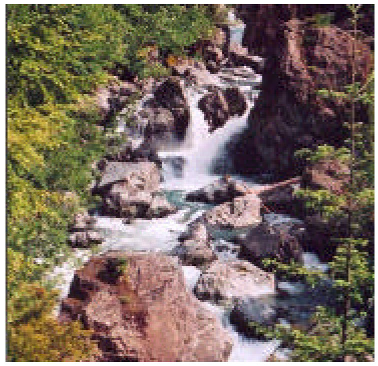
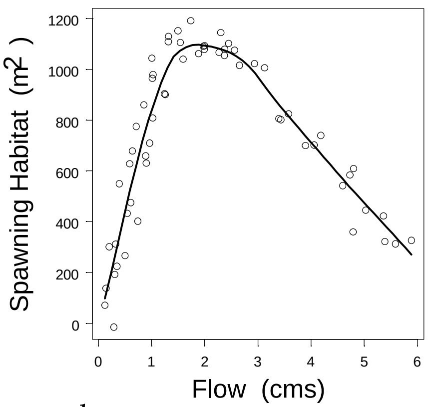
Development of instream flow thresholds as guidelines for reviewing proposed water uses





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List of Abbreviations

Abbreviation	Meaning
BC	British Columbia
BCEAA	British Columbia Environmental Assessment Act
CEAA	Canadian Environmental Assessment Act
cfs	cubic feet per second
cms	cubic meters per second
CSFP	Critical streamflow period
DFO	Fisheries and Oceans Canada
HADD	Harmful alteration, disruption or destruction (of fish habitat)
IFIM	Instream Flow Incremental Methodology
LWBC	Land and Water British Columbia, Inc.
MAD	mean annual discharge
MedAD	median annual discharge
MWLAP	Ministry of Water Land and Air Protection
MSRM	Ministry of Sustainable Resource Management
PHABSIM	Physical habitat simulation system
PMC	Point of maximum curvature
SARA	Species at Risk Act
WUP	Water Use Plan

Acknowledgements

This has been a highly iterative project, and many people have been involved during each step. The project was originally spearheaded by Kevin Conlin and Ted Down, and both provided much support along the way. Gary Robinson made the transition from phase I to II straightforward and provided much needed candid advice. We thank the technical committee members (Mike Bradford, James Bruce, Al Caverly, Kevin Conlin, Paul Higgins, Steve Macfarlane, Steve McAdam, John Patterson, Ron Ptolemy and Dan Sneep), who met to review material on short notice and did so in a spirit of constructive criticism. Ron Ptolemy deserves much credit for catalyzing discussions on flow guidelines and promoting empirical studies of flow issues on BC streams. We are especially grateful to Mike Bradford for helping to set up the historic flow approach and for frequent discussion and review of materials, and to Scott Babakaiff for providing much needed insight from a physical perspective and for constructive review of materials.

1.0 SUMMARY

The Ministry of Water, Land and Air Protection and the Ministry of Sustainable Resource Management are developing Review Guidelines and Assessment Methods to aid in the process of setting instream flows that will protect fish and fish habitat in British Columbia streams. The Review Guidelines support a two-tiered review process for proposed water uses on BC streams. The first level is a scoping level process that sets instream flow reference points—seasonally-adjusted thresholds for alterations to natural stream flows that are expected to result in low risk to fish, fish habitat, and productive capacity. These thresholds are meant to act as a "coarse filter" during the review of proposed water uses; they are general reference flows to be used on BC streams when there is limited biologically or physically relevant data available. Good quality physical and biological data may indicate that it is safe to undertake water diversions in excess of the thresholds. In the absence of such information however, it cannot be assumed that exceeding the thresholds will be without risk. Projects that propose to exceed these flow thresholds must therefore collect additional data, which will be reviewed and used during a more detailed project review. The Assessment Methods are a set of endorsed techniques for assessing flow alterations on British Columbia streams, and ultimately for studying their ecological effects. The Assessment Methods include techniques for collecting data used in screening level reviews as well as data used during more intensive project reviews. This document presents technical information used to support proposed instream flow thresholds as part of the Review Guidelines.

Based on a variety of formal and informal evaluations we pursued the possibility of adