suitability of environmental conditions for aquatic resources is directly related to the characteristics of the flow regime. This method represents an ecologically based flow regime that incorporates the spatial and temporal flow conditions necessary to ensure long-term protection of aquatic environments.

The Method Formula

The formula for the IFN method is the greater of either:

- A 15 per cent instantaneous reduction from natural flow or,
- The lesser of either the natural flow or the 80 per cent exceedance natural flow based on a weekly or monthly (depending on the availability of hydrology data) time step.

Acknowledgements

The Alberta Instream Flow Needs Steering Committee provided the initial oversight for this project. The Committee was comprised of members from Alberta Environment, Alberta Sustainable Resource Development and Fisheries and Oceans Canada. Throughout the drafting of this document many Alberta Environment staff provided valuable input. We wish to thank John Mahoney, Wendell Koning, Anil Gupta, Chiadih Chang, Chris Teichreb, Dave McGee, Pat Marriott, Doug Ohrn, Keith Leggat, Preston McEachern and Sal Figliuzzi for their time and effort.

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The final draft of the document was critically reviewed by a number of scientists from across North America. We wish to thank: Dr. Hal Beecher, (Washington Department of Fish and Wildlife); Dr. Thomas Hardy (Texas State University); Dr. Donald Orth (Virginia Tech); Dr. Tim Hardin (Oregon Department of Fish and Wildlife); Dr. Robert Metcalfe (Ontario Ministry of Natural Resources); Ian Chisholm (Minnesota Department of Natural Resources); and, Joe Klein (Alaska Department of Fish and Game) for their thoughtful comments.

To everyone who helped, our sincere appreciation.

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1.0 Introduction

Aquatic ecosystems include the full diversity of rivers, streams, lakes and wetlands, as well as the groundwater systems linked to them. Aquatic ecosystems provide important ecological services, such as wetlands, helping to improve water quality, reducing flood peaks and recharging groundwater aquifers. They also provide cultural, heritage and scientific values, as well as a rich diversity of plant and animal life, and support a variety of human uses, such as fisheries and recreation.

Water is a precious resource required for aquatic ecosystems as well as humans. In some areas of Alberta, water resources are currently under significant pressure to meet human demand. As Alberta's population and economy continue to grow, demand for this renewable but finite resource will also grow. The Government of Alberta is committed to work with citizens, communities, and industry to ensure the water resources are being used in an environmentally sustainable manner.

Alberta has fish communities of considerable ecological, domestic and recreational importance both regionally and globally. Alberta's fisheries are a high quality resource. Compared with other regions in North America, Alberta has a relatively low diversity of fish species (Nelson and Paetz 1992). This low diversity results from a combination of Alberta having:

- A cold climate;
- A dry environment with relatively few water bodies; and
- A more recent history (within the last 13,000 years) that left much of the province as the last area for recolonization during the last glacial retreat (Joynt and Sullivan 2003).

These factors provide further reason to carefully manage the water that fish depend upon for survival. Sufficient water of good quality is among the most essential requirements for sustaining fish productivity within Alberta's fish-bearing rivers and lakes. Consequently, Albertans face the challenge of maintaining these conditions while satisfying expanded needs of industries, municipalities, communities and individuals. Adding to this challenge are growing demands for water by private, public and commercial developments. Unless these increasing demands for and uses of Alberta's waters are properly managed, they will harm fish production and other elements of the aquatic environment through adverse modifications to flow characteristics in rivers (instream flows) and water volumes in lakes.

To protect aquatic environments, scientific studies have shown that significant changes to the natural-flow conditions of rivers and streams can adversely affect the biology, water quality, fish and fish habitat, and channel-maintenance processes of riverine and adjacent terrestrial environments.

Ideally, site-specific information, such as, hydrology, water quality, aquatic habitat, and species data is collected and analyzed to assist provincial water managers set flow targets and objectives that maintain or improve the health of aquatic environments. However, site-specific environmental information is not always available to resource managers, and rigorous study of all streams and rivers in Alberta is neither technically nor economically feasible in the short term.

This document describes a science-based method to establish flow recommendations where site-specific riverine information is not available. The method is intended to provide full protection to rivers and streams, and is based on the current scientific literature and site-specific studies carried out in Alberta, Canada and other jurisdictions around the world. It is also intended to support the major water strategies within the Government of Alberta and to fulfil their objectives. The method is not intended to replace site-specific studies but rather to provide a reliable tool where no site-specific data exists. As new knowledge or data becomes available, then a new instream flow recommendation would be made that would replace the method-based flow recommendation. The method presented in this report is based on the best current scientific understanding of aquatic ecosystems.

2.0 Managing Aquatic Ecosystems in Alberta – the Legislative and Policy Context

Provincial and federal legislation, strategies, and their supporting policies, guide aquatic ecosystem protection and management in Alberta. The documents described in this section provide context for the need and applicability of the instream flow needs (IFN) method.

2.1 Key Legislation

Water Act

Alberta Environment (AENV) administers the *Water Act* and its regulations. A primary function of the *Water Act* is to regulate the diversion of water from surface and groundwater sources. This occurs through licensing protocols, as well as by means of approvals for activities within waterbodies.

In addition to supplying a streamlined, one-window licensing and approval process for water-related activities and diversions, the *Water Act* also provides guidance that:

- Allows for water management plans to be developed to address local and regional issues;
- Recognizes the importance of protecting Alberta's rivers, streams, lakes, and wetlands, by requiring that a strategy for the aquatic environment be developed as part of the provincial water management planning framework;
- Encourages cooperation and proactive measures to resolve water-management problems; and
- Gives Albertans the opportunity to participate in and provide advice on water management.

Fisheries Acts – Federal and Provincial

Both federal and provincial statutes provide the legal basis for managing fish and fish habitat. The federal *Fisheries Act (Canada)* addresses the harmful alteration of fish habitat and the required compensation. The *Fisheries Act (Alberta)* and regulations, proclaimed in 1997, provide for the development and implementation of regulations to manage the harvest and allocation of use of the fish resources.

2.2 Key Strategies

Alberta's Commitment to Sustainable Development

Alberta's Commitment to Sustainable Development (1999) outlines the Government of Alberta's accountability to the people of the province for the sound management of natural resources, as well as for the protection of the environment. The Commitment provides the following five points for the management of resources and the natural environment:

- The use of Alberta's natural resources shall be sustainable.
- The management of Alberta's natural resources shall support and promote the Alberta economy.
- Alberta's environment shall be protected.
- Resources shall be managed on an integrated basis.
- Alberta's natural resources shall be managed for multiple benefits.

Water for Life

Water for Life: Alberta's Strategy for Sustainability outlines the Government of Alberta's vision for water management and identifies several outcomes and key directions that balance the social, economic, and environmental aspects of water and resource management. *Water for Life* confirms three key goals (Government of Alberta 2008):

- Safe, secure drinking water;
- Healthy aquatic ecosystems; and
- Reliable, quality water supplies for a sustainable economy.

Water for Life also commits to the development and use of:

- Place-based approaches to manage watersheds through water management planning; and
- Tools to set ecosystem objectives in the absence of detailed studies or site-specific information (Government of Alberta, 2003).

Fish Conservation Strategy for Alberta: 2006 - 2010

The *Fish Conservation Strategy for Alberta: 2006 – 2010* provides a framework for the Department of Alberta Sustainable Resource Development (ASRD) to ensure Alberta's fishery resources are conserved and used sustainably to benefit present and future Albertans.

The Fish and Wildlife Division's stewardship role, as described in the strategy, is contained in a policy and legislative framework for managing Alberta's fisheries. As stated in the strategy:

> *Maintenance of biodiversity and productivity of aquatic ecosystems helps to maintain healthy fish populations, which provide social and economic benefits to Albertans. Achieving sustainability of fish stocks and other aquatic resources requires that these resources, and the ecosystems that support them, be managed in such a way that their long-term viability and productivity are maintained for the benefit of future generations.*

To achieve the habitat maintenance goal, the first objective is fish habitat protection:

> *To maintain the productive capacity of aquatic habitats to support healthy and diverse fish resources.*

For every water body in Alberta, site-specific fisheries management objectives are set or will be set using a standard approach (Alberta Sustainable Resource Development 2006).

2.2 Key Strategies (continued)

Framework for Water Management Planning and the Strategy for the Protection of the Aquatic Environment

The Framework for Water Management Planning promotes a watershed model for water management and a holistic approach for managing aquatic ecosystems. It also outlines water management planning principles and processes. The framework applies to all types of waterbodies, including streams, rivers, aquifers, and lakes. The principles endorsed by the Government of Alberta during the development of the framework provide general direction for the establishment of outcomes, objectives, and planning (Alberta Environment 2002). The principles include:

- Water must be managed sustainably;
- Water is a vital component of the environment;
- Water plays an essential role in a prosperous economy and in balanced economic development;
- Water must be managed using an integrated approach with other natural resources;
- Water must be managed in consultation with the public; and
- Water must be managed and conserved in a fair and efficient manner.

The Strategy for the Protection of the Aquatic Environment recognizes that the environment is a complex natural system of interconnected parts. The strategy confirms Alberta's commitment to maintain, restore or enhance conditions of aquatic environments, and to maintain biological diversity. The strategy stipulates protection by taking action to sustain current conditions and to restore conditions to their natural state. This is accomplished through management of four inter-related aquatic ecosystem components:

- Water quantity – the amount of water available;
- Water quality – the chemical, biological, and physical characteristics of the water;
- Aquatic habitat – the physical and biological structure of the water body and the surrounding land; and
- Aquatic species – the plants and animals living in or associated with water bodies, wetlands, and riparian areas.

3.0 Ecological Principles – Riverine Environments

The presence and absence of specific fish habitats depend largely on the dynamics of the physical, biological, and chemical processes associated with flowing water (riverine) systems. The flow regime of a riverine system is of critical importance to fish habitat. Recently, many authors have provided detailed discussion on the importance of flow – in terms of magnitude, frequency, timing, rate of change, and duration – to river ecosystems. Poff et al. (1997) provide a detailed discussion of the role of flow as the "master variable" in riverine systems. The following key points have been extracted from that document:

- The natural flow regime plays a critical role in sustaining native biodiversity and ecosystem integrity in rivers.
- The physical structure of the riverine system, and thus of the habitat, is defined largely by physical processes, especially the movement of water and sediment within the channel.
- For many riverine species, completion of the life cycle requires an array of different habitat types, whose availability over time is regulated by the flow regime.
- The timing or predictability of flow events is critical ecologically because the life cycles of many aquatic and riparian species are timed to either avoid or exploit flows of variable magnitudes.
- Modification of the natural-flow regime dramatically affects both aquatic and riparian species in streams and rivers.
- A focus on one or a few species and on minimum flows fails to recognize that what is "good" for the ecosystem may not consistently benefit individual species and that what is good for individual species may not be of benefit to the ecosystem.
- Recognizing the natural variability of river flow and explicitly incorporating the five components of the natural flow regime (that is, magnitude, frequency, duration, timing, and rate of change) into a broader framework would constitute a major advance over most present management, which focuses on minimum flows and on just a few species.

In summary, the protection of fisheries must include protection of hydrological and physical processes that maintain the natural structure and function of flowing water, as well as protecting biological components. A detailed description of instream flows in context of riverine ecology is found in Appendix A.

4.0 How to Use the Method for Setting Instream Flow Needs in Alberta

This section describes the method used in Alberta to calculate instream flow needs (IFN) requirements for those river reaches where no site-specific instream flow needs studies exist.

The method is based upon the results of numerous site-specific studies carried out in Alberta and an extensive review of instream flow studies and riverine ecology. The calculation has been simplified so that it only requires hydrology data. As the name suggests, with the method no effort is expended going into the field and collecting any physical, biological or chemical data. The amount and type of hydrology data that is required is discussed in Appendix B. Using only hydrology data, two calculations are made to develop the instream flow recommendation:

- The Per cent of Natural Flow Component; and
- The Ecosystem Base Flow Component.

4.1 Per cent of Natural Flow Component

Throughout the world, a flow recommendation that preserves the natural hydrograph, or parts of the natural hydrograph, has been done by defining:

- a reduction from the natural flow on an instantaneous basis, or
- a fixed value depending on a water-year type and season.

The reduction can be either a fixed-flow-value reduction from natural or a per cent-of-the-natural flow. The per cent reduction factor can vary depending on the flow range or the time of year.

Today, the advice of the scientific community points toward using natural-flow characteristics as a reference for determining instream flow needs (National Research Council 2005). Natural variability is important to sustain aquatic and riparian biota, as well as riverine processes. There are basically two general emerging approaches – the “building block” and the “per cent of flow” – that can be used to set the per cent of natural flow component.

4.1.1 Building Block Approach vs. Per cent of Flow Approach

The building-block approach (King and Louw 1998) sets a recommended instream flow hydrograph, or set of hydrographs. For example, base flows of a certain magnitude are needed during one season to maintain aquatic organisms. These base flows can be set at different levels in other seasons to enable, for example, fish migrations. On top of these flows are higher flow pulses and overbank flows that coincide with the natural occurrence of high flows. There can be different hydrographs for different water years (dry, average, wet) to provide specific habitat needs or to facilitate various ecological processes. While generally not presented in studies that use this methodology, these varying flow magnitudes can be converted into a per cent-reduction factor from natural flows for each season, week or month.

In the per cent-of-flow approach, levels of allowable flow depletion are expressed as percentages of the natural flow. This approach is generally applied in unregulated rivers where the natural flow remains relatively intact and the societal goal is to protect the aquatic ecosystem. The following international and Canadian examples provide insight into how the per cent-of-flow approach works.

4.1.2 Findings from International Studies

The Southwest Florida Water Management District developed a per cent-flow-reduction factor based on seasons and flow magnitude. For example, on the Peace River at the Arcadia gauge site, for the time period June 25 to October 27, the flow reduction factor was set at 8 per cent when flows were greater than the 25 per cent exceedance flow. When flows were less than the 25 per cent exceedance value, the flow reduction factor was set to 13 per cent (Kelly et al. 2005a). A similar per cent-flow-reduction approach was used on the Myakka and Alafia Rivers (Kelly et al. 2005b; Kelly et al. 2005c).

In their original work on the Klamath River in northern California, Hardy and Addley (2001) used a similar approach to the work that had been carried out on the nearby Trinity River where they set fixed flow values for each month for the 10 (wet) to 90 (dry) per cent-exceedance-flow levels. In their subsequent work, they increased the resolution of their flow recommendations and set flow values at 5 per cent exceedance increments for the 5–95 per cent exceedance range (Hardy et al. 2006). While not reported in their work, these fixed flow values can be translated into per cent reductions from the natural flow.

For the Skagit River in Washington State, a criterion was set to protect the aquatic ecosystem of the estuary in the months of September through January. This criterion stipulates that the total withdrawals of water from the Skagit River not exceed 1/10 of the 50 per cent exceedance (median) flow for each month, based on the period of record (1941–1995) for the U.S. Geological Survey (USGS) stream gauge on the Skagit River near Mt. Vernon, WA (Sta. #12-2005-00) (Washington Dept. of Ecology 2001). This criterion was set in order to maintain channel morphology and other estuarine and riverine functions. (See also Appendix C for further information on international studies.)

4.1.3 Findings from Canadian Studies

In Banff National Park, Parks Canada has adopted, for both Forty Mile Creek and the Pipestone River, the rule of allowing 10 per cent of the stream flow to be withdrawn at any flow until stream flows drop to the 90 per cent exceedance flow (Golder Associates 2002). No withdrawal is permitted once the stream flow is below the 90 per cent exceedance level.

Three additional Alberta studies have been carried out in the last decade where a per cent of the natural flow component was used. This was done using an evaluation procedure where constant per cent reductions in flow from the natural flow were evaluated in terms of:

- Fish-habitat reduction;
- Reduction in recruitment for riparian vegetation; and
- Changes to the magnitude, frequency, and duration of channel-forming flows.

4.1.3 Findings from Canadian Studies (continued)

Specifically for fish habitat, time series evaluations are a highly recommended approach as thoroughly described by Bovee et al. (1998). Carrying out fish habitat time-series analysis requires the development of evaluation metrics. For fish habitat studies in Alberta, many potential threshold criteria were investigated with three ultimately being selected to evaluate the impact of reductions in habitat. Clipperton et al. (2002 and 2003) agreed that, "…the difference in average habitat, the maximum weekly loss in average habitat, and the maximum instantaneous habitat loss were the most useful metrics for making comparisons."

The overall strategy of the per cent of natural flow component is aimed at identifying an instream flow regime that, relative to the natural-flow regime, would limit fish habitat reductions to amounts generally accepted as small. The rationale is that if habitat reductions are limited to small amounts, one can reasonably assume that a high level of protection has been provided by the IFN determined on this basis.

Clipperton et al. (2002) stated that if the average habitat reduction of the most severely impacted life stage was less than 10 per cent, the overall habitat reduction could be considered small in the context of the magnitude of uncertainties inherent in the habitat calculations. Clipperton et al. (2002) also used other habitat metrics to examine habitat changes for shorter periods than are represented by average values.

Several metrics were used to evaluate the effects of change in discharge relative to natural conditions for each of several flow reduction scenarios ranging from 5 per cent to 30 per cent. Each metric can be used to examine different effects of changes in flow, such as chronic (long-term) impacts or acute (short-term) impacts. Many metrics were reviewed by Clipperton et al. (2002). A short list of those many metrics that were evaluated are:

- Per cent changes in average habitat calculated separately for the 50–90 per cent, 10–50 per cent, 10–90 per cent habitat exceedance ranges.
- Maximum weekly loss in average habitat. The habitat averages for each week were calculated for the period of record for natural and the IFN flow scenario, and the greatest per cent loss from natural was reported.
- Maximum weekly loss in average habitat calculated separately for the 50–90 per cent, 10–50 per cent, 10–90 per cent habitat exceedance ranges.
- Maximum instantaneous habitat loss, which was the greatest single percentage habitat loss recorded for all weeks in all years.

From their review of the many habitat metrics that were examined, Clipperton et al. (2002) determined a set of key metrics with appropriate threshold levels would be used to evaluate each flow-reduction scenario. They agreed the most useful metrics for making comparisons were:

(1) Difference in Average Habitat:

The difference in average habitat was viewed as an indicator of chronic effects of flow reduction on habitat availability and the aquatic ecosystem over the long term. This metric included data pooled across weeks and for the entire period of record. Clipperton et al. (2002) considered,

> *…a reduction in average habitat of less than 10 per cent could be considered small in the context of the magnitude of uncertainties inherent in the habitat calculations and that a high level of protection would be provided with average habitat losses of less than 10 per cent.*

The threshold habitat loss would apply only to the most severely negatively impacted life stage. All other life stages would have had less habitat loss or even habitat gains.

(2) Maximum Weekly Loss in Average Habitat:

Clipperton et al. (2002) considered the maximum weekly loss in average habitat to be an indicator of chronic effects of flow reduction on habitat availability and the aquatic ecosystem over an intermediate length of time. The maximum weekly loss in average habitat was used as the evaluation metric. This metric would detect problems with specific times of the year. Clipperton et al. (2002) believed that a threshold value slightly higher than that used for the average habitat metric was appropriate, given the shorter period of time represented by this metric. A threshold value of 15 per cent was adopted for the maximum weekly loss in average habitat.

(3) Maximum Instantaneous Habitat Loss

The maximum instantaneous habitat metric is based on the habitat available during each individual week over the period of record under natural flow and under each flow reduction scenario. Although the term instantaneous is used, the habitat values being evaluated are actually weekly averages, because a weekly time step was used for all of the modelling. Clipperton et al. (2002) considered the maximum instantaneous habitat loss to represent acute effects on habitat availability and the aquatic ecosystem. Since the other two evaluation metrics are based on averaged data, Clipperton et al. (2002) wanted a check to ensure that large habitat losses were not being missed in the longer-term evaluations. The rationale for including this metric was that an instantaneous habitat loss of sufficient magnitude might result in significant changes to the ecosystem. These changes would persist over a much longer time period than the duration of the acute habitat reduction. Clipperton et al. (2002) defined an instantaneous habitat loss of 25 per cent as the threshold value for this metric. This higher threshold is considered appropriate because the habitat reduction is expected to be short-term. Because the habitat values used are based on weekly modelling, the actual instantaneous loss for a single day, or for hours within a day, could be higher than 25 per cent.

4.1.3 Findings from Canadian Studies (continued)

(3) Maximum Instantaneous Habitat Loss (continued)

Clipperton et al. (2002) noted that no single habitat-evaluation metric can adequately assess the change in habitat from natural. Impacts of the same habitat loss are greater if it is long term rather than short term. By using all three metrics, there is a measure of long-term chronic (difference in average habitat), seasonal or short-term chronic (maximum weekly loss in average habitat), and acute (maximum instantaneous habitat loss) impacts on habitat.

Each life stage for each species of interest was included in the final analysis and evaluation metrics were calculated for each life stage. The threshold habitat-loss criteria were applied to the most severely negatively impacted life stage, and all other life stages would have had less habitat loss or habitat gains. Clipperton et al. (2002) suggested the rationale for this approach is that by protecting the life stage with the highest flow requirements, all life stages with lower flow requirements will also be protected within a variable flow regime.

This approach has been carried out on several reaches of the main stems of the rivers in the South Saskatchewan River Basin (SSRB) (Figures 1 and 2) and four reaches on the Athabasca River (Figure 3). From these studies, it can be seen there is a range of flow reductions from the natural flow where the threshold for one of the three evaluation criteria is exceeded. To date, based on physical fish habitat the most conservative result has been a 15 per cent reduction from natural flow, or, similarly stated, 85 per cent of the natural flow. It can be seen in Table 1 that a constant per cent-flow reduction from natural in the 15–30 per cent range is most common. There are three reaches where the flow-reduction factors are greater than 30 per cent the Bow River (BW4), on the Oldman River (OM 2) and on the St. Mary River (SM 1). In these cases, it was observed that the output from the habitat models - the Weighted Usable Area curves - peaked at a relatively low flow compared to the hydrology of the reach. The curve peaks were also very broad and not sensitive to flow reductions.

Table 1.

Summary of fish habitat based IFN per cent-of-natural flow component recommendations.

River	Reach	Per cent-of-Natural Flow Component IFN Recommendation	Per cent Reduction from Natural Flow
South Saskatchewan River Basin*			
Red Deer	1	80%	20%
	3	80%	20%
	5	75%	25%
	6	80%	20%
	7	75%	25%
Bow	2	75%	25%
	4	45%	55%
Oldman	2	60%	40%
	3	70%	30%
	4	85%	15%**
	5	70%	30%
	6	80%	20%
	7	80%	20%
Belly	1	70%	30%
	2	80%	20%
St. Mary	1	60%	40%
Waterton	1	75%	25%
	2	80%	20%
Highwood River Basin*			
Highwood	2	80%	20%
	4	85%	15%**
Athabasca River Basin*			
Athabasca	2	73%	27%
	3	85%	15%**
	4	83%	17%
	5	80%	21%

* Maps of each of the river basins with more detailed information are provided on the following pages.
** Most conservative instantaneous flow reduction factor.

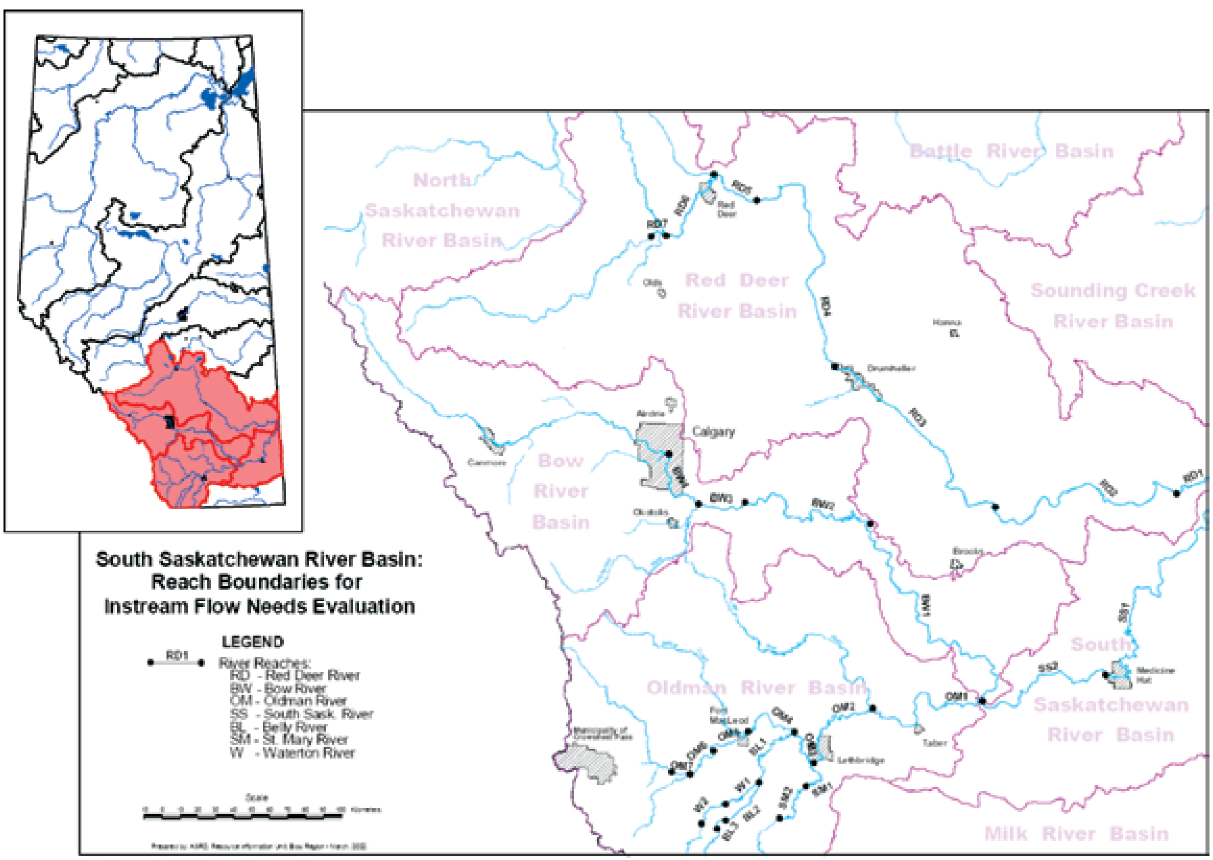
(Source: Clipperton et al. 2002; 2003; Paul 2006).

4.1.3 Findings from Canadian Studies (continued)

The IFN recommendation for the Highwood River study (Clipperton et al. 2002) was made using the fish habitat based procedure described above. For the South Saskatchewan River Basin study (Clipperton et al. 2003), the fisheries component was carried out as described above; however, the final IFN determination included a riparian component. It should be noted the integration of the two instream flow components - fish habitat and riparian vegetation - resulted in an IFN recommendation that is not always a constant per cent flow reduction factor from the natural flow for the entire range of flows that occur in any given week.

Figure 1.

Location of the IFN reach boundaries for the Red Deer (RD), Bow (BW), Oldman (OM), St. Mary (SM), Belly (BL), Waterton (W) and South Saskatchewan (SS) Rivers.



As stated in Clipperton et al. (2003), an evaluation of the riparian vegetation component, (known as the Poplar Rule Curve), developed in the Oldman River Basin indicated the detailed criteria might not be directly applicable to all reaches within the SSRB. Furthermore, taking the specific models developed for cottonwoods (*Populus spp.*) and applying them to watersheds elsewhere in the province where these species do not exist is not recommended (John Mahoney, Alberta Environment, personal communication). Since the method used to determine the instream flow needs for the riparian vegetation component cannot be applied outside the SSRB, the method is therefore based solely on the fish habitat metrics as described above. The underlying assumption is that fish habitat acts as the surrogate for all other biological components in the aquatic ecosystem.

Figure 2.

The Highwood River study area showing segment boundaries.

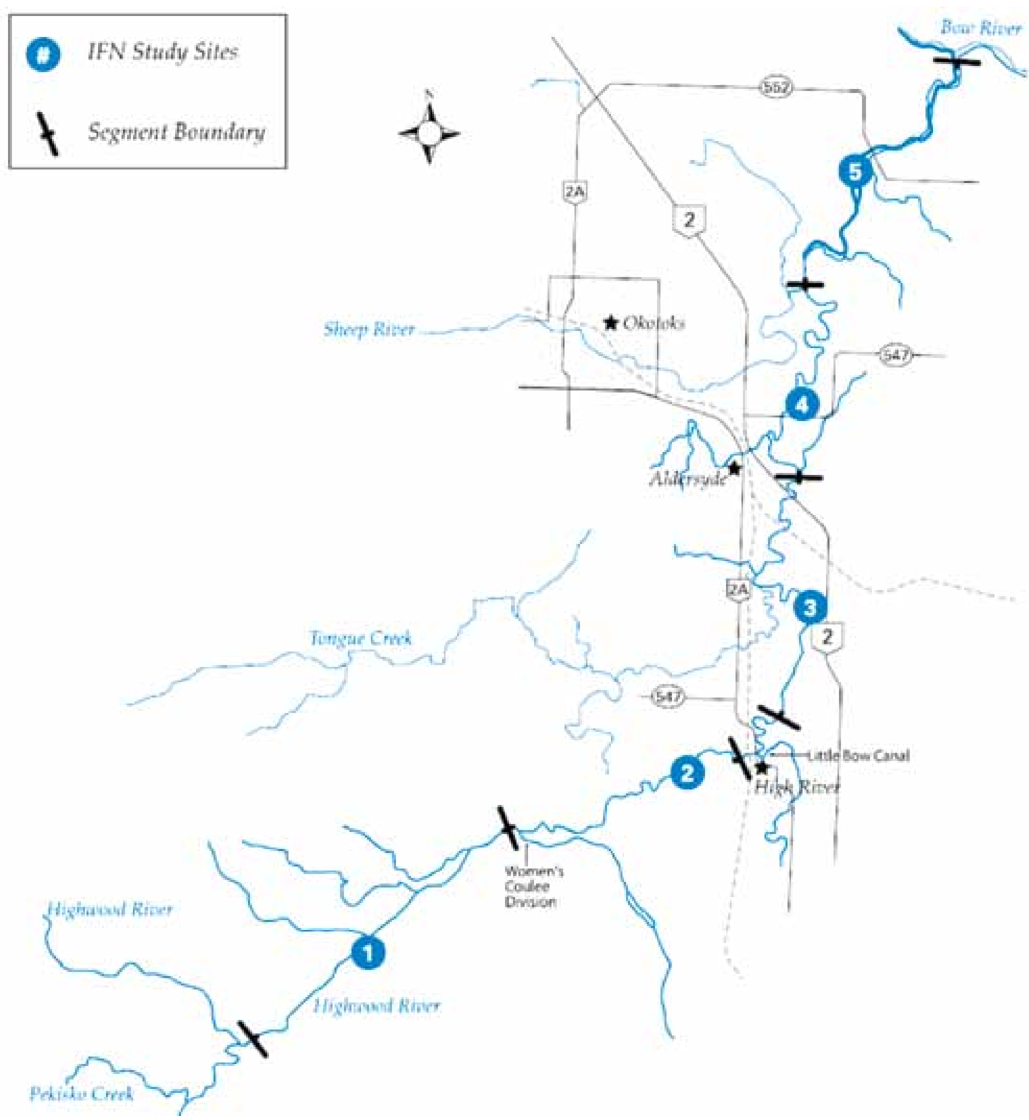
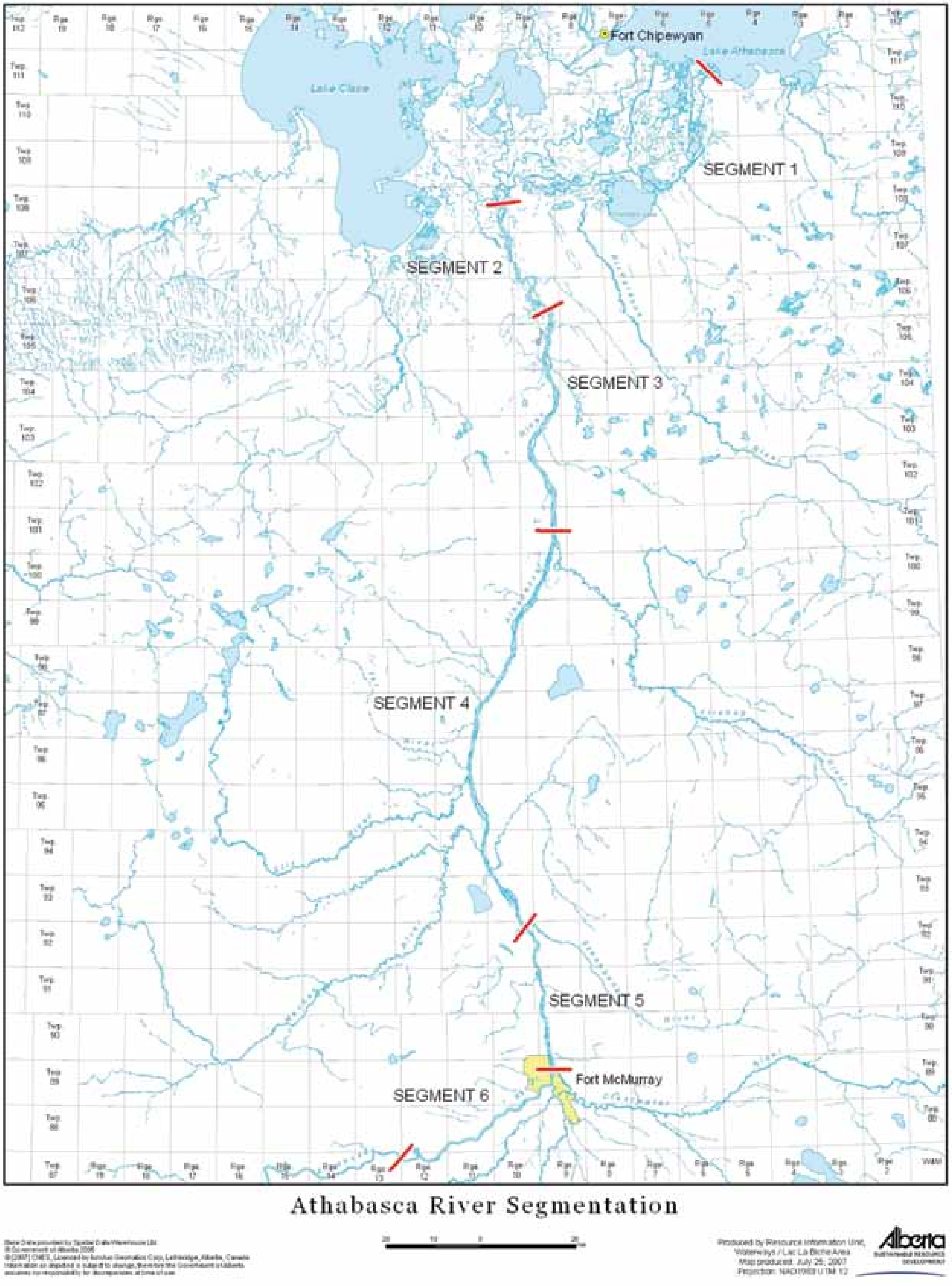


Figure 3.

Athabasca River Instream Flow Needs Segment Boundaries.



The approach used in the South Saskatchewan River Basin was applied to the initial phase of a study on the Athabasca River. Acute, chronic, and long-term habitat metrics were developed for fish species for two reaches in the vicinity of Fort McMurray. The metrics that were used were:

- Metric 1 (chronic, long-term) – a 10 per cent loss in total average habitat from natural, calculated as the average using data for all weeks and all years;
- Metric 2 (intermediate) – a 15 per cent maximum weekly loss of average habitat from natural, calculated as the average habitat for each week (that is, week 16, week 17, etc.) using data from every year in the period of record (that is, 1958-2004) and the week with the greatest per cent loss from natural was reported; and
- Metric 3 (acute, short-term) – a 25 per cent maximum instantaneous habitat loss from natural, calculated as the greatest single percentage habitat loss recorded for an individual flow record for all weeks in all years.

Implicit in the criteria listed is that no long-term loss of fish or other aquatic or riparian resources will be detected. Until such time as rigorous monitoring verifies this assumption, the standard of a small but acceptable loss is only an assumption based on reasonable understanding. This study is under way with additional data expected for other reaches, including the delta area. To date, the most conservative flow recommendation for the open-water season is a 15 per cent reduction from the natural flow. (See also Appendix C for further information on Canadian studies.)

4.1.4 Considerations and Limitations - Per cent of Natural Flow Component

Determining how transferable any per cent-of-flow factor is between and amongst rivers in the province has not been done. In the future, investigation of these relationships could be carried out if the need arises. Alternatively, it may be more cost-effective to carry out site-specific studies rather than calibrating a guideline. Pending further investigation, and given the uncertainty in the science, plus a desire to protect the aquatic ecosystem, the most conservative per cent-of-flow reduction recommendation from all studies carried out in Alberta to date is recommended. The per cent of natural flow component for a "desktop" method would be, *…a 15 per cent instantaneous reduction from natural flow or 85 per cent of the instantaneous natural flow.*

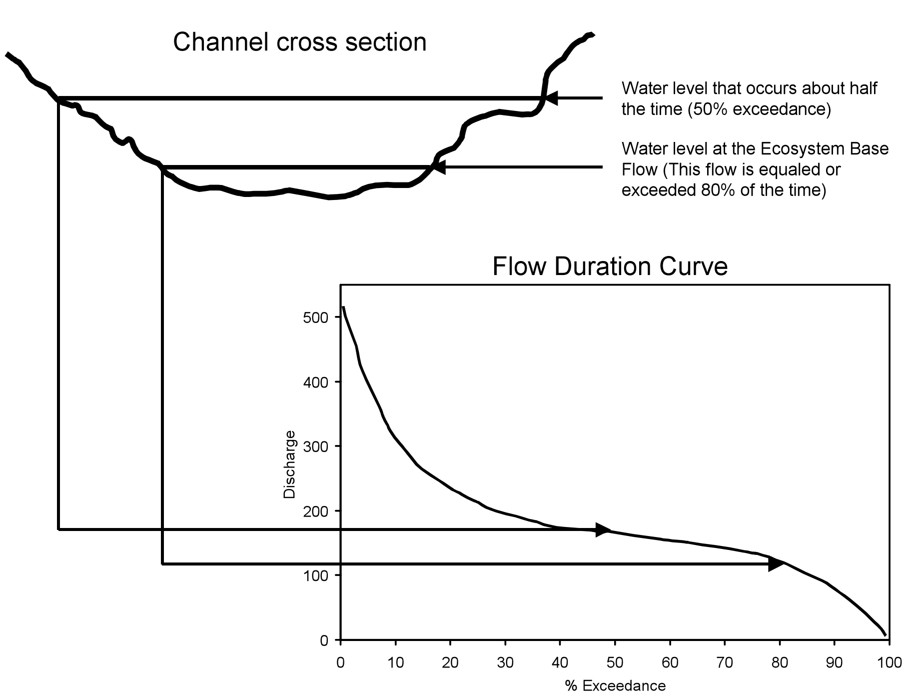
4.2 Ecosystem Base Flow Component

In addition to the using the per cent of natural flow component calculations (discussed in the preceding section) to develop an instream flow recommendation, this method also incorporates an “ecosystem base flow” (EBF) component to make flow recommendations. An instream flow needs recommendation must address the natural-flow paradigm to fully protect the aquatic ecosystem; therefore, both an EBF and a flow reduction factor are required.

Throughout the world, over the past two decades, one of the fundamental concepts that has evolved within the science of instream flows is for studies to include some type of recommendation for an EBF. A generalized diagram of what the EBF looks like relative to a median flow is shown in Figure 4. The water level at the EBF is considerably lower than a flow that occurs on a more regular basis. During these low-flow events space becomes limited for aquatic organisms and the further reduction in habitat through the taking of water exacerbates an already critical condition.

Figure 4.

Channel cross-section water levels for corresponding flow exceedances.

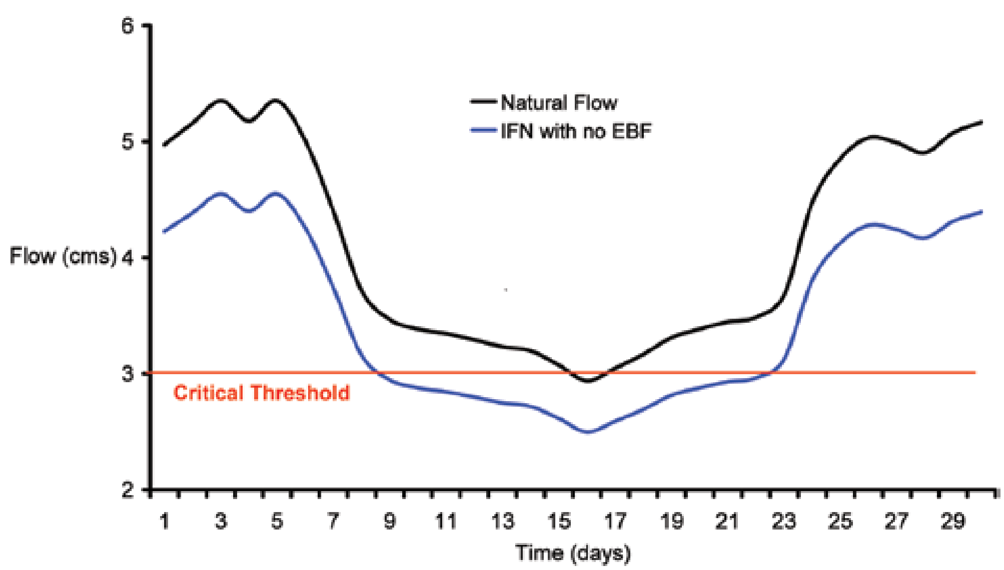


Applying only a constant per cent reduction when natural flows are below a critical threshold would increase negative impacts. Over time, low-flow periods create bottlenecks with respect to aquatic ecosystem production. Low flows during late summer may limit available fish-rearing habitat and low flows in the fall may limit spawning habitat. Perhaps most important, low flows during winter limit over-wintering habitat for the free-swimming life stages of fish and may limit suitable conditions for incubation of eggs.

Without an EBF, a constant per cent flow reduction factor will not protect the aquatic ecosystem during periods of very low flows. For example, when flows are naturally below a critical threshold, continued withdrawal of water will result in an increased magnitude and duration (that is, the amount of time) flows are below the threshold. As shown in Figure 5, a one-day period of flows below the threshold is increased to a 14-day period below the threshold when an IFN recommendation consists only of a per cent-of-flow component. In some situations, fish can survive in isolated pools but not for increased periods of time. Another consequence of having only a per cent-of-flow component to an IFN recommendation is there would be flows prescribed that are below the naturally occurring low flow (Figure 6). As well, the frequency and duration of flows below the natural low flow would be increased. Given the stress on the aquatic system is greatest during low flows, a per cent-of-flow factor by itself does not provide for adequate protection of the aquatic ecosystem.

Figure 5.

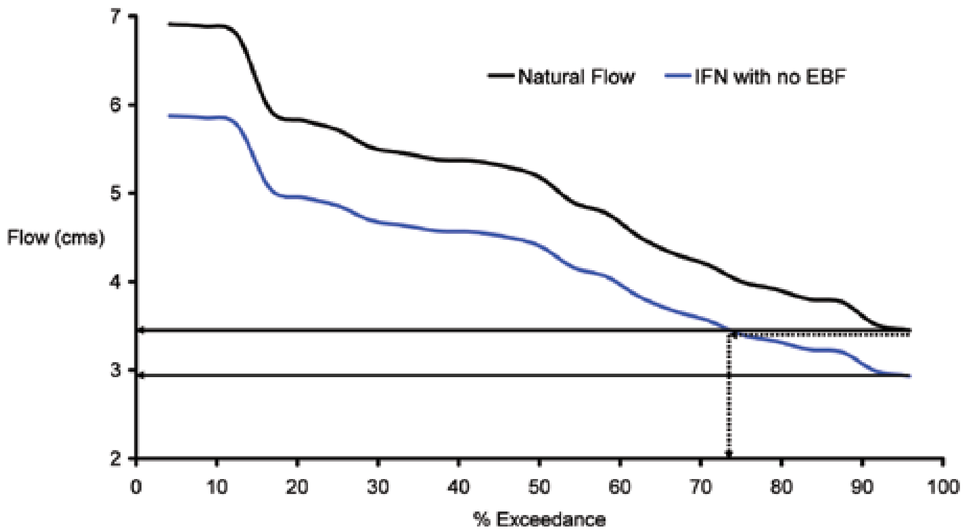
The natural flow and instream flow recommendation with only a per cent-flow reduction component (that is, no EBF) in relation to a critical flow threshold. Both magnitude and duration below the threshold is increased for the IFN recommendation.



4.2 Ecosystem Base Flow Component (continued)

Figure 6.

Exceedance curves for natural flow and the instream flow recommendation with only a per cent-flow-reduction component (that is, no EBF). Without an EBF, the IFN recommendation shows the lowest natural flow would: a) be reduced further; and b) increase in frequency.



Regardless of whether these flows are called ecosystem base flows, subsistence flows, base flows, passby flows or low-flow cut-offs, the intention for their inclusion in an instream flow needs determination is the same – they are designed to protect the aquatic ecosystem during critically low-flow conditions. The EBF represents a flow at which further human-induced reductions in flow would result in unacceptable levels of risk to the health of the aquatic resources. A recent definition for a subsistence flow put forward by the National Academy of Sciences (NAS) is,

> *"Subsistence flow is the minimum stream flow needed during critical drought periods to maintain tolerable water quality conditions and to provide minimal aquatic habitat space for survival of aquatic organisms" (National Research Council 2005).*

In some studies, the subsistence flow is calculated using water quality models and water quality guidelines. The implication of these critically low flow cut-offs, or ecosystem base flows to water users, is that there are naturally occurring flow thresholds for rivers and streams below which it is recommended there be no water abstractions. Continued water use could require licencees to use other sources of water, for example, recycling, on-site storage and conjunctive groundwater surface water management.

Even though the concept of an EBF is widely accepted by instream flow practitioners and is part of instream flow recommendations, specific detailed research has not been undertaken to define what an EBF would be for various river systems. However, there are numerous examples from around the world where EBFs have been established using a variety of techniques. The main areas where EBFs were developed are Australia, South Africa, and the United Kingdom. The latter was in response to the European Union (EU) Water Framework Directive(s) to protect aquatic resources within the EU (European Parliament and the Council of the European Union 2000).

In Alberta, the United States, and throughout the world, many studies have been carried out where IFN practitioners, scientists, and agencies responsible for aquatic resource stewardship have included in them EBF recommendations (as one part of an IFN recommendation). Results from a number of international and Canadian reports and studies with EBF recommendations can be found in Appendix C.

4.2.1 Ecosystem Base Flows in Alberta

In Alberta, the EBFs have been calculated for a number of river reaches throughout the province using fish habitat, water quality, and riparian models. The approaches vary slightly depending on available data, but overall the evaluation metrics and approach is similar. In Alberta, the preferred format for presenting instream flow recommendations is in flow exceedance format on either a weekly or monthly time step depending on availability of hydrology data. A range in EBFs, expressed in per cent exceedance, for all detailed studies carried out to date in Alberta are shown in Table 2.

Unique EBFs are generated for each week for the period of record. The four different EBF values (lowest, average, median, and highest) are provided to give a sense for the absolute range (lowest and highest) of EBFs that can occur in any given reach, as well as an indication of the central tendency (average and median). For example, in Reach 1 of the Red Deer River EBFs were generated for each week of the open water season (Julian weeks 14-44; April through November) based on period of record 1912 to 1995. Therefore, in Reach 1 there are 31 EBFs, one for each week, which range from 78 to 89 per cent exceedance and have a median value of 89 per cent exceedance. This means almost all the EBF values are equal to 89 per cent exceedance. There is very little variation in the recommended EBF throughout the open water season.

4.2.1 Ecosystem Base Flows in Alberta (continued)

As shown in Table 2, site-specific EBF values for Alberta range from 38 per cent in the Highwood River to 95 per cent in the Bow River. The exceedance value for the Highwood River was based on establishing a low-flow period (late summer, fall and early spring) when fish habitat would often, and under natural conditions, be limiting populations (pp. 102-103, Clipperton et al. 2002). In essence, Clipperton et al. (2002) established periods within the year when water should not be extracted from the Highwood River, except for years when flows were unusually high for that period of time. The exceedance value for the Bow River occurred during weeks outside the riparian growing season (weeks 16-37) and when the flow associated with the 80 per cent habitat exceedance value was greater than 95 per cent. For the Bow River, the EBF was defined at the 95 per cent flow exceedance (Clipperton et al. 2003). There is no hard and fast rule or universally accepted fish habitat minima. Bovee et al. (1998) suggest a 90 per cent exceedance value, or other event, that can be used to quantify extreme, low-frequency habitat events. These metrics have been associated with survival rates of early life history phases of fish. They suggest the best approach is to use an average of the lowest habitat events, for example, 80 to 100 per cent exceedance probabilities.

The majority of EBF values derived from studies within Alberta fall between 78 per cent and 95 per cent flow exceedance values (Table 2). Excepting the Highwood River, mean and median values fall between 80 per cent and 90 per cent flow exceedance values. While these values should not be overly surprising given how EBFs were determined, it does indicate an EBF at the 80 per cent flow exceedance value can be applied as a general rule-of-thumb for providing full protection to Alberta's riverine environments.

Table 2.

Range in weekly Ecosystem Base Flow per cent exceedance values interpolated from detailed studies on fish habitat, and riparian vegetation within the Province of Alberta.

River	Reach	Ecosystem Base Flow*			
		Lowest	Average	Median	Highest
South Saskatchewan River Basin					
Red Deer[1]	1	78	88	89	89[6]
	3	69	86	89	89[6]
	5	85	89	89	89[6]
	6	82	88	89	94
	7	79	84	80	89[6]
Bow[1]	2	88	90	89	95
	4	84	90	89	95
Forty Mile Creek[2]		90			
Pipestone River[3]		90			
Oldman[1]	2	85	89	89	89[6]
	3	79	83	80	89[6]
	4	79	85	88	89[6]
	5	79	86	89	89[6]
	6	78	86	88	89[6]
	7	79	87	89	89[6]
Belly[1]	1	47	82	81	89[6]
	2	74	83	81	89[6]
St. Mary[1]	1	73	85	88	89[6]
Waterton[1]	1	78	84	81	89[6]
Highwood[4]	2	40	78	82	95
	4	38	73	81	95
Athabasca River Basin					
Lower Athabasca River[5]	2, 4 and 5	80			

Except for the lower Athabasca River, values are based on the open-water season (approximately weeks 14–44). Base flows determined for maintenance of water quality below municipal centres (by dilution of sewage effluent) were further excluded from the table. Note: A "low" per cent exceedance value is a high flow value while a "high" per cent exceedance value is a low flow value.

1 Interpolated from tables in Appendix G of Clipperton et al. (2003).
2 From Golder Associates (2002).
3 From Roe et al. (1996).
4 Interpolated from tables in Appendix VIII of Clipperton et al. (2002).
5 Based on the Athabasca River discussion provided in the current report and Appendix C.
6 Maximum EBF values are derived from 90 per cent flow exceedance for the EBF component of the Poplar Rule Curve (Clipperton et al. 2003). The 89 per cent values shown result from interpolating the EBF from the tables presented in Appendix G of Clipperton et al. (2003).

4.2.2 Comparing Ecosystem Base Flows

In many of the studies from outside Alberta (available in Appendix C) the EBFs are presented in a number of varying formats: fixed-flow values, a percentage of mean annual discharge, etc. The corresponding natural-flow per cent exceedance values were not presented; therefore, it is not possible to make direct comparisons to the weekly or monthly EBFs calculated in Alberta. However, some of the studies did present their EBF recommendations in monthly per cent exceedance values. In some instances, the authors were contacted and they agreed to re-format their flow recommendations in per cent exceedance format. Those data are presented in Table 3.

Table 3.

Monthly Ecosystem Base Flow exceedance values for: Carnation Creek (British Columbia), the Peace River (Florida), a portion of the Snake River Basin (Idaho), and Trout Creek (British Columbia).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Carnation Creek, British Columbia	*	*	*	*	*	*	*	18	*	*	65	*
Peace River, Florida	*	99	98	96	92	99	*	*	*	*	99	99
Snake River Basin, Idaho	80	80	80	80	80	80	80	80	80	80	80	80
Trout Creek, British Columbia	84	85	90	64	90	77	83	65	81	84	88	84

* Data not available

As shown in Table 3, there is considerable variance in the range of per cent exceedance values for the various rivers. There are many factors that contribute to this variability. First, there is the legal and institutional setting. For each river, there are different federal, state, and provincial laws and policies governing an instream flow prescription. The rivers are from different eco-regions having very different climates, rainfall patterns, slopes, geophysical properties, and hydrology. The types of organisms and their habitat requirements are also as varied as the physical properties of the rivers themselves. Some studies were carried out to restore conditions in a river to bring back species from near extinction, while others were done to set limits for future use of water, thereby protecting existing viable populations. Given that each study was carried out according to its unique set of circumstances, both from a biological and physical perspective, as well as the institutional setting, it is unlikely there would be convergence in absolute terms of the monthly exceedance values.

The unique hydrology for any river can greatly affect the recommended EBF. Relative low per cent exceedance (high flow) values are reported for Carnation Creek in British Columbia. This is an unregulated system, but one that is rain driven and not snowmelt driven. In order to protect riffles according to a standard protocol for trout, the amount of flow required in the dry month of August means a very high exceedance value is set to restrict water users. This illustrates that the differences in climate and precipitation can greatly impact the monthly per cent exceedance requirement.

At the other extreme, for the Peace River in Florida, it is shown the per cent exceedance values restrict water use at very low flows in some months. The Peace River is a very low-gradient system and the species that inhabit the river are very tolerant of low-flow conditions. As long as the fish can move from one pool to the next, no impact to the populations is expected. However, it should be noted that the peer review of this study pointed out the fish passage depths were originally derived from requirements of migratory salmonids in cool, well-oxygenated waters and raised the question as to whether these standards apply to Florida's warm water streams. They suggested more research is required to ensure other factors such as high water temperatures, low dissolved oxygen, algal blooms, and increased predatory pressure do not negatively impact the aquatic ecosystem.

The winter season ecosystem base-flow recommendations for Forty Mile Creek in Banff National Park are set consistently at 90 per cent for each month. The researchers in this ongoing study acknowledged the uncertainty in setting an ecosystem base flow and made it a condition of the water licence that a stream flow monitoring program be carried out during the water-withdrawal period to empirically determine the impacts to the fish populations (Golder Associates 2002).

For Trout Creek in British Columbia, studies were carried out to develop a water-use plan that protected fish and fish habitat and ensured a secure water supply. To protect the fish habitat and populations in the creek, conservation flows were set based on a generalized model of habitat response to varying flow percentages of the mean annual discharge. It is believed that flows less than the conservation flows will result in an eventual significant reduction in available fish habitat and associated fish production. While the approach, specific methods, and tools used to set the ecosystem base flows are not the same as those that have been applied in Alberta, from a general perspective, the monthly per cent exceedance values are relatively similar (See Tables 2 and 3). Of all the rivers in Table 3, Trout Creek is perhaps the most similar, in terms of climate, slope, geomorphometry, and species to Alberta east-slope streams.

Another confounding issue in comparing ecosystem base flows is the varying opinions of what is meant by "fully protecting the aquatic ecosystem", or "long-term sustainability of fish stocks". There is no common definition and all practitioners approach these definitions from their unique perspective. It is understandable and reasonable to expect there will be differences in flow recommendations between studies. Notwithstanding these differences, the intent of the "ecosystem base flow" appears to be somewhat similar; to protect the resource and to set a threshold below which off-stream usage of water would have an adverse effect on the environment.

In general, setting the amount of habitat protection provided by ecosystem base flows requires subjectivity and sometimes can be arbitrary. Collective understanding on the effects of meeting, or not meeting, an ecosystem base flow is insufficient to predict the response of the aquatic ecosystem, including specific details about the organisms that live in rivers. Rarely when using habitat models is there a point at which a threshold exists between instream conditions being good or bad. It would be a simple task to specify critical levels of flow regime change if it were possible to define an ecological edge where the degree of impact goes from minimal to severe. Aquatic ecosystems are very complicated and it is likely there are continuums of impacts where as flows get lower, habitat is reduced. In Alberta, as elsewhere, these so-called breakpoints where the rate of change of habitat increases with decreased flow may be used as a basis for setting the ecosystem base flow. This linking of the point of greatest change in habitat with change in flow is a reasonable approach. However, there have been no studies done to show any definitive biological response. Whether detailed instream-flow studies have been carried out or a guideline value is being used, the acceptance of an ecosystem base flow will be a focused point of debate among all stakeholders.

4.2.2 Comparing Ecosystem Base Flows (continued)

It should be noted that all examples of EBFs presented in this section also have a companion per cent-reduction factor, or fixed-flow-reduction factor, to address the natural-flow paradigm as discussed in Section 2.1. For the instream flow needs recommendation to address the natural-flow paradigm and to fully protect the aquatic ecosystem over the long term, both the EBF and the flow-reduction factor are required. An EBF without the attendant per cent-reduction component would likely not fully protect the aquatic ecosystem.

4.2.3 Considerations and Limitations – Ecosystem Base Flow Component

As in the case of the applicability of a single instantaneous flow-reduction factor, similar questions arise for the EBF. No sensitivity analysis has been carried out with respect to understanding if the most conservative EBF recommendation, the 80 per cent exceedance value, is applicable between or among watersheds in the province. Other scientists and authors have recently advocated for the need to understand and account for the differences in flow variability among rivers and between watersheds (Arthington et al. 2006, Henriksen et al. 2006). In the future, investigating these relationships and validating the method recommendations should be carried out in Alberta. Alternatively, it may be more cost effective to simply carry out site-specific studies. Given the uncertainty in the science and the desire to fully protect the aquatic ecosystems, until further investigation is completed, the most conservative EBF recommendation value from all studies completed in Alberta to date is recommended, *…the 80 per cent exceedance natural flow based on a weekly or monthly time step depending on the availability of hydrology data.*

4.3 Combining the Per cent of Natural Flow and Ecosystem Base Flow Components

Once the per cent of natural flow and the ecosystem base flow components have been calculated, they are simply plotted together and the greater of the two values is selected as the IFN flow recommendation. This is done in a flow duration curve format and, depending on the available hydrology data, it is done on a monthly or weekly time step.

4.4 Example Calculation of the Alberta Instream Flow Method

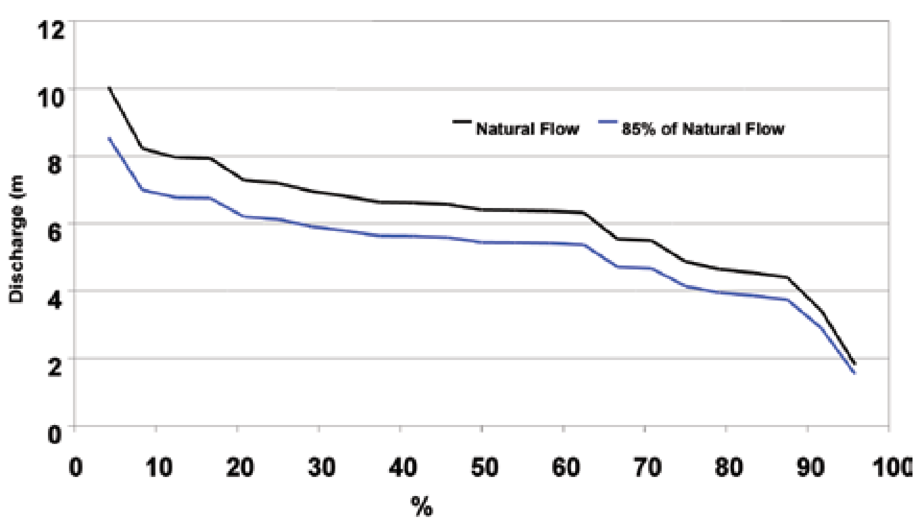
The following provides a detailed example of how to apply the instream flow needs method.

4.4.1 Step 1: Calculate the Per cent of Natural Flow Component

Depending on the availability of the hydrology data and using natural hydrology data for the stream, flow-duration curves are created based on a weekly or monthly time step. This is done according to the Alberta Environment standards and practices as described in Appendix B. The natural flow data is reduced by 15 per cent (85 per cent of the natural flow). An example of this calculation is shown in Figure 7.

Figure 7.

Per cent-of-Natural Flow recommendation for the Clearwater River for the first week of December (Week 49).

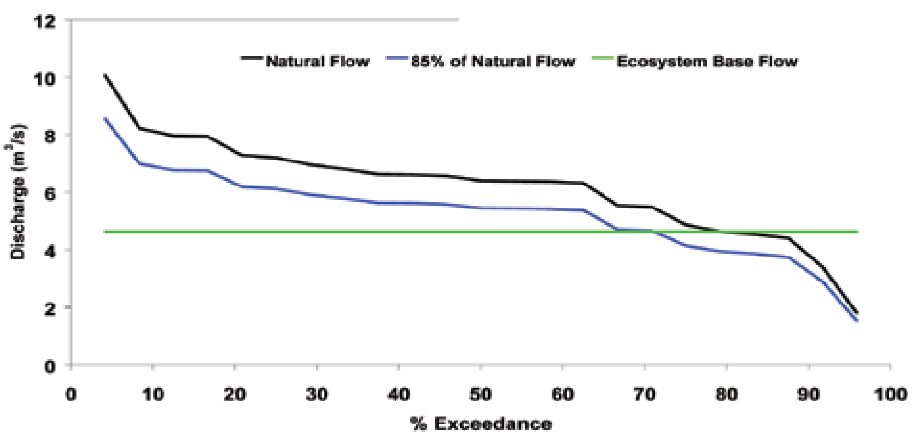


4.4.2 Step 2: Calculate the Ecosystem Base Flow Component

Using the weekly or monthly flow data, set the 80 per cent exceedance natural flow as the EBF for each week or month. This is a threshold below which there would be no further out-of-stream use of water. An example of this calculation is shown in Figure 8. While the per cent exceedance value for each week of the 52 weeks throughout the year is fixed at 80, the corresponding flow values are different for each week. This is due to the fact there is a unique set of hydrology data for each week.

Figure 8.

Ecosystem Base Flow recommendation for the Clearwater River for the first week of December (Week 49).

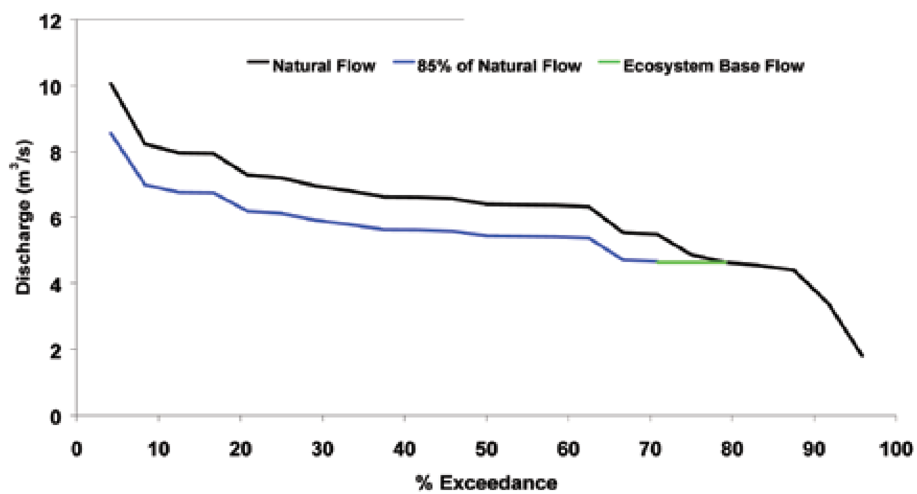


4.4.3 Step 3: Combine the Per cent of Natural Flow and Ecosystem Base Flow Components

The final IFN determination is set by combining the greater of either; a) a 15 per cent instantaneous reduction from natural flow or, b) the lesser of either the natural flow or the 80 per cent exceedance natural flow based on a weekly or monthly time step depending on the availability of hydrology data. An example is shown in Figure 9.

Figure 9.

Example natural flow exceedance curve and IFN determination for the first week of December (Week 49).



4.5 Considerations When Using the Method

Applying a method based on a simple formula across a diversity of rivers having unique channel characteristics, flow regimes, and watershed properties, places the method in the category of "one-size-fits-all". While the Alberta method is designed to address the intra- and inter-annual variability of flow, it may not fully address all riverine parameters (biological, chemical, and physical) that vary across river and watershed types in a site-specific context. There is risk the recommendation may not meet the objective of fully protecting the aquatic ecosystem. The method should be subject to periodic review to ensure it is updated as new information becomes available and that its application is consistent with the appropriate scale and purposes for which it was developed.

The flow recommendations that result from using this method are calculated from hydrology data. These stream flow records are often of short duration (20-30 years in length), and may be seasonal records as is often the case in northern Alberta (that is, data available for the ice free season only). A number of studies have documented the range of hydrologic variability in streams and rivers in Alberta over the last several centuries (Axelson et al. 2009), and illustrate that translating instrumental records into management systems may not account for the full range of variability aquatic ecosystems require.

In Alberta, the winter time period is known to be a sensitive period when naturally occurring low flow conditions limit productivity. Both low water temperature, which reduces metabolic rates, and the lack of food are factors

4.5 Considerations When Using the Method (continued)

that make the winter a sensitive time period. Little is known when it comes to winter and how this method addresses this sensitive time period. When applying this method, it is necessary to address this shortcoming by analysing the only data that is available - hydrology data - and making a decision to either apply the method or to apply a higher flow level. Until such time that biological data is available to guide such decisions, best professional judgement is all that can be used.

The method does not specifically account for the vertical connection of surface to groundwater and lateral connectivity to adjacent floodplain areas. For example, flow changes in a river can influence other system aspects such as the physical and biological characteristics of nearby aquatic features, for example, wetlands, lakes, small streams and groundwater resources.

There are upstream and downstream trends in the amount of physical habitat in rivers. Rosenfeld et al. (2007) have demonstrated that based on hydraulic geometry, optimal flows for habitat proportionally increase as streams become smaller and decrease downstream as stream size increases. From their work they conclude these nonlinear downstream trends in habitat suggest that fixed flow percentage approaches may underestimate optimal flows for certain types and certain places along streams and rivers, for example, headwaters. Stream flow data is often only available for a single location on a river, so assessing trends, much like with the physical habitat, relies on extrapolation to overall river conditions and characteristics. Others have observed this trend and have suggested that rivers should be classified according to river size and that this classification should be related to critical ecological values (Jowett and Hayes 2004).

4.6 Summary

This method is based on currently accepted information and studies on the science of instream flow needs and a review of available site specific studies in Alberta, North American and international studies.
The proposed method provides for the protection of aquatic resources:

- Based on sound ecological principles that inherently protect the natural variability of the flow regime;
- Supported by existing site-specific studies and research within the province and internationally;
- By being conservative given the complexity of aquatic ecosystems and uncertainty in the science; and
- By meeting the intent of relevant provincial and federal legislation.

In rivers and streams, the suitability of environmental conditions for aquatic resources is directly related to the characteristics of the flow regime. This method represents an ecologically-based flow regime that incorporates the spatial and temporal flow conditions necessary to ensure long-term protection of aquatic environments.

The complexity and limited knowledge available on ecosystems results in uncertainty on how best to manage natural resources such as water. Our understanding of certain riverine components such as water quality, riparian health, and fish habitat is arguably more advanced relative to other components such as geomorphology or population dynamics. Likewise, our understanding of environmental flows is better for the open water period compared to our understanding of ecosystem processes during the ice-covered period, including the time of ice formation and break-up (Beltaos 1995). Until such time that detailed studies and further research has been carried out, a precautionary approach is used to set environmental flows.

Appendix A

Instream Flows in the Context of Riverine Ecology

Appendix A - Instream Flows in the Context of Riverine Ecology

1.0 Ecological Principles

As a science, riverine ecology is relatively new. Many of the conceptual foundations of this new science were developed by studying streams in Europe, South Africa, and North America that were already highly regulated (Ward et al. 2001). However, in recent years, the understanding of river ecology has expanded beyond the view of rivers as stable, single channel, longitudinal corridors that are often a result of regulation to also include a more dynamic view of a natural stream channel that has complex interactions with its flood plain and groundwater zones (Ward et al. 2001). Despite the efforts of natural resource agencies to restore many regulated streams using mechanistic approaches, such as improving water quality, habitat mitigation, or the use of fish hatcheries, there continue to be wide-spread declines in fish populations and species diversity, and a host of other indicators of aquatic ecosystems' sustainability (National Research Council 1992; Independent Scientific Group 2000). It has been proposed that large-scale restoration of the biological integrity of an aquatic ecosystem cannot be achieved without restoring the functional integrity of a variable and dynamic flow regime (National Research Council 1992; Independent Scientific Group 2000).

Poff et al. (1997) suggest that *…the natural flow regime of virtually all rivers is inherently variable and that this variability is critical to ecosystem function and native biodiversity.* Over the past decade, the importance of preserving elements of the natural hydrograph as a means of protecting or restoring aquatic ecosystems has gained more attention in both the academic and natural-resource-management communities (Annear et al. 2004, 2002; Bovee et al. 1998; Castleberry et al. 1996; Frissell and Bayles 1996; Goldstein 1999; Hardy 1998; Hughes and Noss 1992; Hughes et al. 2001; Karr 1991; National Research Council 1992; Poff et al. 1997; Potyondy and Andrews 1999; Rasmussen 1996; Richter et al. 1997; Stalnaker 1994; Stanford et al. 1996; Ward 1998; Ward et al. 1999; Ward and Tockner 2001). The concept of a "natural-flow paradigm" is based on evidence that suggests the intra- and inter-annual flow variability is necessary for maintaining or restoring the native integrity of aquatic ecosystems, with respect to the natural magnitude, timing, duration, frequency, and rate of change of flows (Richter et al. 1996). Richter et al. (1997) also conclude, *…if conservation of native biodiversity and ecosystem integrity are objectives of river management, then river management targets must accommodate the natural flow paradigm.*

This is not to say that the natural flow is best simply because it is natural; it is the pattern of flows that is important. Different components of the flow regime have distinct functions, and it is maintaining this functional diversity and interconnectivity that will result in habitat diversity as well as species diversity (Ward and Tockner 2001). The natural variability of flows, both seasonally and from year to year, has shaped aquatic ecosystems over many thousands of years, and the species associated with these dynamic systems have adapted to take advantage of this functional diversity, for example, cottonwood recruitment (Mahoney and Rood 1998).

Although the acceptance of these ecological principles is widespread and can be supported by a large body of knowledge (for example, Poff et al. 1997 was based on over 110 references), incorporating these ecosystem principles into river-management practice is a difficult challenge (Richter et al. 1997). Annear et al. (2004, 2002) conducted a detailed review of the most common methods for developing instream needs by IFN practitioners from across the United States and Canada, and concluded that the predominance of single-flow recommendations has not succeeded in protecting the integrity of aquatic ecosystems. Annear et al. (2004, 2002) suggest that the following five interrelated components should be considered in the setting of aquatic ecosystem objectives: hydrology, geomorphology, biology, water quality, and connectivity.

Several detailed literature reviews have been produced supporting the concepts of the natural-flow paradigm (see Poff et al. 1997; Richter et al. 1997; and Annear et al. 2004, 2002). These reviews compiled numerous references from decades of research that provide evidence of the effects of altering different components of the natural-flow regime and clearly support the rationale behind the natural-flow paradigm and many more studies have been published since the time of Poff et al. (1997). A similar level of detail has not been replicated for this report since comprehensive reviews are available in the scientific literature. The references (See Reference Section) of this report are not exhaustive and are intended only to provide a few key examples of the main concepts.

The following sections offer a general overview of the different elements of the natural-flow paradigm or theory, specifically:

- Physical processes;
- Biological processes; and
- Interconnectivity of the riverine ecosystem.

1.1 Physical Processes

In recent years, increasing attention has focused on channel-forming, channel-maintaining, and flushing flows (Reiser et al. 1987; Wesche et al. 1987; Hill et al. 1991; Whiting 1998; Kondolf 1998). Channel-forming flows are necessary to create and maintain the habitats that are used by river-dwelling species (Hill et al. 1991; Whiting 1998). Flushing flows have a lower magnitude than channel-maintenance flows, but are important for removing fine sediment from spawning gravel in years when channel maintenance flows do not occur (Milhous 1990). These flows tend to be much greater than flows that provide suitable micro-habitat conditions for fish, but they are relatively infrequent events of short duration, and refuge areas are usually available allowing the majority of the fish to cope.

A normally functioning alluvial stream channel will be in a state of dynamic equilibrium, which can be defined as a system where there is approximate sediment equilibrium (Dunne and Leopold 1978; Bovee et al. 1998). This occurs, on average over a period of years, when sediment export equals sediment import (USDA Forest Service 1997; Carling 1995). This is not to say that the channel is static. Scouring and deposition will occur, point bars will be formed and disappear and the channel will meander. However, over time, the general channel pattern remains fairly consistent for the entire stream (Rosgen 1996; Bovee et al. 1998). When magnitudes or frequencies of occurrence of discharges in the range of channel structure flows are altered over time, a channel can be put into disequilibrium. Some gravel-bed channels respond by altering their size (width and depth), rate of lateral migration, stream bed elevation, bed-material composition, structural character, ratio of pools to riffles, composition of stream side vegetation, and water-carrying capacity, and can increase the potential for vegetation encroachment (Rosgen et al. 1986; Williams and Wolman 1984; Hill et al. 1991). Time scales for channel morphology to adjust to impounding and regulating flow have also been studied at a number of dams in the United Kingdom (Petts 1987).

Maintenance of channel features cannot be obtained by a single threshold flow. Rather what is required is a dynamic hydrograph of variable flows for continuation of processes that maintain stream-channel and habitat characteristics (Gordon 1995; USDA Forest Service 1997; Trush and McBain 2000). Within the range of channel structure flows, bankfull flow is generally regarded as the flow that moves most sediment, forms and removes bars, bends and meanders, and results in the average morphologic characteristics of channels over time (Dunne and Leopold 1978; Andrews 1984). Although higher discharges move more sediment, they occur less frequently so that, over the long term, they move less bedload than the more frequent, lesser discharges (Wolman and Miller 1960). It has been recommended (Andrews and Nankervis 1995) that a range of flows, as opposed to a single specified high flow, is needed for channel maintenance. Andrews and Nankervis (1995) found that 80 per cent of the mean annual load was transported by a range of flows between approximately 0.8 –1.6 times the bankfull discharge.

Many different factors interact to define the structure of a channel. Defining a channel maintenance-flow regime based strictly on bed-load movement is a necessary, but perhaps not a sufficient condition to maintain a channel (Andrews and Nankervis 1995). Riparian forests will stabilize the riverbanks and reduce sediment input (Osborne and Kovacic 1993), which will also affect the structure of the channel.

Higher flows also import nutrients, particulate organic matter and woody debris into the channel (Keller and Swanson 1979), thereby increasing habitat diversity and providing food sources for some species (Moore and Gregory 1988; Muth et al. 2000). Flood flows provide a critical interaction between a river channel and its associated side channels and flood plain (Ward et al. 2001). In these fluvial areas, flood flows ensure there is connectivity between the main channel, the side channels and the flood plain, which can provide critical rearing and spawning habitats for some species of fish (Muth et al. 2000). High flows also recharge the flood plain water table, which is critical for the survival of many riparian species (Hughes et al. 2001).

1.2 Biological Processes

The physical processes described in the previous section deal mainly with flow magnitude and are responsible for providing the structural habitat characteristics necessary for many aquatic species. However, many species have adapted to be dependent on the seasonal timing of different flow magnitudes as well. Equally critical as the timing of different flow events, for certain species, can be the duration and rate of change of flow. The following section discusses maintaining the natural pattern of flow variability as it relates to biological requirements and species life histories.

The timing of high flow events or seasonal variation in flow is important to biological systems. Aquatic and riparian species are adapted to either avoid or exploit flows of variable magnitudes. Temporally variable flows create and maintain the dynamics of stream-channel conditions and create the habitats that are essential to aquatic and riparian species (Hughes et al. 2001). The magnitude, timing, and frequency of occurrence of high flow events directly regulate numerous ecological processes, such as spawning cues and movement into and out of flood plain areas for some fish (Muth et al. 2000), or the recruitment and composition of riparian forests (Hughes et al. 2001; Mahoney and Rood 1998). Seasonal sequences of flowering, seed dispersal, germination, and seedling growth are timed to natural flow events (Mahoney and Rood 1998). Seasonal seed release by cottonwoods is timed to coincide with typical spring peak flows that create suitable sedimentation habitat sites for seed germination and seedling survival (Hughes et al. 2001). Peak flows that are not seasonally timed can result in high mortality rates of cottonwood seedlings (Hughes et al. 2001).

Seasonal access to flood plain wetlands for spawning and rearing is essential for the survival of certain riverine fishes (Muth et al. 2000). When access to flood plains is reduced due to the alteration of high flow events, such species may become endangered (Muth et al. 2000) or eliminated. Spring high flows also create an increase in available riffle habitats, which are critical habitats for some spring-spawning fish species (Aadland 1993). In contrast, the life cycle of fall-spawning fish has adapted to avoid high flows (Simonson and Swenson 1990). The stabilization of seasonal flow variation can result in the loss of species diversity and favour introduced species that thrive in this type of environment (Hawkins et al. 1997).

1.2 Biological Processes (continued)

The variability of flow magnitude is also important from year to year. Flood flows are not needed every year. In the years that have high peak flows, they will scour the stream channel, prevent encroachment of riparian vegetation, and deposit sediments to maintain a dynamic alternate bar morphology and successively diverse riparian vegetation community (Hughes et al. 2001; Trush and McBain 2000). Years with lower flows are as valuable as high flows in some years to allow successful establishment of riparian seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000). The natural interaction of high and low flows is essential for normal riparian vegetation development. If only high flows were available, then annual scouring would occur, preventing riparian development. In some situations where only low flows are available, encroachment by riparian vegetation and reduction in stream-channel size can occur, for example, below the diversion weir on the Belly River in Alberta.

Rapid flow increases in streams often serve as spawning cues for native species whose rapidly developing eggs are either broadcast into the water column (Taylor and Miller 1990) or attached to submerged structures as flood waters recede. Gradual, seasonal rates of change in flow conditions also regulate the persistence of many aquatic and riparian species. In the case of cottonwoods, the rate of flood water recession is critical to seedling germination since seedling roots must remain connected to a receding water table as they grow (Rood and Mahoney 1990; Hughes et al. 2001).

In addition, the duration of high flow events is also ecologically important (Poff et al. 1997). Indigenous plants, aquatic invertebrates and fishes have different tolerances to prolonged flooding, allowing some species to persist in locations from which they may otherwise be displaced by dominant, but less tolerant, species. The native species of fish have adapted to the naturally occurring dynamic flow regime. When flow-regime changes become either more (for example, hydropeaking) or less (for example, flood attenuation) variable, new biotic communities may replace locally endemic communities (Hawkins et al. 1997, Quinn and Kwak 2003, Tyus et al. 2000).

Stream invertebrates also respond to changes in the flow regime. Studies have shown that invertebrate species abundance and diversity are significantly reduced in reaches of streams where natural flows are reduced or regulated (Rader and Belish 1999; Growns and Growns 2001). High flows that recharge the water table may also be beneficial to invertebrates since a large proportion of invertebrate biomass can be located deep below the river channel and laterally as far as two kilometres from the river channel in what is called the hyporheic zone (Stanford and Ward 1993).

2.0 Interconnectivity of the Riverine Ecosystem

Continuous, seasonally appropriate instream flows are essential for maintaining self-sustaining fish communities and the aquatic ecosystem in general. Prescribing instream flow needs must provide for the dynamic interaction of flowing water, sediment movement, and riparian vegetation development to maintain good quality habitats and populations of fish and other aquatic organisms (Poff et al. 1997; Annear et al. 2004, 2002). An IFN determination must therefore maintain the existing dynamic characteristics of the entire ecosystem, which means it is essential to maintain functional linkages between the stream channel, riparian corridor, and flood plain to perpetuate essential habitat structure and ecological function.

The natural-flow paradigm as outlined by Poff et al. (1997) has taken many individual research results from different fields and has concisely incorporated them into a unified ecological principle. The complexities of whole ecosystems make them a difficult subject to study and make it almost impossible to test a singular hypothesis, such as the natural-flow paradigm, in a single field experiment. However, when the ecosystem is broken down into discrete components, it can be seen how each component is connected with the other components. Healthy riparian ecosystems provide multiple benefits in terms of channel structure, nutrient and energy cycles, and physical habitat for many aquatic species (Gregory et al. 1991). The long-term sustainability of riparian ecosystems is largely dependent on an appropriate flow regime (Hughes et al. 2001). Habitat structure used by aquatic species is also controlled by channel-maintenance flows. Channel-maintenance flows will move the bedload, and create and maintain the pattern of habitats within the river, but are also dependent on other factors (Andrews and Nankervis 1995), such as bank stability, which is controlled largely by the riparian ecosystem (Osborne and Kovacic 1993).

From this brief description, it can be seen that fish habitat depends upon channel maintenance and riparian flows, and that channel maintenance flows and riparian flows also are closely linked. Although the full complexity of an aquatic ecosystem is difficult to outline and the connections between the different components of the ecosystem can be intricate, consideration of instream flows should focus on multiple components of the flow regime. This is important in attempting to protect all of the interconnected functions of an ecosystem (Annear et al. 2004, 2002).

3.0 Use of Natural Flow as a Benchmark Condition

Annear et al. (2004, 2002) have argued that single component, single-value-flow IFNs largely have failed in the past and a shift towards IFNs that consider multiple ecosystem components and natural variability is needed. Several large-scale IFN projects in which detailed, long-term biological studies have taken place, have concluded that no single minimum flow value can achieve ecosystem protection and have recommended a variable-flow IFN to account for the naturally occurring seasonal and yearly flow variation. Prior to the 1980s, many of the instream flows that were provided in response to water projects were limited to a single “minimum” flow value. At that time, there was little to no appreciation for the importance of natural flow variability. Since the 1980s, instream flow practitioners have come to understand the negative riverine effects that result from a flat-line minimum instream flow. This is contrasted with maintaining or restoring variable flows that more nearly resemble seasonal flow patterns and, more importantly, the processes that sustain natural ecological functions.

Importance of Flow Variability

Today, it is clearly understood that establishing instream flows must recognize the importance of inter- and intra-annual flow variability in riverine systems. Different flow levels enable critical ecological processes. As noted by Annear et al. (2004, 2002), seasonal high flows are critical components of river ecology. This is especially true at the terrestrial/aquatic interface where high flows deposit sediment, shape channels, rejuvenate and maintain riparian vegetation and habitats, improve water quality, expand and enrich food webs, maintain the valley, and provide access to spawning and rearing sites in the flood plain. Instream flow recommendations should and must be based on natural flow variability in order to preserve the long-term sustainability of the aquatic ecosystem.

Throughout the world, instream flow needs methods have been evolving to account for natural flow variability and all ecosystem functions. Instream flow science is changing from developing a single, minimum or flat-line flow to a range of flows that account for seasonal and inter-annual variation, magnitude, timing, frequency, and rate of change (Annear et al. 2004, 2002). From a hydrological perspective, the different flow ranges have been described using a variety of terms. In a recent review of the Texas Instream Flow Program, the National Academy of Sciences described the different flow (National Research Council 2005) levels as:

- **Subsistence Flow** defined as: “the minimum stream flow needed during critical drought periods to maintain tolerable water quality conditions and to provide minimal aquatic habitat space for the survival of aquatic organisms.”
- **Base Flow** described as: “the ‘normal’ flow conditions found in a river in between storms.” Base flows provide sufficient habitat to support the diverse, native aquatic communities, and maintain groundwater levels necessary for riparian vegetation.

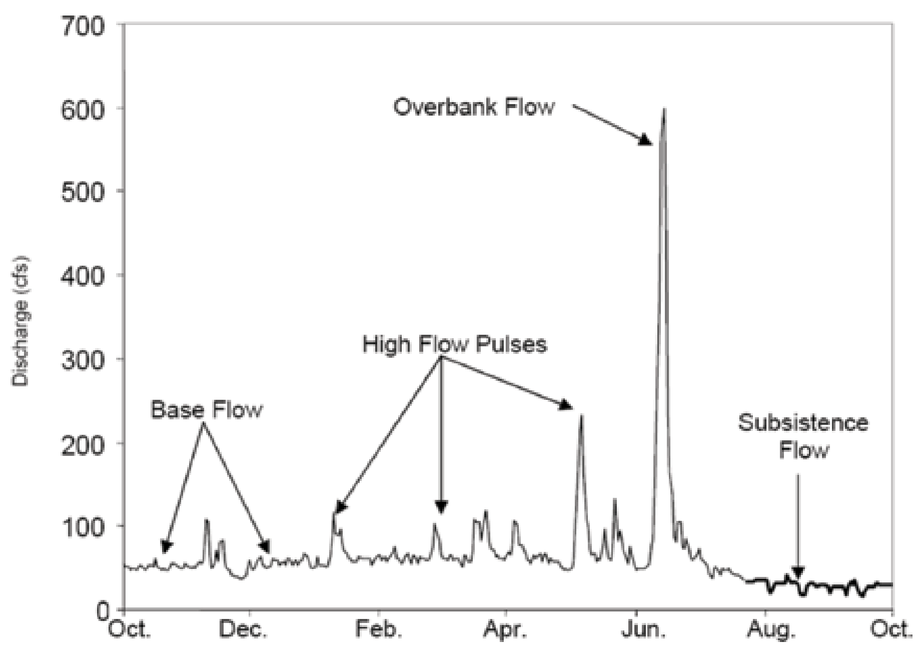
- **High Flow Pulses** labelled: “short-duration, high flows within the stream channel that occur during or immediately following a storm event; they flush fine sediment deposits and waste products, restore normal water quality following prolonged low flows, and provide longitudinal connectivity for species movement along the river.”

- **Overbank Flows** classified as: “an infrequent, high flow event that breaches riverbanks. These flows can drastically restructure the channel and flood plain, recharge groundwater tables, deliver nutrients to riparian vegetation and connect the channel with flood plain habitats that provide additional food for aquatic organisms.”

This program aptly points out that under today’s norm, *…instream flow science promotes the inclusion of one or more of these flows in an instream flow study*. When all the flow ranges are combined, they are referred to as a flow regime (Figure 10).

Figure 10.

Daily stream flow hydrograph with base flows, subsistence flows, high flow pulses and overbank flows. (Source: National Research Council 2005)



International Studies on Flow Variability

Examples of IFN studies that are grounded on natural flow variability are readily available from around the world. In South Africa, the "Building Block Methodology" (King and Louw 1998; King et al. 2000) and the more recent variant, Downstream Response to Imposed Flow Transformation, or "DRIFT" (Brown and King 2000), are holistic approaches that address all biophysical aspects of rivers and are based on natural flow variability. The DRIFT approach has been carried out on numerous rivers in several basins in South Africa (Arthington et al. 2003; Brown and King 2002; King et al. 2003).

Similarly, in the Pioneer River in Australia, the "Benchmarking Methodology" is a "top-down" approach that involves identifying key hydrological indicators that have geomorphological or ecological relevance. For each of these indicators, the implications of different levels of departure from its natural flow value are described (Brizga 2001). Similar approaches have been used in other parts of Western Australia (Arthington et al. 2004) and the United Kingdom (Petts and Maddock 1996).

In Alberta, the studies on the Highwood River (Clipperton et al. 2002), the Red Deer, Bow, Oldman, Waterton, Belly, St. Mary, and South Saskatchewan Rivers (Clipperton et al. 2003) accounted for natural flow variability and used the natural flow as a benchmark condition. In other parts of Canada and throughout the United States, many studies have been completed recently of locations where restoration of some component(s) of natural flow regimes has occurred or been proposed for specific ecological benefits. Annear et al. (2004) listed 16 studies carried out in North America where the goal was to restore various components of the natural flow regime. The list is growing. More recently, the Nature Conservancy (2005) has compiled a global database that describes efforts to restore river flow conditions to benefit river ecosystem health. The database lists 855 rivers in 53 countries, of which thirteen of the rivers are in the province of Alberta.

Natural Flow – a Benchmark and Starting Point

While a wide variety of tools and approaches are used to define instream flow needs, the common thread among these studies is their use of the natural flow as a starting point or benchmark condition. Furthermore, the natural flow allows for a direct comparison of the flow variability and seasonality in the recommended instream flow regime to that of the natural flow regime. The approach used in Alberta, where detailed studies are carried out, can be referred to as a per cent-of-flow method. This approach determines the appropriate levels of allowable flow depletion by expressing it as a per cent reduction from natural flow while keeping in mind a stated objective (full protection of the aquatic ecosystem) for the river. The per cent-of-flow approach that preserves natural flow variability is discussed in detail in Section 2.1 of the main body of the report. In addition to the concept of "mimicking" the natural hydrograph when making an IFN determination, it is also common practice to include a "base flow" or low flow cut-off point. This is a flow that is considered to be a relatively low naturally occurring flow below which it is recommended there be no withdrawals.

Appendix B

Hydrological Data

Appendix B - Hydrological Data

The instream flow needs (IFN) method requires naturalized flow data that is summarized in either monthly or weekly duration curve format. In many circumstances, flow data can be obtained from a discharge record collected at an accredited stream gauging station, with a length of record adequately capturing both inter and intra-annual variability of the stream or river (that is, magnitude, duration and frequency of flows). However, there are often situations where there are insufficient stream gauging stations and data readily available for use, and flow records may have to be synthesized in order to compute IFN recommendations using this method.

The following provides background and describes standards and processes that should be considered when using this method, specifically in addressing:

- Data quality and standards;
- Calculation of natural flows;
- Sources of data;
- Use of hydrographs and exceedance plots; and
- Development of synthetic datasets and regional hydrological analyses.

1.0 Data Quality and Standards

Canada's hydrometric program provides for the collection, interpretation, and dissemination of surface water quantity data and information. The program is carried out through cost-sharing agreements signed under the *Canada Water Act* in 1975 between Environment Canada, the provinces and Indian and Northern Affairs representing the territories. Under the agreements, the federal government publishes the data that have been collected according to national standards to the national HYDAT database.

All data that are part of the hydrometric program must be collected to conform to national standards so that data from across the country are comparable, compatible and of sufficient accuracy. In Canada, the national standards are established and documented by the Water Survey of Canada, part of the Meteorological Service of Canada (for details on standards, see http://www.wsc.ec.gc.ca/CDP/index_table_num.htm).

All available discharge data should be included in the analysis, whether the data is continuous or discontinuous over its length. Depending on the integrity of the dataset in things such as continuity, instrumentation, age of records, short discharge records may not accurately reflect the hydrology of the river reach. In circumstances where hydrological records are of short duration or have seasonal, annual or decadal gaps (that is, historical high/low flow periods are known to be missing from the record; stations operational for eight months of the year), the data can be brought up to accepted standards by infilling with discharge data from nearby stations or void-filled using base flow interpolation methods (World Meteorological Organization (WMO) 1994).

2.0 Calculation of Natural Flows

Recorded flows are the “actual data” collected at a stream gauging station. Natural flows are defined as the rate or quantity of water moving past a specified point on a natural stream/river from a drainage area where there are no effects from stream diversion, storage, power production, import, export, return flow, or change in consumptive use caused by land use activities. The process by which these effects are eliminated or corrected for instream flow data sets is referred to as “naturalization”.

Where no regulation occurs and water diversion is low, recorded flows can be a suitable approximation of natural flow for a given river or stream, for example, rivers in the mountains or northern parts of the province. However, in rivers that are regulated, especially in southern parts of Alberta, streams are highly affected by disturbances such as water diversions for irrigation and agriculture, municipal and industrial activities, reservoirs and storage, and power generation. In such locations, the volumes of water diverted or stored can be substantial, so the magnitude and distribution of discharges recorded are significantly different than what would have occurred naturally – both on a seasonal and annual basis.

Data requirements for the calculation of natural flows typically include:

- Recorded daily stream flow data;
- Precipitation data;
- Evaporation data;
- Water use data (diversions and return flows);
- Reservoir data;
- Land-use information; and
- Routed daily stream flow data.

General discussion on flow naturalization in Alberta, as well as a detailed description of calculations procedures, data quality issues, analysis techniques, and methods to compare and extend records of short duration can be found in two key documents; *South Saskatchewan River Basin historical weekly natural flows 1912 to 1995: Main report,* (Alberta Environmental Protection 1998) and, *Natural Flow Study, North Saskatchewan River, Alberta* (Alberta Environment 2005).

3.0 Sources of Data

The primary sources of stream flow data in Alberta are:

- the Water Survey of Canada (http://www.wsc.ec.gc.ca/); and
- the Alberta Water Information Centre http://www3.gov.ab.ca/env/water/water_information_centre.cfm).

However, in some situations industry associations, urban centres, municipalities, academic researchers, and universities may also possess high quality flow data that is suitable for use. Prior to use of stream flow data from accredited sources, such as the Water Survey of Canada, the data quality and standards associated with the flow observations should be clearly understood.

Where flow naturalization is required, a wide variety of data sources are used to correct the flow record. Table 4 summarizes the various types of data required for flow naturalization, as well as the data providers. The list of data providers shown in the table is not exhaustive and the data providers, especially pertaining to historical water-use data and reservoir data, will vary throughout the province. For example, a study by Alberta Environmental Protection (1998) required data from Atmospheric Environment Services (climate data), Water Survey of Canada (hydrometric data), Alberta Agriculture (water use and area of land irrigated), Prairie Farm Rehabilitation Administration (drainage basin areas), and TransAlta Utilities Ltd (reservoir data) to naturalize stream flow records in the South Saskatchewan River Basin.

Table 4.

Sources of data for flow naturalization.

Data type	Data Provider
▸ Recorded daily stream flow data ▸ Lake/reservoir data ▸ Drainage basin areas	▸ Water Survey of Canada ▸ Alberta Water Information Centre
▸ Precipitation data ▸ Evaporation data	▸ Meteorological Service of Canada/ Atmospheric Environment Services
▸ Historical water use data by sector (for example, irrigation, thermal power production, municipal, industrial)	▸ Alberta Environment

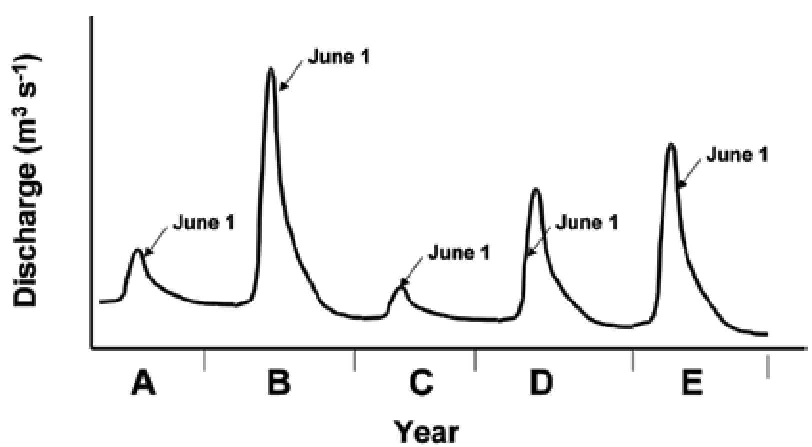
4.0 Use of Hydrographs and Exceedance Plots

The traditional format for displaying and outputting hydrology data using this method are hydrographs and flow exceedance curves. Hydrographs (Figure 11) illustrate the graphical relationship of discharge with respect to time, as well as characteristics of the hydrologic regime in streams and rivers (precipitation, evaporation, soil moisture storage, groundwater, and runoff). Exceedance plots (Figure 12) illustrate the relationship of stream or river discharge expressed as a percentage of time a given discharge is equalled or exceeded.

When making an instream flow recommendation using this method, the best time step is on a weekly basis. In those situations where it is possible to generate weekly flow exceedance curves, the annual hydrograph is generated, as well as weekly exceedance plots (52 weeks in total for a 12-month stream flow station). Where data is only available in monthly intervals, a simple linear interpolation method is used to generate weekly discharges.

Figure 11.

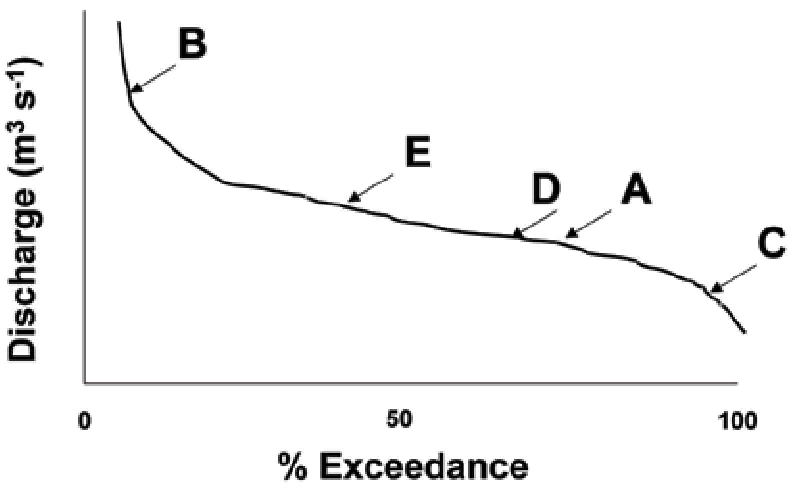
Hydrograph showing the graphical relationship of discharge with respect to time.



4.0 Use of Hydrographs and Exceedance Plots (continued)

Figure 12.

Exceedance plot showing the relationship of discharge expressed as a percentage of time a given discharge is exceeded (that is, recurrence interval).



5.0 Development of Synthetic Datasets and Regional Hydrological Analyses

In many situations, historical flow records are not available for a particular stream or river. There are a number of strategies for estimating natural flows where hydrological data do not exist. They range from simple scaling and extrapolation techniques that transfer stream flow observations from gauged to ungauged locations, to the more complex regional hydrological analyses undertaken using hydrological models. Undertaking such analysis is resource intensive and requires extensive technical expertise. Alberta Environment (1998) and WMO (1994) highlight typical expectations for regional analyses, hydrological modelling, and extrapolation/interpolation techniques.

Appendix C

Details of Studies

Appendix C - Details of Studies

This appendix contains information on relevant international and Canadian studies.

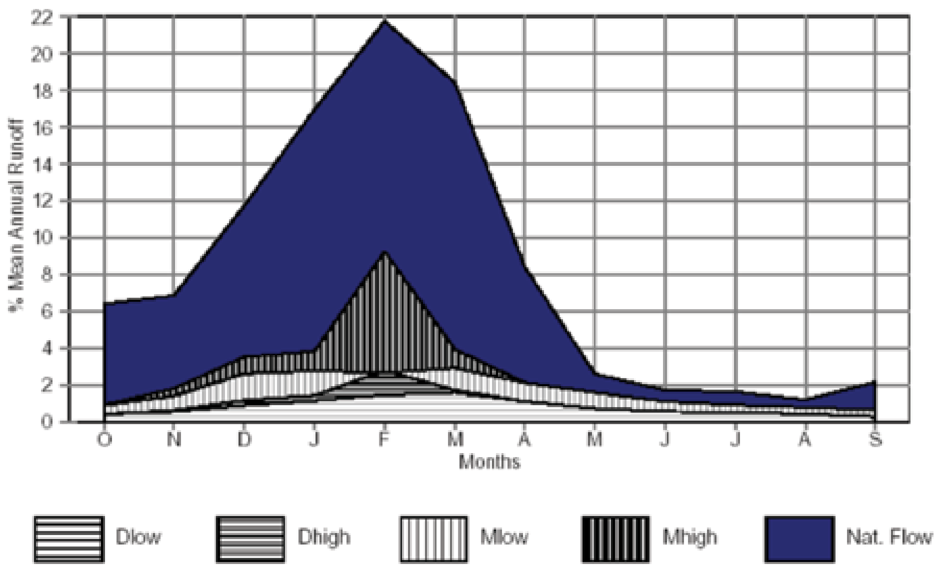
1.0 International

1.1 South Africa

The South African Building Block Method (BBM) is a bottom-up process based on maintaining the inter-and intra-annual flow variation within a river system. It recognizes that river ecosystems are made up of the basic elements (building blocks) of the flow regime, which include: low flows that provide minimum habitat for indigenous species; medium flows that provide for sediment transport and cues for fish migration; and higher flows or floods that maintain channel structure and allow for connectivity to flood plains. These flows can be identified and described in terms of their timing, duration, frequency, and magnitude. The flow components, or building blocks, are combined to describe the instream flow requirement (IFR). The IFR is the seasonal distributions of low and high flows for river maintenance and the IFR differs for a normal-flow year and a dry or drought-flow year. The seasonal distributions form the "building blocks" for the river as illustrated in Figure 13.

Figure 13.

Example of the monthly flow distributions of the natural flow (Nat. Flow), drought low and high-flow (Dlow, Dhigh) and maintenance low- and high-flow (Mlow, Mhigh) for the Mkomazi River, South Africa, derived using the BBM.



(Source: Hughes 1999).

The BBM is based on field investigations across a wide range of river systems, including artificial manipulations of low flow regimes below naturally occurring levels. The experimental flow reductions were set well below what any of the reaches had experienced historically. During these low flow treatments, hydraulic habitats, macroinvertebrates, geomorphology, water quality, etc., were monitored (Tharme and King, 1998). Even though there are quantitative assessments of riverine components and ecological responses, the methodology is primarily driven by a stakeholder process, in which the “acceptable levels” of various flow components are reached by consensus. The original BBM, and the more current Downstream Response to Imposed Flow Transformation (DRIFT), combines field data with expert opinion to assess a number of flow scenarios. The flows are altered relative to the current flow condition and for each alternative a severity rating is given for each of the flow regimes. One flow scenario that is usually selected is one termed the minimum degradation scenario. The minimum degradation scenario is when maintenance of the river in a state similar to the current condition is the main objective. Only water in excess of that required to attain this condition would be available for diversion. While the hydrological conditions assumed for this scenario would result in ecological changes, in the opinion of the experts, none of them is considered likely to affect the long-term viability or sustainability of the riverine ecosystems as they currently exist.

To evaluate each scenario, a number of flow condition or components are set, one being the “dry-season low flows” (Brown and King 2000). A specific example on the Senqu River in the Lesotho Highlands indicates that the dry-season low-flow ranges at the most downstream site, IFR Site 6, could be reduced from 0.90–to–120.00 cms to 0.90–70.00 cms. So, while the upper limit of flows that define the dry season can be reduced, the lower limit is not reduced (Metsi Consultants 2002; King et al. 2000). It is indicated that the flows are considered to be realistic in that this reach is below water regulation structures and stored water can be used to meet the low-flow recommendation. A similar approach was used for the Breede River where the natural “dry-season low flows” are 0.1–16.0 cms and one reduction level considered was 0.1– 9.0 cms. The high end of the range can be lowered, but the low end of the range is not changed (Brown and King 2002). In the Lesotho Highlands region, Arthington et al. (2003) report a minimum fish-passage requirement based on individual species. These fixed-flow values can be translated into a natural per cent-exceedance value for any given time step.

The BBM or DRIFT recognizes there is a very low, or critical minimum flow, below which discharges should never be reduced. However, the work did not specify a single process by which it might be determined. The work notes that on a month-by-month basis, three hydrologic indices are routinely used at the international level to identify flow magnitudes that had merit for delineating the approximate discharge range below which flow reductions likely have unnatural impacts. These indices are the Q90 and the Q95 (respectively, the river flow which is equalled or exceeded 90 per cent and 95 per cent of the time) values from one-day flow duration curves and the seven-day consecutive low flow (Tharme and King 1998).

1.2 Australia

Queensland has developed an approach to set environmental flow objectives that relies on key flow indicators that are benchmarked against “acceptable” levels of departure from natural flow conditions. This is undertaken within an established risk-assessment framework involving stakeholders and experts. The approach recognizes the ecological functions of various aspects of the natural flow regime and includes an EBF. For the EBF, what are referred to as Level 1 and Level 2 risk categories are set to indicate flow characteristics that depart from natural conditions. Lowering flows beyond these levels would result in a higher likelihood of major or very major impacts to ecological conditions.

For the Pioneer River, a system for assessing flow scenarios was developed using hydrologic indicators. Key flow indicators were proposed to address low flows: the daily exceedance duration of 10 cm and 30 cm depth flows; change in the daily exceedance duration of monthly indicator flows (natural 50 per cent, 80 per cent and 90 per cent daily exceedance duration); and the length/frequency of spells less than 10 cm and 30 cm (Brizga 2001).

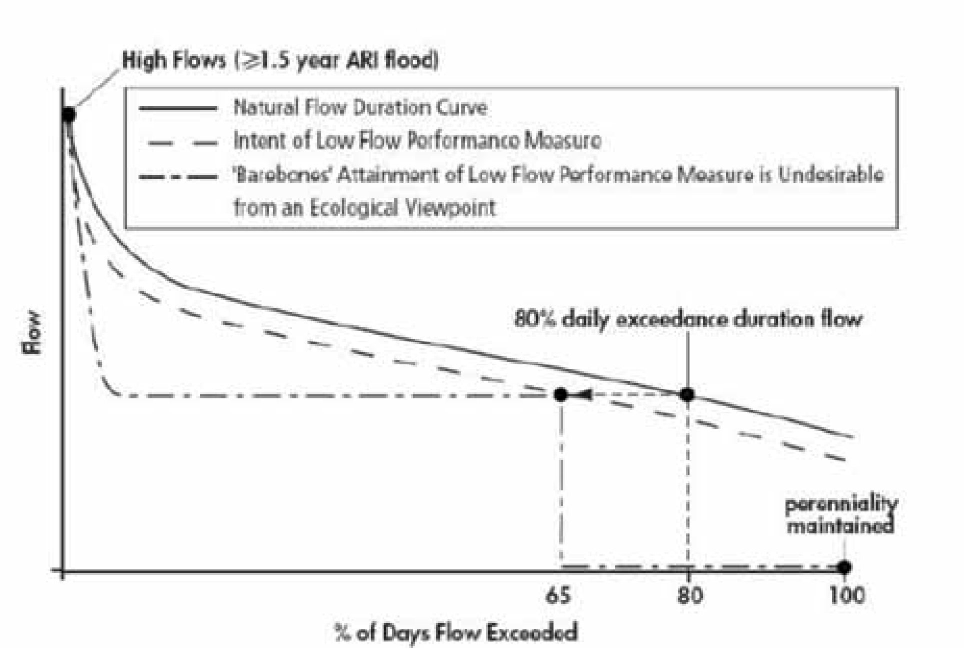
The system was built on the basis of information from an application in Australia of the South African Building Block Methodology as well as further investigations. A 10 cm depth of flow over riffles (gravel substrate) and glides (sand substrate) was identified as being indicative of flow levels associated with the normal functioning of these hydraulic habitat types. From these investigations, it was concluded that a 10 cm depth of flow over riffles (gravel substrate) and glides (sand substrate) is typically associated with low flow conditions in smaller streams, and very low flow conditions in larger rivers. The other metrics investigated were the monthly indicator flows based on the 50 per cent, 80 per cent, and 90 per cent natural daily exceedance duration values, which typically cover a range of low to medium flows (Brizga 2001). It was concluded that unlike the 10 cm and 30 cm flow metrics, which differ in their significance depending on size and type of river, an indicator based on natural daily exceedance duration flows is scaled to the river or stream in question. It was concluded they are not directly related to hydraulic characteristics and are not as easily interpreted from an ecological viewpoint as the 10 cm and 30 cm flow metrics.

For this project, the investigators gave a higher priority to the daily exceedance duration of indicator flows based on natural daily exceedance durations than to the daily exceedance duration of 10 cm and 30 cm depth flows. The indicator flow approach is applied on a monthly basis, taking into account seasonal variability that is masked by the application of the 10 cm and 30 cm depth flows to the year as a whole. The final recommendation proposed that changes in low-flow regime be assessed in terms of two complementary measures: daily exceedance duration and dry spell length/frequency (Brizga 2001). To meet the objective of a Level 1 impact (defined as the level above which assessed sites are more likely to have no or minor water resource development impacts on geomorphological and/or ecological conditions), the daily exceedance durations of monthly indicator flows (50 per cent, 80 per cent, and 90 per cent natural daily exceedance durations) could be reduced 10 per cent from natural flows. This sets the ecosystem base flow for the Level 1 ecosystem objective.

It should be pointed out that based on the level of uncertainty inherent with the researchers’ ecological-risk assessment, they recommend setting conservative environmental flow objectives. No fixed formulae are applied; the risk-assessment framework and specification of key flow indices basically rely on professional judgement in establishing the corresponding thresholds of key flow indicators. Figure 14, illustrates the basic concept of how the low-flow indicators are applied based on an 80 per cent daily exceedance duration flow.

Figure 14.

Example of determining an EBF.



(Source: Brizga 2001).

The benchmarking approach has been used on the Burnett River (Brizga 2000) and is viewed as a good approach to be used elsewhere in Australia, provided appropriate study is undertaken to validate the metrics (Arthington and Pusey 2003). Others have proposed the Flow Events Method (Stewardson and Gippel 2003) for the Snowy River in southeast Australia. The approach is to develop environmental flow regimes by defining geomorphic and biological processes that are affected by flow variability. One component in setting the environmental flow regime is to set a minimum flow for each month. Using site-specific information, the minimum is set and falls in the 50–99 per cent flow exceedance range.

In general, the EBF developed from the "top-down" approach, using benchmarking to a reference site, requires site-specific knowledge and expertise for each riverine discipline. While the goal of the method is to set an EBF, it is acknowledged that,

> *It would be a relatively straightforward task to specify critical levels of flow regime change if it were possible to define a simple environmental threshold or 'ecological edge' above which there is minimal impact, and below which there is major impact. In reality, the situation is generally more complicated. (Brizga 2001).*

The benchmarking approach sets an EBF that is tied to an acceptable departure from the natural flow regime (that is, +/- 10-to-20 per cent of the 50, 80, and 90 per cent daily exceedance flows).

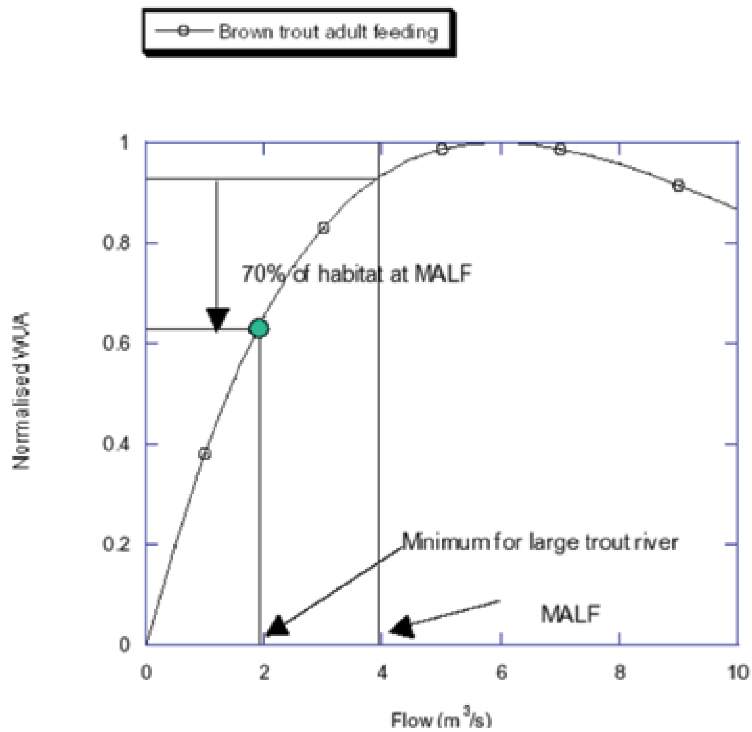
1.3 New Zealand

For the Environment Southland draft Regional Water Plan in New Zealand, Jowett and Hayes (2004) suggested levels of habitat maintenance could be based on retaining a percentage of the habitat at the mean annual low flow (MALF) based on the value and significance of the instream resource. The MALF is usually the arithmetic average of the seven-day annual minimum flows, calculated as a moving mean through each year. The seven-day average is not very different from the annual minimum daily flow. However, using the seven-day average helps to avoid erroneous "spikes" in the data (Ian Jowett, New Zealand National Institute of Water and Atmospheric Research Limited, personal communication). In those situations where the proposed amount of water abstraction is small (for example, less than 10 per cent of the MALF) and there are no data on stream morphology, it was recommended that the historical MALF could be used to set the minimum flow. The rationale for considering less than 10 per cent of MALF as a small abstraction arises because the change in flow variability and the amount of time at MALF would be small and the effects on stream biota not perceptible (Jowett and Hayes 2004). Since there are no site-specific flow-habitat data, the assumption is made that habitat is proportional to flow for flows less than the MALF. It was also noted that in those situations, a cautious approach to flow setting is required to maintain the amount of habitat provided by the MALF.

In those situations where habitat data are available, it is suggested that minimum flows should be based on retaining a percentage of the amount of habitat at MALF. For example, in those situations where the fishery quality is ranked as "high" for any particular critical value (perennial fishery, spawning life stages present, etc.), Jowett and Hayes (2004) suggest the habitat-retention factor could be set as high as 90 per cent of MALF. Figure 15 shows an example of how to calculate the minimum flow based on adult brown trout feeding data in a large river where the habitat-retention factor was set to 70 per cent. In using this approach, it is suggested that rivers should be classified according to river size, in terms of median flow, and that this classification should be related to critical ecological values. Once the minimum flow is set, the amount of water available for allocation is determined. This is the amount of water that can be taken out of the river when flows are greater than the minimum flow. No water should be taken out of the river once flows fall below the minimum flow.

Figure 15.

Calculation of minimum flow requirement for 70 per cent habitat retention based on the brown trout adult feeding life stage for a large trout river.



(Source: Jowett and Hayes 2004)

For the Waipara River in New Zealand, Jowett et al. (2005) found a relationship between reductions in fish abundances with the magnitude and duration of low flows. In particular, they found significant reductions in fish abundance with the year of lowest flow. They concluded that the effects of low flows on fish abundances were consistent with habitat requirements and indicate minimum flows based on habitat analyses could safeguard the fish community. In a previous study, Jowett (1994) determined minimum flows for the Waipara River based on the maintenance of fish habitat and passage. The selection criterion used was either the optimum of the flow versus habitat curve, or a change in slope on the curve where the quality of habitat began to decline more rapidly with flow. For one of the fish species studied, 0.12 $m^3 \cdot s^{-1}$ was the point where the amount of instream habitat began to decline rapidly as flows decreased. Jowett recommended abstraction of water should cease when flows were less than this. A flow value of 0.12 $m^3 \cdot s^{-1}$ is close to the natural normal summer flow in this part of the river. It is believed that setting a minimum flow based on the flow below which instream habitat begins to decline rapidly would be successful in maintaining most of the fish species in the river.

1.4 United Kingdom

One of the earliest studies that proposed an ecologically acceptable flow regime was in England and Wales in the case of chalk streams that had been affected by groundwater abstraction (Petts 1996). In addition to prescribing flood plain, channel maintenance, and optimum flows, a minimum or hands-off flow was determined. For the River Babingley, a minimum flow of 0.28 $m^3 \bullet s^{-1}$ was set to protect adult trout in summer and autumn-spawning habitat. The flow value of 0.28 $m^3 \bullet s^{-1}$ is the 87 per cent exceedance flow based on the 1977 to 1992 period of record. It should be noted the annual 87 per cent exceedance flow would be different than exceedance values for flows based on a weekly or monthly time step.

In October 2000, the European Parliament and the Council of the European Union established a Water Framework Directive (WFD) (Directive 2000/60/EC 2000) for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters, and groundwater (European Parliament and the Council of the European Union 2000). The goal was to ensure all aquatic ecosystems met good status by 2015. The WFD requires member states to establish river basin management plans. To meet this mandate, in the United Kingdom (U.K.) the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) developed updated water-resource regulatory standards. These standards deal with abstraction and impoundments for rivers and lakes throughout the U.K. based upon their ecological status.

Using consensus workshops, experts on macrophytes, macro-invertebrates, and fish, as well as more general experts in river and lake management from the Environment Agency of England and Wales, Scottish Environment Protection Agency, and the Heritage Service Northern Ireland set regulatory standards for each river water body type. With regard to rivers, the experts defined thresholds of flow alteration to ensure good ecological status (GES). The experts expressed concern that insufficient knowledge was available to define precise generic environmental standards. Therefore, they approached the definition of criteria and setting of thresholds from a precautionary approach. In general, the recommended thresholds were in the range of 10–20 per cent for per cent of flow reduction factors when flows were greater than the Q_{95}, and set an EBF or hands-off criterion at the Q_{95} (Acreman et al. 2006).

1.5 France

In France, the *Water Law* (1992) requires for all renewed hydro-projects, a minimum flow release of 1/10th of the mean annual flow. According to Sabaton et al. (2004), the increases in flow in several rivers resulted in increases in modelled habitat. Monitoring showed increases in trout biomass.

1.6 Norway

In Norway, studies have been carried out in west coast rivers inhabited by brown trout and Atlantic salmon where modelling of available habitats from extreme summer minimum flows to 30-year high flows showed critical minimum flow levels, below which habitat was drastically reduced (Heggenes et al. 1996). From these studies, it was concluded that low-flow conditions appeared to have much more serious effects on habitat suitability than normal high flows. The magnitude and duration of these low flows may be critical in their effects on the salmonid population dynamics. Their modelling showed the availability of habitat decreased drastically below a critical minimum flow. This underlines the importance of setting minimum flows in regulated rivers.

2.0 U.S.A.

2.1 Alaska

In Alaska, stream flow recommendations are based on a modification of the Tennant Method. The Alaska Department of Natural Resources (ADNR) and Alaska courts have accepted this approach as a valid instream flow analytical procedure. Tennant designed his method to afford users considerable flexibility in applying it and, when combined with use of additional available biologic and hydrologic data, allows recommendations to be calibrated and adjusted to fit different geographic regions, hydrologic cycles, or seasonal biologic needs (Annear et al. 2004).

To provide intra-annual flow variability, and the effect of these conditions on habitat quality, refined hydrologic summaries, such as monthly, weekly, or daily flow duration analyses are reviewed. If the final recommendation from the combined analysis differs from the original Tennant recommendation because of additional biologic or hydrologic information (that is, fish suitability data, flow duration records, etc.), an explanation for how the deviation differs is provided including how the adjustment provides better habitat suitability for fish utilization.

The distribution of mean daily flows in ice-affected Alaskan streams is often strongly skewed due to long periods of winter base flows, with most flow occurring during the three to six month open water season. In these instances, Tennant's recommended flow ratings can become a poor representation of seasonal stream flows. For example, observed mean daily flows for open water months often exceed QAA (average annual flow) by as much as 200 to 1,000 per cent. In such cases, flow duration and mean flow statistics pertinent to the time period in question (and when available), are evaluated to ensure flow recommendations account for flow variability expected to naturally occur and considered necessary to support fish and fish habitat needs. In general, monthly, weekly, or in highly variable systems, daily flow recommendations will be flows equalled or exceeded 70 - 30 per cent of the time during the period of interest. Flows within this range are normal hydrologic conditions and are expected to provide conditions and habitat to which fish have most likely adapted.

Life-stage specific periods of habitat use by fish species are used to further refine the flow recommendations, when data are available. For example, during periods of off-channel habitat use (for example, rearing salmonids in flood plain ponds and sloughs) flows near 30 per cent exceedance may be needed during high flow conditions (spring and fall) to provide access to and from these areas. Whereas lower flows may be adequate during periods when fish are predominantly using primary channel habitats. Off channel habitats become inundated only on a seasonal basis and flow duration estimates are used to identify when these flows occur.

Alaska also acknowledges the need for flows on a periodic basis for habitat and channel maintenance. Channel maintenance flows are flows up to bank full flow and higher, with bankfull flow generally defined as a flow with a return interval of one and a half to two years. The hydrologic record is analyzed to estimate the magnitude, duration, and timing of these flows using flow duration analyses.

2.2 California

In California, the Pacific Gas and Electric Company (PG&E) has a complex arrangement of storage reservoirs, tunnels, and powerhouses on the Mokelumne River in Central California. In the late 1990s, as part of Federal Energy Regulatory Commission project relicensing, PG&E, three federal agencies, three state agencies, four non-governmental organizations, and one water agency developed ecological and recreational stream flows for 16 reaches affected by the project. The participants used several analysis tools to develop the final stream-flow recommendations.

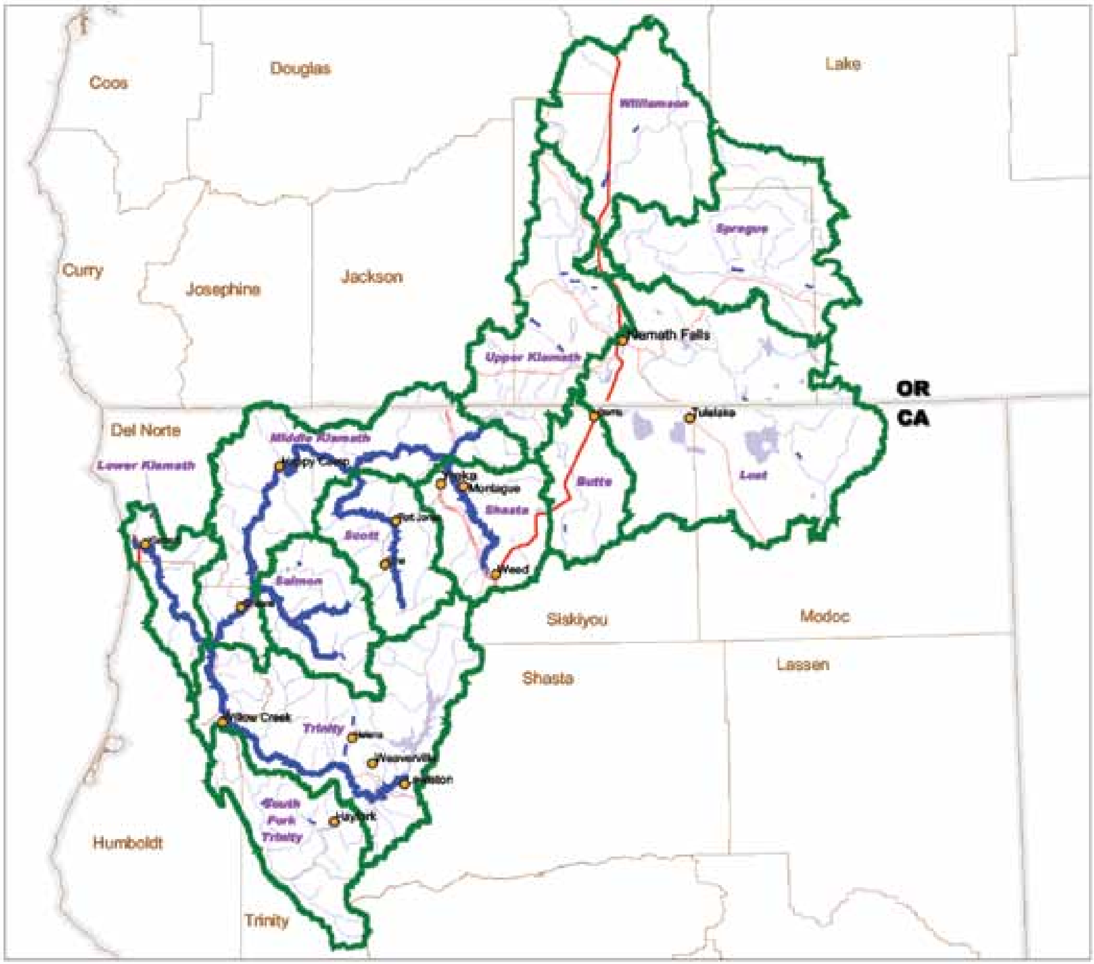
They addressed the requirements of the ecosystem by accounting for flow magnitude, duration, and timing of stream flows. Using professional opinion, they identified the most important issues for stream-flow management: minimum flows to sustain aquatic life, pulse flows to maintain the sediment budget, and adaptive management. They recognized that all of the tools used had limitations. When it was determined that a minimum flow was not producing the expected results, they would adjust the recommended stream flows (McGurk and Paulson 2002).

Minimum stream flows were developed by examining unimpaired daily stream flow data for each month in multiple years from each of the three water-year types (wet, average, dry). For example, October mean daily unimpaired stream flows at Lower Bear River Reservoir for water years 1974, 1980, and 1982–84 were deemed as being typical of wet water years. By cross-referencing with daily precipitation records to identify 5-to-15-day periods without rainfall, a minimum unimpaired stream flow of six cfs was identified (Pacific Gas and Electric 2000). This value was selected as the recommended minimum stream flow not because it was the lowest value in the unimpaired record across a number of years, but because it was frequently observed as the base-flow value that typically occurred. The use of mean or median values from all the days in the month over the period of record was not considered an appropriate technique for identifying base flows, because it included stream flow responses due to storms. Including these unlikely events would not give an accurate representation of base-flow conditions (Bruce McGurk, Pacific Gas and Electrical Company, personal communication, 2005). It is not known what the corresponding natural per cent exceedance value is for six cfs in this reach.

The Klamath River has been subject to intensive study over the past several decades (Figure 16). The impetus for these studies was the passage of the 1986 *Klamath River Basin Restoration Act*. For the Bureau of Reclamation's Klamath Project, there was the requirement to develop annual and longer-term operations plans in anticipation of the listing or proposed listings of Klamath River Basin anadromous fish. The revised interim instream-flow recommendations were made to maximize the potential to meet recovery and sustainability of the anadromous species and other aquatic resources within the main stem Klamath River between Iron Gate and the estuary (Hardy and Addley, 2001). Flow recommendations were developed for the 10-to-90 per cent exceedance range (that is, nine water-year types, see Figure 17). This was very similar to and an expansion of the five water-year type approach of critically dry, dry, average, wet, and extremely wet that was used in the Trinity River. (U.S. Department of the Interior 2000)

Figure 16.

Klamath and Trinity River Basins.



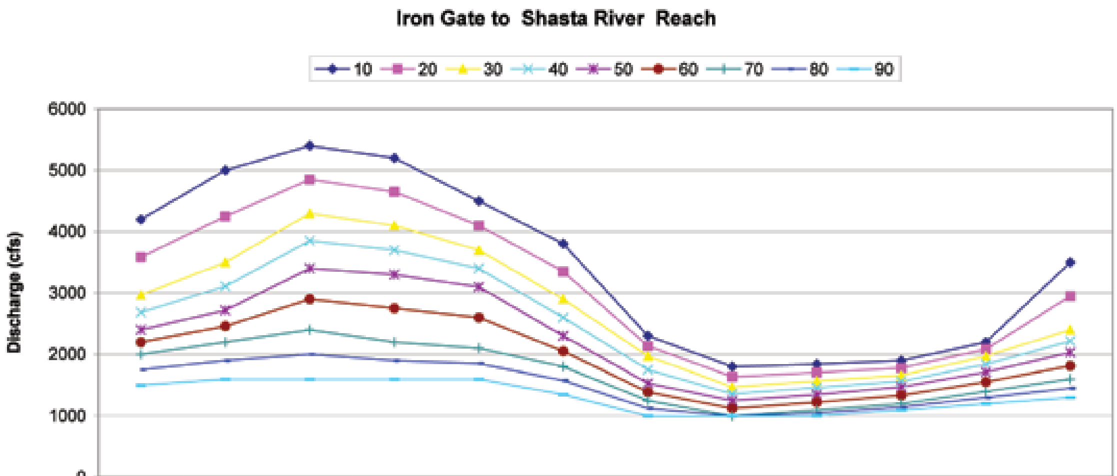
(Source: Hardy and Addley 2001).

Based on water quality considerations, temperature, and physical habitat for fish, an ecosystem base flow of 1,000 cfs has been set during the low flow season (July through September). When the natural inflow to the Iron Gate Reservoir is 1,000 cfs, the release from the Iron Gate dam is 1,000 cfs. During critically dry years when natural inflows to the Iron Gate Reservoir fall below 1,000 cfs, the release from the Iron Gate Dam is equal to the natural inflow (Thom Hardy, Utah State University, personal communication).

2.2 California (continued)

Figure 17.

Recommended monthly instream flows below Iron Gate Dam at each exceedance flow level.



	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10	4200	5000	5400	5200	4500	3800	2300	1800	1840	1900	2200	3500
20	3585	4250	4850	4650	4100	3350	2135	1635	1705	1780	2085	2950
30	2970	3500	4300	4100	3700	2900	1970	1470	1570	1660	1970	2400
40	2685	3110	3850	3700	3400	2600	1750	1360	1460	1565	1840	2215
50	2400	2720	3400	3300	3100	2300	1530	1250	1350	1470	1710	2030
60	2200	2460	2900	2750	2600	2050	1390	1125	1225	1335	1555	1815
70	2000	2200	2400	2200	2100	1800	1250	1000	1100	1200	1400	1600
80	1750	1900	2000	1900	1850	1575	1125	1000	1050	1150	1300	1450
90	1500	1600	1600	1600	1600	1350	1000	1000	1000	1100	1200	1300

(Source: Hardy and Addley 2001).

The work on the Klamath River continued from this original effort and more recently the study team adapted the recommendations provided in the National Research Council (2005) report to specifically target the following components of the flow regime when considering instream flow recommendations: overbank flows, high flow pulses, base flows, subsistence flows and ecological base flows (Hardy et al. 2006). The outcome of the work was a continuum of flow recommendations over the entire flow range for each month (See Table 5).

Table 5.

Instream flow recommendations for the Klamath River below Iron Gate Dam.

Iron Gate IFR: Average b/w Flow and Habitat Based Flow												
% Exceedence	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
5	1735	2460	3385	3990	4475	4460	4790	3845	3185	2215	1560	1565
10	1715	2415	3280	3835	4285	4355	4585	3710	3055	2140	1540	1545
15	1700	2365	3205	3795	4210	4285	4425	3615	2975	2075	1495	1515
20	1680	2315	3120	3705	4215	4160	4230	3480	2850	2000	1405	1490
25	1660	2260	3015	3645	4080	3990	4065	3390	2755	1925	1375	1465
30	1645	2220	2945	3510	3925	3940	3930	3225	2660	1830	1335	1430
35	1635	2160	2870	3405	3660	3860	3705	3115	2540	1740	1305	1405
40	1625	2110	2800	3215	3435	3685	3485	2960	2455	1635	1255	1370
45	1575	2060	2690	3015	3220	3585	3245	2815	2340	1515	1215	1335
50	1565	2000	2545	2820	3015	3380	3030	2675	2225	1330	1170	1305
55	1545	1935	2385	2630	2810	3150	2815	2510	2070	1265	1105	1275
60	1525	1875	2235	2420	2565	2910	2590	2385	1980	1205	1055	1235
65	1510	1830	2090	2210	2335	2630	2405	2165	1840	1135	1020	1195
70	1490	1775	1950	2015	2135	2350	2260	2050	1635	1070	1005	1160
75	1470	1710	1815	1825	1950	2050	2045	1905	1465	1015	975	1120
80	1450	1670	1650	1620	1770	1835	1940	1690	1320	945	935	1080
85	1430	1600	1520	1460	1615	1585	1740	1415	1160	905	910	1045
90	1415	1545	1380	1245	1485	1410	1530	1220	1080	840	895	1010
95	1395	1500	1260	1130	1415	1275	1325	1175	1025	805	880	970

Source: (Hardy et al. 2006).

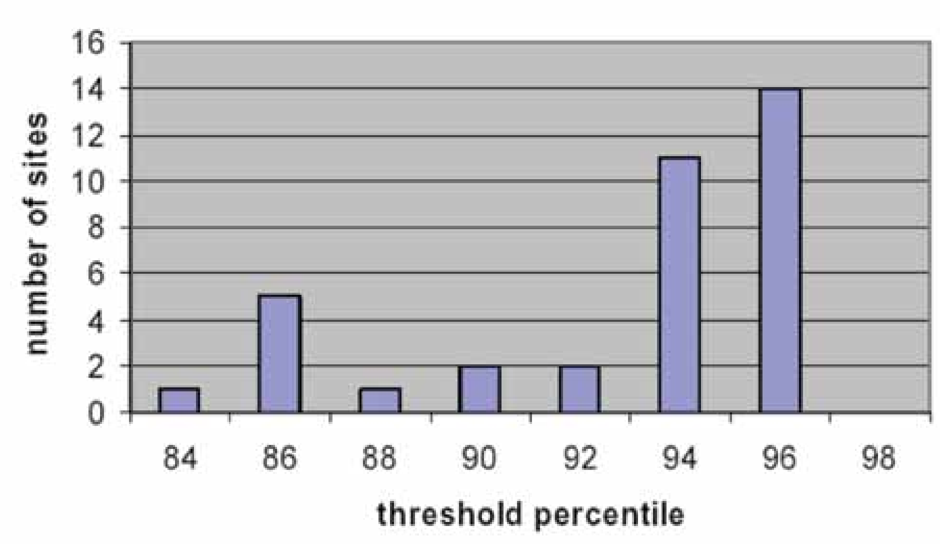
With respect to the EBF, Hardy et al. (2006) explicitly addressed this flow component. They defined the EBF as the *…flow at which further human induced reductions in flow would result in unacceptable levels of risk to the health of the aquatic resources*. They acknowledged that even though the concept of an EBF is understood and widely accepted by instream flow practitioners, *…no systematic quantitative research has been undertaken to define what an EBF would be for particular river systems and their unique flow dependent resources.* In developing the EBF, Hardy et al. (2006) thoroughly reviewed protocols developed in Australia, South Africa, and the United Kingdom (see previous sections). In addition to those reviews, in developing an EBF, they drew upon a project – Rapid Assessment of Physical Habitat Sensitivity to Abstraction (RAPHSA) – currently under way between the Centre for Ecology & Hydrology and Environment Agency in the U.K., and Utah State University.

The RAPHSA database contains 65 river sites where detailed hydraulic data have been collected for the purposes of carrying out detailed habitat modelling, such as PHABSIM. Each site was analyzed to identify thresholds, or break points, in the relationship between river width and flow using habitat-duration curves. For 36 sites, threshold points were identified. For the other sites, the relationship took the form of a smooth curve with no obvious break point. The range of break points is shown in Figure 18. For one site, the value is Q_{84} while the modal value is around Q_{95} with a mean of Q_{92}. Acreman et al. (2006) reported that no obvious relationship was found between threshold level and river site type.

2.2 California (continued)

Figure 18.

Distribution of thresholds in the relationship between flow and width at RAPHSA sites.



(Source: Acreman et al. 2006).

From their analysis, Acreman et al. (2006) concluded the "Q_{95} marks a significant point where below which conditions in the river change rapidly and hence the river is more sensitive to flow change." They therefore concluded this provides justification for setting the EBF, or hands-off flow, at Q_{95}. For the Klamath River, Hardy et al. (2006) adopted the recommendation of the RAPHSA work in the U.K. to set an Ecological Base Flow that is equivalent to the monthly 95 per cent exceedance level.

2.3 Colorado

The goal of a study carried out on the Yampa River in Colorado was to define the base- flow needs of endangered fish populations. The approach to defining flow needs was to identify the relationship of habitat availability to discharge and relate availability to habitat use by endangered fishes (Modde et al. 1999). The investigators used three techniques:

(1) Identify the greatest rate of change in stream morphology as flows decline (that is, curve break analysis), determining the flow at which there is the greatest decline in major features of the channel (that is, wetted perimeter);

(2) estimate of available habitat based on suitability curves; and

(3) define barriers to fish passage, (that is, the lowest flow required for fish passage over riffle depth).

Specifically, the curve break analysis was used to define the flow below which the greatest loss in habitat availability occurred for each mesohabitat type. The curve break indicated the specific flow at which a given habitat variable (for example, width, depth, etc.) declined at the greatest rate per mesohabitat type. Modde et al. (1999) determined the mean curve break flow for riffles to be 93 cfs. They suggested that base flow management for endangered fishes in the Yampa River below Craig, Colorado should target 93 cfs.

The authors noted from the historic record that flows less than 93 cfs have been recorded. They concluded that since flows have dropped below 93 cfs during the period of record and endangered fishes are extant in the Yampa River, it seems logical that 93 cfs is not a threshold flow. Flows less than 93 cfs will not reduce endangered fish populations, as long as the flow pattern is similar to the historical frequency. Modde et al. (1999) concluded that flows below 93 cfs are near the threshold flow that may be limiting to productivity of aquatic invertebrates and other aquatic organisms dependent on viability of riffle habitats. They recommended a flow management plan not be restricted to achieving 93 cfs in 100 per cent of the years, but should include examining the frequency, magnitude, and duration of flow events under 93 cfs observed during the period of record (1916–1998). The corresponding natural monthly per cent exceedance values are for 93 cfs are not known.

2.4 Florida

The Southwest Florida Water Management District (SWFWMD), by virtue of its legislative mandate to protect water resources from “significant harm”, establishes minimum flows and levels (MFLs) for streams and rivers. Minimum flow levels are defined as *…the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area*. (Kelly et al. 2005a). The District developed minimum flow compliance standards that include prescribed seasonal flow reductions based on aquatic and wetland habitat availability, and low flow thresholds based on fish-passage depth and wetted-perimeter analysis. The low flow threshold is defined to be a flow where no withdrawals are permitted. For the middle segment of the Peace River, the low flow threshold was determined to be 67 cubic feet per second at the Arcadia gauge site and 45 cfs for the Zolfo Springs gauge site (Kelly et al. 2005a). The corresponding monthly exceedance values for the low-flow threshold flow value of 67 cfs are presented in Table 6.

Table 6.

Monthly low flow threshold natural per cent exceedance values for the Arcadia gauge site on the Middle Segment of the Peace River in Florida.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% Exceedance	*	99	98	96	92	99	*	*	*	*	99	99

* No data available.
(Source: Adam Munson, Southwest Florida Water Management District, personal communication.)

Flow prescriptions using the same approach, including a low-flow threshold, have been made for the upper segment of the Peace River (Southwest Florida Water Management District 2002), the Alafia River (Kelly et al. 2005b), and the Myakka River (Kelly et al. 2005c). The Alafia, Upper and Middle Peace River reports were peer reviewed. For the Upper Peace River report, the peer reviewers believed the minimum flows were *…scientifically reasonable target values with defensible justification to support…connection of currently isolated stretches of river and to promote fish passage* (Gore et al. 2002). For the Middle Peace River report, the peer reviewers felt that the continued use of the 0.6 ft standard represents best available information and is reasonable and consistent with overall SWFWMD water allocation policy (Gore et al. 2005). They noted the fish passage depths were originally derived from requirements of migratory salmonids in cool, well-oxygenated waters and questioned the adequacy of these standards for use in Florida’s warm water streams. They suggested there is,

> *“…*[an] *emerging consensus that minimum depth criteria used in Florida need to be re-evaluated to ensure that they adequately prevent negative effects associated with low flows in warm water ecosystems, including high water temperatures, low dissolved oxygen, algal blooms and increased predatory pressure, in addition to mere physical passage of fish”. (Gore et al. 2005).*

The peer review panel recommended that research into fish-passage depths for warm water streams be carried out to develop fish-passage criteria more suitable for warm water aquatic ecosystems and that address other negative impacts of low flows.

2.5 Idaho

The Snake River Basin Adjudication (SRBA) is a water-rights adjudication of the Snake River within the State of Idaho (Snake River Basin Adjudication 2004). As a part of that adjudication, the Nez Perce Tribe and the federal government of the United States filed a variety of claims to water rights, based on treaties entered into between the United States and the Nez Perce Tribe. During the process, the State of Idaho and certain Idaho water users contested those claims. By order of the SRBA Court in 1998, the parties were instructed to enter into negotiations to resolve the instream flow water right claims by focusing on finding ways to protect fish habitat, while preserving existing water uses.

The claims for the Tribe included instream flow water rights, claims to support the Tribe's consumptive water needs, and claims to springs in the area ceded by the Tribe in 1863. The proposed settlement includes provisions resolving all of the issues relating to the Tribe's water right claims. After several years of negotiations, the parties developed a framework for a proposed settlement agreement. The proposed settlement agreement determined, among other things, the Tribal claims to water rights. For the Salmon/Clearwater Rivers component, the agreement provides benefits for species listed under the *Endangered Species Act* by improving instream flows, habitat, and passage. For some streams, the instream flows, held by the Idaho Water Resources Board, have a base-flow component to prevent de-watering of streams by future consumptive uses, for example, irrigation. These future consumptive uses would be curtailed at the unimpaired (natural) monthly 80 per cent exceedance flow (Cindy Robertson, Idaho Department of Fish and Game, personal communication).

2.6 Maryland, New York and Pennsylvania

The Susquehanna River Basin is situated in Maryland, New York, and Pennsylvania. The Susquehanna River Basin Commission (SRBC) has developed guidelines for using and determining passby flows, conservation releases, and consumptive-use compensation to help protect aquatic resources, competing users, and instream flow uses downstream from the point of withdrawal (Susquehanna River Basin Commission 2002). These requirements are also intended to prevent water quality degradation and adverse lowering of stream flow levels downstream from the point of withdrawal. According to the SRBC,

> *"A passby flow is a prescribed quantity of flow that must be allowed to pass a prescribed point downstream from a water supply intake at any time during which a withdrawal is occurring. When the natural flow is equal to, or less than, the prescribed passby flow, no water may be withdrawn from the water source, and the entire natural flow shall be allowed to pass the point of withdrawal."* (Susquehanna River Basin Commission 2002).

There are situations where passby flows are not required. However, for those instances where they are required, guidance for determining the appropriate passby flows are based upon different protection designations in accordance with the Pennsylvania Department of Environmental Protection regulations. Streams are divided into three categories:

(A) Exceptional value waters;

(B) High quality waters; and

(C) Cold-water fishery waters.

2.6 Maryland, New York and Pennsylvania (continued)

Each category has rate-of-withdrawal rules based on loss of habitat associated with reductions in flow. For example the passby flow for categories A and B, is 25 per cent of the average daily flow. For all streams, the passby flow is not less than the $7Q_{10}$ flow (that is, if the computed passby flow is less than the $7Q_{10}$ for the stream, then the $7Q_{10}$ is applied as the passby requirement). The $7Q_{10}$ is defined as the lowest average, consecutive seven-day flow that would occur with a frequency or recurrence interval of one in ten years.

2.7 Minnesota

A study was carried out for the Rainy River in Minnesota, (Figure 19) to provide water management recommendations to maintain and restore the river's health (O'Shea 2005). As part of the recommendation that maintains natural seasonal and annual variability, a flow is prescribed below which no additional water should be removed from the river. For the spring season (April–June), the flow was 12,000 cfs and for the remainder of the year the recommended ecosystem base flow was 7,000 cfs. Flow values in terms of monthly natural exceedance values were not reported.

Figure 19.

Location of Rainy River and Long Sault and Manitou rapids study sites.

(Source: O'Shea 2005)

2.8 Rhode Island

The Rhode Island Department of Environmental Management Office of Water Resources is the agency responsible for setting state standards for water quality and freshwater wetland protection. Integral to that was the need to define instream flow needs for, among other things, the protection and propagation of fish and wildlife. The Department developed a state-wide standard based on the following four main criteria:

(1) The reference streams selected to develop the standard should not be significantly influenced by current pumping or dams (regulation);

(2) The standard must be flexible (this means allowing for site-specific alternatives and that the standard may be applied to varying sized watersheds);

(3) The standard must recognize Rhode Island's hydrogeologic features; and

(4) The standard must be simple to apply (Richardson 2005).

A thorough review of standard-setting methods was conducted and found the results converged around the United States Fish and Wildlife Service aquatic base flow (USFWS ABF) default summer flow value of 0.5 ft^3sec^{-1} per mi^2 (Larsen, 1981). It was concluded to further investigate the USFWS ABF method. Using gauged stream-flow data from selected Rhode Island and nearby Connecticut and Massachusetts rivers, refinements were made to the USFWS ABF. This was done as it is known there are hydrogeologic and climatic dissimilarities between Rhode Island and the areas that were evaluated to develop the USFWS ABF method. Following a detailed and comprehensive analysis of hydrology, physiography, and geomorphology data from numerous gauges and sites throughout the state, the state was divided into two regions: the Coastal Lowlands and the Eastern Highlands. The Eastern Highlands have the greatest elevation, with resistant metamorphic and resistant igneous rocks, while the Coastal Lowlands are areas of low relief, sedimentary deposits, and deep stratified drift. The stream flow data from the two physiographic regions were evaluated and found to be statistically significantly different. From this analysis, the standard USFWS ABF single value of 0.5 ft^3sec^{-1} was adjusted to reflect the site-specific hydrology in Rhode Island. Secondly, to better reflect the natural flow regime that will protect aquatic life functions dependent on the natural flow regime, a monthly time step is used instead of an annual or seasonal time step. The monthly ecosystem base flow values for the two physiographic regions in Rhode Island are shown in Table 7.

Table 7.

Rhode Island – Aquatic Base Flow Monthly Instream Flow Values.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Eastern Highlands	0.65	1.18	1.65	1.94	2.15	2.76	2.85	1.82	0.82	0.4	0.34	0.32
Coastal Lowlands	0.66	1.24	1.8	2.23	2.45	2.79	3	2	1.17	0.64	0.54	0.53

(Source: Richardson 2005).

2.8 Rhode Island (continued)

This standard is designed to be protective of rivers and streams, and to provide a relatively simple approach to determining instream flow values below which no water withdrawals should be permitted. The guideline is only applied to those points in the stream where the upstream watershed is greater than 5 mi^2 and to those streams that have continuous flow throughout the year. Also, it is noted the standard is representative of natural flow in streams not currently significantly altered by withdrawals.

The intent of the standard is to protect the aquatic ecosystem. The Department advises any proponents that if they wish to carry out their own scientific study to develop site-specific instream flow needs values, the Department will consider such information on a case-by-case basis when reviewing a permit application.

2.9 Utah

A study was carried out for the Green River in Utah and Colorado, below the Flaming Gorge Dam. The goal of the study's recommendations is to provide the annual and seasonal flow and temperature patterns to enhance populations of endangered fishes. For this study, the following six objectives were developed:

(1) Provide appropriate conditions that allow gonad maturation and environmental cues for spawning movements and reproduction;

(2) Form low-velocity habitats for pre-spawning staging and post-spawning feeding and resting areas;

(3) Inundate flood plains and other off-channel habitats at the appropriate time and for an adequate duration to provide warm, food-rich environments for fish growth and conditioning and to provide river flood plain connections for the restoration of natural ecosystem processes;

(4) Restore and maintain the channel complexity and dynamics needed for the formation and maintenance of high-quality spawning, nursery, and adult habitats;

(5) Provide base flows that promote favourable conditions in low-velocity habitats during summer, autumn, and winter; and

(6) Minimize differences in water temperature between the Green River and Yampa River in Echo Park to prevent temperature shock and possible mortality to larval Colorado pikeminnow transported from the Yampa River and into the Green River during summer (Muth et al. 2000).

Part of the flow recommendation included a relatively low base flow that should be maintained for the summer through winter period (August through February). It was recommended the base flow releases from Flaming Gorge Dam should be based on the year's hydrologic condition. For Reach 2, the recommended annual mean base flows in dry years would range from 26–31 m3/s (900–1,100 cfs) and for Reach 3, they range from 38–72 m3 /s (1,300–2,600 cfs).

2.10 Vermont

In the State of Vermont, the Vermont Fish and Wildlife Department (VFWD) sets instream flow recommendations for all streams in the state where private operators need water for snow making at ski resorts. For new snow making operations, rules are set for maintaining flows for two time periods: October and November, and December through March. During October and November, an applicant may withdraw 50 per cent of the portion of the water between the February median flow and 1.4 cubic feet per second per square mile of watershed (cfsm), plus any portion of inflow in excess of 1.4 cfsm. During December through March, a value of 1.1 cfsm is used instead of 1.4 cfsm. Where site-specific gage data are not available, the Vermont statewide average February median flow (FMF) is used (0.8 cfsm) and flow data are subsequently collected so a site-specific value can later be used (Rod Wentworth, Vermont Fish and Wildlife Department, personal communication).

The rationale for the threshold numbers of 1.4 and 1.1 cfsm was based on an examination of hydrology, habitat-flow curves, and negotiation. For the October and November period, the VFWD set a goal to provide spawning fish with flows that were close to natural conditions. It was reasoned that since flows are often naturally higher when fish spawn than during subsequent incubation, a higher level of flow protection is warranted during October and November. Furthermore, the VFWD wanted to provide depths and velocities that the adults needed during the spawning season, to allow access to spawning areas that would then subsequently also be suitable incubation areas during the winter.

In addition to a fixed flow-value reduction factor, the VFWD set an ecosystem base flow below which no withdrawals could occur. It set the EBF at 0.8 cfsm, which is the state-wide average February Median Flow (FMF) (Vermont Fish and Wildlife Department 1995). Site-specific gage data, where available, are used to determine the FMF. The value of 0.8 cfsm is used where such data are lacking or inadequate. The VFWD selected the February median flow to assure that fish are not subjected to flow regimes that are more severe than the natural conditions to which they have become adapted. In Vermont, February is typically the winter month with the lowest stream flow. For the winter period, low flow conditions in February result in the most metabolic stress to aquatic organisms, due to ice impacts and the high physiological stress associated with over-wintering. The VFWD reasoned that over the long term, aquatic organisms have evolved to survive periodic adverse flow conditions without major population changes. It is known that the physiological condition of fish tends to weaken during the winter and more frequent low flow conditions are likely to increase stress. Low flows also contribute to creating harmful ice conditions. The VFWD concluded that since winter is known to be a period of substantial trout mortality, it made sense from a biological perspective to recommend a flow that does not deviate substantially from the flow regime occurring naturally during the lowest flow month (Wentworth 1997). This rationale is also supported by the U.S. Fish and Wildlife Service and is the basis for their use of the February median flow in its flow policy for New England.

2.11 Washington

For the Skagit River near Mt. Vernon (USGS Sta. #12-2005-00 at river mile 15.7) in Washington State monthly minimum flows were set based on extensive application of habitat models (for November and December a weekly time step was used). The specified flows, which range from 10,000 to 13,000 ft^3sec^{-1} throughout the year, were set to maintain the aquatic ecosystem that sustains fish, wildlife, and other environmental resources. A threshold to limit total withdrawals of water from the Lower Skagit River was developed to protect the aquatic ecosystem in the region (Washington Dept. of Ecology 2001). The recommended flow values were based on studies carried out on the lower main stem Skagit River and Skagit estuary. The corresponding natural monthly per cent exceedance values for the recommended minimum flows are not known.

3.0 Canada

3.1 British Columbia

Trout Creek in the Okanagan Region of British Columbia is a highly regulated river. Historical water use practices resulted in conflicts between the out-of-stream water users and the regulators who manage the fisheries. Studies were carried out to develop a water-use plan that protected fish and fish habitat, and ensured a secure water supply. To protect the natural minimum amount of fish habitat in the creek to which local fish populations have ecologically adapted, conservation flows were set based on a generalized model of habitat response to varying flow percentages of mean annual discharge for a wide range of streams in B.C. (Northwest Hydraulic Consultants 2005). It is believed that flows less than the conservation flows will result in an eventual significant reduction in available fish habitat and associated fish production. As shown in Table 8, during the low-flow months (October through March) the conservation flow is defined as 20 per cent of the mean annual discharge (MAD). From several studies carried out throughout British Columbia, it was determined that below 20 per cent MAD, there are changes to the depth and velocity character in riffles (Ron Ptolemy, British Columbia Ministry of Environment, personal communication). The goal is to maintain the depth and velocity profiles in riffles since they are the most productive areas of streams for spawning, fry rearing, and invertebrate production. It has also been determined that below 20 per cent MAD in winter, there is greater chance of freezing eggs that are incubating and reducing food production by eliminating invertebrates. As also shown in Table 8, the per cent of MAD factors that describe the monthly conservation flow increase during the higher-flow months are based on criteria regarding other stream attributes such as fish passage, spawning, fry rearing, riparian vegetation, and channel maintenance. The corresponding monthly per cent exceedance values for the conservation flows are presented in Table 8.

Table 8.

Trout Creek conservation flows at point of diversion expressed as a naturalized monthly exceedance value.

Month	Conservation Flow			
	% MAD	CF	% Exceedance	Criteria
January	20	0.54	84	Over-wintering
February	20	0.54	85	Over-wintering
March	20	0.54	90	Over-wintering
April	100	2.7	64	Rainbow trout -passage/spawning
May	200	5.4	90	Channel maintenance
June	100	2.7	77	Riparian
July	30	1.08	83	Resident Rainbow trout rearing
August	23	0.81	65	Rearing
September	25	0.675	81	Kokanee passage/spawning
October	20	0.54	84	Rearing
November	20	0.54	88	Over-wintering
December	20	.54	84	Over-wintering
Average	**Median**		**84**	

Note: MAD = Mean Annual Discharge, CF = Conservation Flow
(Source: R. Ptolemy, British Columbia Ministry of Environment, Victoria).

For the Sooke River on Vancouver Island, a conservation flow of 10 per cent MAD was determined as the conservation flow in the low flow months. In general, the steeper the slope of the stream, the lower the per cent of MAD that is required for setting the conservation flow (Ron Ptolemy, British Columbia Ministry of Environment, personal communication). Monitoring of the conservation flow releases has been carried out and overall results indicate that flow releases are eliciting a positive response in the assemblage and abundance of aquatic invertebrates (Burt 2006). There is also some evidence suggesting there is an improvement in the performance of trout fry.

It should be noted the per cent of MAD factor for the conservation flow, in terms of weekly or monthly per cent exceedance values, varies considerably between different eco-regions in British Columbia. For example, for Carnation Creek, a small creek on the west coast of Vancouver Island near the town of Bamfield, the 20 per cent MAD value (0.163 m^3sec^{-1}) has a corresponding exceedance value of 18 per cent for the month of August. August is an extreme low-flow month. Typically flows as low as 7 $Lsec^{-1}$ (0.007 m^3sec^{-1}) can naturally occur. More frequent base flows that occur 80 per cent of the time are in the 20 $Lsec^{-1}$ (0.02 m^3sec^{-1}) range, or 2.5 per cent MAD. Carnation Creek is not renowned for trout production (steelhead or cutthroat) and this may be linked to the naturally occurring low base flows.

3.1 British Columbia (continued)

November is a month of higher flows when salmon are migrating into spawning areas to reproduce. The conservation flow for this month is based on optimal spawning /passage flows that are about 1.3 m^3sec^{-1} or 160 per cent MAD. The corresponding exceedance value for 1.3 m^3sec^{-1} for the month of November is 65 per cent. The hydrology of Carnation Creek is quite typical of small, coastal streams (rain-driven). The above analyses for Carnation Creek and Trout Creek clearly show the conservation flow exceedances will be different for snowmelt-driven streams in the interior of British Columbia, as it will for Alberta streams. (Ron Ptolemy, British Columbia Ministry of Environment, personal communication).

3.2 Alberta

In Banff National Park a recreation facility withdraws water from Forty Mile Creek for snowmaking. To set instream flow needs for the creek, field investigations were carried out to identify the types of aquatic habitat available and to determine their use by the resident fish community. The environmental assessment focused on the potential effects of water withdrawals on fish populations and aquatic habitats. For an impact to occur, the investigation assumed a link between the water withdrawal and influence on the fish. The link is through changes in physical characteristics of the stream that are related to fish habitat (that is, wetted perimeter, mean depth, cross-sectional area of pools). It was assumed that if there is no change to those characteristics, then there will be no effect on fish populations (Golder Associates 2002).

The goal of the study was to ensure water withdrawal did not adversely affect flow regimes or potential over-wintering fish habitat downstream of the water intake when flow values fall below critical levels. A critical threshold was identified, below which water withdrawals would be curtailed. The threshold was based on an understanding of historical monthly flows, real-time measurements of flow volumes upstream of the intake, and habitat investigations. Based on this study, the recommended minimum flow was set to the weekly 90 per cent exceedance flow. Withdrawal may not reduce the stream flow below the 90 per cent exceedance flow. Given the uncertainty in making the recommendation, it was stipulated that a stream-flow-monitoring program be carried out during the water-withdrawal period.

The technical team that carried out the study on the Highwood River believed that a constant per cent reduction from natural flows, if applied during periods when flows are naturally low, such as late summer or early fall, would likely result in significant negative impacts to habitat availability during those low-flow periods (Clipperton et al. 2002). The rationale provided by the Highwood River IFN technical team was based on the observation that in many east-slope streams in Alberta these low flow periods create potentially limiting habitat conditions, even under the natural flow regime. Based on this premise, the team believed a highly protective ecosystem IFN determination should not result in an increase in the frequency, duration or magnitude of naturally limiting habitat conditions.

The Highwood River IFN technical team looked at a variety of methods for determining the ecosystem base flow, some of which included:

- Assigning a per cent flow exceedance discharge for each week (for example, the 90 per cent flow exceedance discharge);
- The discharge corresponding with the 80 or 90 per cent habitat exceedance values for one of the guilds of fish species;
- The lowest discharge corresponding to the 80 per cent habitat exceedance value for the fish life stage with the highest flow requirement;
- The Tessmann calculation (Tessmann 1979; Wesche and Rechard 1980);
- One standard deviation below the mean annual discharge; and
- The discharge corresponding with one standard deviation below the mean annual habitat value (Clipperton et al. 2002).

The Highwood River IFN team chose a combination of methods to define the EBF. First, it chose to use a habitat duration analysis as described by Sale et al. (1981). Secondly, the Highwood River IFN Working Group also defined a method for protecting the seasonality of flows by modifying the EBF during the freshet period (Clipperton et al. 2002). To achieve protection during these weeks, the 95 per cent flow exceedance value was calculated and the EBF was defined as either the weekly 95 per cent flow exceedance discharge or the discharge corresponding to the 80 per cent habitat exceedance value, whichever was greater. This protocol was necessary in the Highwood River study because additional information regarding other riverine components, such as riparian and channel maintenance flow requirements, were not known and it was not appropriate to use fish habitat data in these flow ranges.

Following the Highwood River study, another detailed study was carried out on several reaches of the main rivers in the South Saskatchewan River Basin (SSRB). For this study, the SSRB IFN technical team once again examined a number of methods for determining the ecosystem base flow component (Clipperton et al. 2003). These included:

- Assigning a per cent flow exceedance discharge for each week (for example, the 90 per cent flow exceedance discharge);
- The discharge corresponding with the 80 or 90 per cent habitat exceedance values for specific guilds of fish;
- The lowest discharge corresponding to the 80 per cent habitat exceedance value for the most affected life stage;
- One standard deviation below the mean annual discharge;
- The discharge corresponding with one standard deviation below the mean annual habitat value; and
- The Tessmann calculation (Tessmann 1979; Wesche and Rechard 1980).

3.2 Alberta (continued)

As with the Highwood River study, the SSRB IFN technical team chose to use the species life stage with the highest flow requirement to calculate the 80 per cent habitat exceedance value. Habitat duration curves were then calculated for each week, using the natural flow data for each reach. The lowest discharge that corresponded with the 80 per cent habitat exceedance value was selected as the EBF.

In the South Saskatchewan River Basin IFN study, there were data for the riparian and channel maintenance components. These data were used and are expected to meet fisheries needs during the freshet. Therefore, the fish habitat analysis was removed from that time period. The EBF for the weeks where fish habitat was included in the analysis was largely based on the discharge corresponding with the 80 per cent habitat exceedance value.

For the Athabasca River, a cautionary threshold (potential short-term impacts on the aquatic ecosystem) was established weekly at the higher of either: a) flow corresponding to the 80 per cent habitat exceedance value for the most sensitive fish species or life-history; or b) the 90 per cent exceedance flow (AENV/DFO 2006). A further potential sustainability threshold – where increased duration and frequency of flows would threaten long-term ecological sustainability – was established at the 95 per cent exceedance flow (AENV/DFO 2006). These low-flow thresholds in the Athabasca River were established from:

- Previous Alberta-based studies (Clipperton et al. 2002; Clipperton et al. 2003);
- IFN contributions from other jurisdictions (Hardy and Richards 2005); and
- Site-specific analyses of wetted-area duration curves (Paul 2005; discussed below).

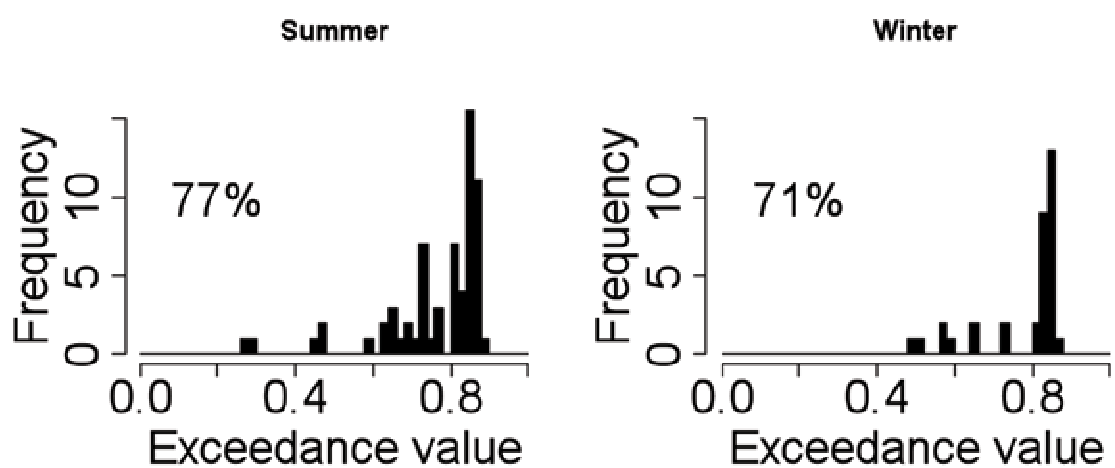
The latter study is similar to that reported by Acreman et al. (2006) for the 65 RAPHSA (Rapid Assessment of Physical Habitat Sensitivity to Abstraction) sites (see Figure 18).

Changes in slope of duration curves for wetted area were examined in three segments of the lower Athabasca River (Paul 2005). The segments of the Athabasca River studied were 2, 4, and 5 (see Figure 3).

Wetted area was estimated using the River2D hydrodynamic model (Steffler and Blackburn 2002) to develop empirical relationships between wetted-area and flow (Trillium 2005a, 2005b, 2005c). River2D was calibrated to representative study sites within each of the three river segments (Trillium 2005a, 2005b, 2005c). Segments 4 and 5 included wetted area estimates through winter using ice-cover capabilities of River2D (Steffler and Blackburn 2002). Empirical relationships were then coupled to observed weekly flows from 48 years of record (1957-2004) to develop weekly wetted-area duration curves (Figure 21). Breakpoints in slope were estimated statistically by fitting line segments to the observed duration curves for wetted area (Paul 2005).

Figure 20.

Habitat exceedance values of estimated breakpoints in weekly wetted areas for segments 2 (summer only), 4 and 5 of the lower Athabasca River. Per cent of weeks with statistically detectable breakpoints is indicated. Eighty-four weeks were examined for the summer and 48 for the winter.



Breakpoint values were detected in wetted-area duration curves for over 70 per cent of the weeks during either summer or winter (Figure 3). Median threshold values were 0.82 and 0.83 for summer and winter, respectively; 60 per cent and 74 per cent of the observed breakpoints for summer and winter, respectively, occurred between exceedance values of 0.80 and 0.90. Because wetted area increases monotonically with flow, exceedance values for wetted area correspond directly to flow exceedance values. The majority of breakpoints in observed wetted-area duration curves for the lower Athabasca River occur between the 80 per cent and 90 per cent flow exceedance values.

Based on these three lines of reasoning (that is, previous Alberta-based studies, international studies, and breakpoint analysis), an ecosystem base flow that provides full protection to the aquatic environment can be established at the 80 per cent flow exceedance for segments 2, 4, and 5 of the lower Athabasca River.

3.3 Ontario

The 80th per cent exceedance is used in Ontario as a recommended monthly baseflow or low flow target to meet aquatic ecosystem objectives in water management plans for waterpower facilities (Robert Metcalfe, Ontario Ministry of Natural Resources, personal communication). Their analyses indicate that the 80th per cent exceedance flow from monthly period of record flow duration curves (POR-FDC) consistently underestimates the median baseflow calculated using baseflow separations (Nathan and McMahon 1990), particularly during low flow periods. It is during these low flow periods when adequate baseflow magnitudes are required to sustain ecological integrity in riverine systems. Generally, monthly median baseflow magnitudes were found to correspond with lower per cent exceedance (higher flow) values on the monthly POR-FDC. POR-FDC values for individual months ranged from the 53rd to 84th per cent exceedance flow for eight reference rivers examined. A mean annual exceedance value, calculated from the 12 individual POR-FDC exceedance values for each river, indicated that on average the median baseflow value corresponded to the 72nd exceedance flow, and ranged from the 63rd to the 79th exceedance value among sites. The lower exceedance (higher flow) values corresponded to drainage basins having a lake dominated hydrology while higher exceedance (lower flow) values correspond to baseflow contributions in better drained basins.

Glossary

Glossary

Abiotic – The nonliving material components of the environment such as water, sediment, and temperature.

Allocation – See water allocation.

Alluvial stream – A stream with a bed and banks of unconsolidated sedimentary material subject to erosion, transportation, and deposition by the river.

Annual flow – The total volume of water passing a given point in one year. Usually expressed as a volume (such as acre-feet) but may be expressed as an equivalent constant discharge over the year, such as cubic feet per second.

Aquatic habitat – A specific type of area and its associated environmental (that is, biological, chemical, or physical) characteristics used by an aquatic organism, population, or community.

Aquatic life – All organisms living in or on the water. This includes plants from the smallest phytoplankton through algae, periphyton, and emergent vegetation as well as animal life from zooplankton through benthic invertebrates, fishes, and amphibians, reptiles, birds, and mammals.

Aquifer – An underground formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Bankfull discharge – The discharge corresponding to the stage at which the flood plain begins to be inundated, usually provided by natural peak flow every one to two years. The maximum discharge that the channel can convey without overflowing onto the flood plain. Calculating the bankfull discharge is one deterministic method of calculating the channel forming discharge.

Bedload – Material moving on or near the stream bed and frequently in contact with it.

Biotic – Of or pertaining to the living components of an ecosystem.

Consumptive use – Represents the difference between the amount of water diverted and the amount of water returned to a water body.

Channel – That cross section containing the stream that is distinct from the surrounding area due to breaks in the general slope of the land, lack of terrestrial vegetation, and changes in the composition of the substrate materials.

Channel-forming flow – A theoretical discharge that, if maintained indefinitely, would produce the same channel geometry as the natural long-term hydrograph. Generally applicable only to stable, alluvial streams that have the ability to change their shape and are neither aggrading nor degrading. Often referred to as the bankfull flow, dominant flow, effective flow, or a flow of a specified recurrence interval, typically between the mean annual and five-year peak flow.

Channel-maintenance flow – 1. A range of flows making up a portion of the rising and falling limbs of the annual hydrograph that is capable of keeping the stream in a condition of sediment equilibrium over time (years) by moving all sizes and amounts of bedload sediment, scouring vegetation, and maintaining riparian vegetation. The range of flows required begins at a flow that mobilizes hydraulically limited gravels and extends up to the instantaneous 25-year flow. **2.** A range of flows that transports bedload sediment through the channel network, prevents constriction of the channel by sediment and vegetation, and sustains channel bank and flood plain vegetation.

Cubic Metres Per Second – measure of stream flow or discharge. Also, expressed as m^3/s or m^3sec^{-1}

Connectivity – Maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes.

Degradation – 1. A decline in the viability of ecosystem functions and processes. **2.** Geologic process by which stream beds and flood plains are lowered in elevation by the removal of material.

Deposition – The settlement or accumulation of material out of the water column and onto the stream bed.

Dewatered – A length of stream without water (due to human removal).

Discharge – The rate of stream flow or the volume of water flowing at a location within a specified time interval. Usually expressed as cubic metres per second (cms) or cubic feet per second (cfs).

Diversion – 1. A withdrawal from a body of water by means of a ditch, dam, pump or other man-made contrivance. **2.** A withdrawal from a water body for the purpose of human consumption or activity.

Diversity – That attribute of a biotic (or abiotic) system describing the richness of plant or animal species or complexity of habitat.

Drainage area – The total land area draining to any point in a stream. Also called catchment area, watershed, and basin.

Drought – A prolonged period of less-than-average water availability.

Dynamic equilibrium – A quasi steady-state condition attained in an alluvial channel, whereby sediment supplies are just balanced by sediment transport capacity, resulting in no net change in average stream bed elevation over time.

Ecosystem – Any complex of living organisms interacting with non-living chemical and physical components that form and function as a natural environmental unit.

Ecosystem Base Flow – A flow at which any human-induced reductions in flow would result in not meeting the defined objective for the aquatic ecosystem.

Exceedance – That probability of an event exceeding others in a similar class. Note that this may be "equal or exceed" or "exceed only." Probabilities may also be expressed as non-exceedance; that is, the probability of being "less than or equal" or just "less than."

Exceedance plot – A plot of discharge versus the percentage of time a given discharge is exceeded. For example, the highest discharge for the period of record has an exceedance value that approaches 0 per cent, whereas the discharge that is exceeded half the time has a value of 50 per cent.

Fishery – 1. The interaction of aquatic organisms and aquatic environments and their human users to produce sustained benefits for people; **2.** A dynamic product of physical, biological, and chemical processes. Each component (process) is important, affects the other, and presents opportunities for impacting or enhancing the nature or character of fisheries resources. Fish populations are merely one attribute of a fishery.

Flood – Any flow that exceeds the bankfull capacity of a stream or channel and flows out on the flood plain.

Flood plain – 1. The area along waterways that is subject to periodic inundation by out-of-bank flows. **2.** The area adjoining a water body that becomes inundated during periods of over-bank flooding and that is given rigorous legal definition in regulatory programs. **3.** Land beyond a stream channel that forms the perimeter for the maximum probability flood. **4.** A relatively flat strip of land bordering a stream that is formed by sediment deposition. **5.** A deposit of alluvium that covers a valley flat from lateral erosion of meandering streams and rivers.

Flow – 1. The movement of a stream of water or other mobile substance from place to place. **2.** Discharge. **3**. Total quantity carried by a stream.

Flow regime – The distribution of annual surface run-off from a watershed over time such as hours, days, or months (See also Hydrologic regime).

Flushing flow – A stream discharge with sufficient power to remove silt and sand from a gravel/cobble substrate, but not enough power to remove gravels.

Fluvial – Pertaining to streams or produced by river action.

Frazil ice – Fine spicules of ice formed in water (that is, slush) that are the first stage of ice formation. They may accumulate to form cap ice or anchor ice in settings that have high turbulence.

Full Protection – No measurable environmental decline over the long term due to human changes in the flow regime away from natural conditions. For example, fish population structure and function are similar to communities in the natural flow regime.

Groundwater – In general, all subsurface water that is distinct from surface water; specifically, that part which is in the saturated zone of a defined aquifer. Sometimes called underflow.

Habitat – The physical, chemical, and biological surroundings in which an organism or population (living and nonliving) lives; includes life requirements such as food and shelter (See Physical habitat).

Glossary (continued)

Hydrograph – The graphical relationship of discharge with respect to time

Hydrologic regime – The distribution over time of water in a watershed, among precipitation, evaporation, soil moisture, groundwater storage, surface storage, and runoff.

Hyporheic zone – **1.** The layer of stream channel substrate that extends as deep and wide as interstitial flow. **2.** The interface between the stream bed and shallow groundwater.

Indigenous – A fish or other aquatic organism native to a particular water body, basin, or region.

Instantaneous flow – **1.** Discharge that is measured at any instance in time. **2.** Flow that is measured instantaneously and not averaged over longer time such as day or month. (Instream flow references are generally related in cubic feet per second (cfs) but regardless of unit of measure are not accomplished through averaging discharge volume over time.)

Instream flow – Any quantity of water flowing in a natural stream channel at any time of year. The quantity may or may not be adequate to sustain natural ecological processes and may or may not be protected or administered under a permit, water right, or other legally recognized means.

Instream flow requirement – **1.** That amount of water flowing through a natural stream course that is needed to sustain, rehabilitate, or restore the ecological functions of a stream in terms of hydrology, biology, geomorphology, water quality, and connectivity at a particular level. **2.** That amount of water flowing through a natural stream course needed to sustain instream values at an acceptable level based on appropriate study. Instream values and uses include protection of fish and wildlife habitat, migration, and propagation; outdoor recreation activities; navigation; hydropower generation; waste assimilation (water quality); and ecosystem maintenance, which includes recruitment of fresh water to the estuaries, riparian vegetation, flood plain wetlands, and maintenance of channel geomorphology. Water requirements sufficient to maintain all of these uses at an acceptable level are the instream flow requirements.

Invertebrate – All animals without a vertebral column (for example, aquatic insects).

Life stage – An arbitrary age classification of an organism into categories related to body morphology and reproductive potential, such as spawning, egg incubation, larva or fry, juvenile, and adult.

Main stem – The main channel of a river, as opposed to tributary streams and smaller rivers that feed into it.

Meander – The winding of a stream channel.

Mean monthly flow – The average flow for one month that is computed from several years' worth of data for that month, which is usually expressed as cfs or cms.

Metric – Of or relating to measurement.

Micro-habitat – Small localized areas within a broader habitat type used by organisms for specific purposes or events, typically described by a combination of depth, velocity, substrate, or cover.

Minimum flow – 1. Traditionally thought of as the lowest stream flow required to protect some specified aquatic function as established by agreement, rule, or permit. In the absence of higher flows at other times of year, aquatic habitat may change, which leads to significant changes in aquatic community structure, which can lead to a subsequent conclusion that a lower minimum flow will maintain aquatic function. **2.** The lowest discharge recorded over a specified period of time.

Minimum degradation scenario – situation where the main objective is maintaining the river in a state similar to the current condition.

Mitigation – An action taken to avoid, alleviate, or compensate for potentially adverse effects to aquatic habitat that have been modified through human actions.

Natural flow – The flow regime of a stream as it would occur under completely unregulated conditions (that is, not subjected to regulation by reservoirs, diversions, or other human works). Also referred to as the virgin flow.

Natural hydrograph – A graph showing the variation in discharge (or river stage) that would exist in the absence of any human alteration, over a specific time period.

Naturalized flow – Measured flows that are adjusted for upstream water licences or uses to approximate the flows that would occur in the absence of regulation and extraction.

Natural Flow – Flow in rivers and streams that would have occurred in the absence of any man-made effects on, or regulation of, flow. In impacted systems, natural flow is a calculated value based on the recorded flows of contributing rivers; physical factors concerning the reach (for example, evaporation, channel losses); water diversions; consumptive use and return flow. In pristine environments, natural flows equal recorded flows.

Passby flow – a prescribed quantity of flow that must be allowed to pass a prescribed point downstream from a water supply intake at any time during which a withdrawal is occurring.

"Per cent-of-flow" method – An approach that determines the appropriate levels of allowable flow depletion expressed as a per cent reduction from natural flow according to a stated objective for the river, for example, full protection of the aquatic ecosystem.

Period of record – The length of time for which data for an environmental variable have been collected on a regular and continuous basis.

Pool – Part of a stream with reduced velocity, often with water deeper than the surrounding areas, which is usable by fish for resting and cover.

Q_{Number} – The Nth percentile flow, Q_{Number} is defined as the river flow that is equalled or exceeded for N% of the period of record. (for example, the Q_{90} is the 90^{th} percentile flow and defines the river flow that is equalled or exceeded for 90 per cent of the period of record. Q_{Number} can be determined from a flow duration curve representing the relationship between the magnitude and frequency of river flows).

Recharge – Process by which water is added to the zone of saturation, as recharge of an aquifer.

Recorded or Regulated Flow – Stream flow that has been affected by regulated releases, diversions, or other anthropogenic perturbations.

Recurrence Interval – The average time interval between events equalling or exceeding a given magnitude in a time series.

Regime – The general pattern (magnitude and frequency) of flow or temperature events through time at a particular location (such as snowmelt regime, rainfall regime).

Restoration – To return a stream, river, or lake to its natural, predevelopment form and function. Restoration typically eliminates the human influences that degraded or destroyed riverine processes and characteristics.

Riffle – A relatively shallow reach of stream in which the water flows swiftly and the water surface is broken into waves by obstructions that are completely or partially submerged.

Riparian – Pertaining to anything connected with or adjacent to the bank of a stream or other body of water.

Riparian vegetation – Vegetation that is dependent upon an excess of moisture during a portion of the growing season on a site that is perceptively more moist than the surrounding area.

River – A large stream that serves as the natural drainage channel for a relatively large catchment or drainage basin.

Scour – The localized removal of material from the stream bed by flowing water. This is the opposite of fill.

Sediment – Solid material, both mineral and organic, that is in suspension in the current or deposited on the stream bed.

Sediment load – A general term that refers to material in suspension and/or in transport. It is not synonymous with either discharge or concentration. (See Bedload).

Side channel – Lateral channel with an axis of flow roughly parallel to the main stem, which is fed by water from the main stem; a braid of a river with flow appreciably lower than the main channel. Side channel habitat may exist either in well-defined secondary (overflow) channels, or in poorly-defined watercourses flowing through partially submerged gravel bars and islands along the margins of the main stem.

Slope – The inclination or gradient from the horizontal of a line or surface. The degree of inclination can be expressed as a ratio, such as 1:25, indicating one unit rise in 25 units of horizontal distance or as 0.04 height per length. Often expressed as a percentage and sometimes also expressed as feet (or inches) per mile.

Glossary (continued)

Stewardship – Responsible management of something entrusted to one's care. In this document, it pertains specifically to the states' and provinces' responsibility to wisely manage natural resources, including instream flow, fish and wildlife populations, riparian corridors, and the like, to ensure that the societal benefits of these natural resources are sustained and protected for future generations

Stream – A natural watercourse of any size containing flowing water, at least part of the year, supporting a community of plants and animals within the stream channel and the riparian vegetative zone.

Stream bed – The bottom of the stream channel; may be wet or dry.

Time step – The interval over which elements in a time series are averaged.

Velocity – The distance travelled by water in a stream channel divided by the time required to travel that distance.

Water Abstraction – The process of taking water from any source, either temporarily or permanently.

Water allocation – Determining the quantity of water from a given source that can or should be ascribed to various instream or out-of-stream uses.

Water body – Any natural or artificial pond, lake, stream, river, estuary, or ocean that contains permanent, semi-permanent, or intermittent standing or flowing water.

Water management – Application of practices to obtain added benefits from precipitation, water, or water flow in any of a number of areas, such as irrigation, drainage, wildlife, recreation, water supply, watershed management, and water storage in soil for crop production. Includes irrigation water management and watershed management.

Water resources – The supply of groundwater and surface water in a given area.

Water right – A legally protected right to use surface or groundwater for a specified purpose (such as crop irrigation or water supply), in a given manner (such as diversion or storage), and usually within limits of a given period of time (such as June through August). While such rights may include the use of a body of water for navigation, fishing, hunting, and other recreational purposes, the term is usually applied to the right to divert or store water for some out-of-stream purpose or use.

Watershed – See drainage area.

Weighted usable area (WUA) – The wetted area of a stream weighted by its suitability for use by aquatic organisms or recreational activity. Units: square feet or square metres, usually per specified length of stream.

Wet year – A water year characterized by above average discharge. Exact measure of deviation from some average, or median value depends on the decision setting.

Withdrawal – Water taken from a surface or groundwater source for off-stream use.

List of Acronyms

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ABF	–	Aquatic Base Flow
AENV	–	Alberta Environment
AFWD	–	Alberta Fish and Wildlife Division
ARI	–	Average Recurrence Interval
ASRD	–	Alberta Sustainable Resource Development
BBM	–	Building Block Method
CFS (cfs)	–	Cubic Feet Per Second
CMS (cms)	–	Cubic Metres Per Second
CF	–	Conservation Flow
DFO	–	Department of Fisheries and Oceans (Canada)
DRIFT	–	Downstream Response to Imposed Flow Transformation
EBF	–	Ecosystem Base Flow
ESA	–	Endangered Species Act
EU	–	European Union
FMF	–	February Median Flow
GES	–	Good Ecological Status
IFIM	–	Instream Flow Incremental Methodology
IFN	–	Instream Flow Needs
IFR	–	Instream Flow Requirement
IHA	–	Index of Hydrologic Alteration
MAD	–	Mean Annual Discharge
MALF	–	Mean Annual Low Flow
MFLs	–	Minimum Flows and Levels
MMF	–	Mean Monthly Flow
NAS	–	National Academy of Sciences
PFRA	–	Prairie Farm Rehabilitation Administration
PHABSIM	–	Physical Habitat Simulation
PRC	–	Poplar Rule Curve
RAPHSA	–	Rapid Assessment of Physical Habitat Sensitivity to Abstraction
RI-ABF	–	Rhode Island Aquatic Base Flow
SNIFFER	–	Scotland and Northern Ireland Forum for Environmental Research
SRBA	–	Snake River Basin Adjudication
SRBC	–	Susquehanna River Basin Commission
SSRB	–	South Saskatchewan River Basin
SWFWMD	–	Southwest Florida Water Management District
USDA	–	United States Department of Agriculture
USFWS	–	United States Fish and Wildlife Service
USGS	–	United States Geological Survey
VFWD	–	Vermont Fish and Wildlife Department
WFD	–	Water Framework Directive

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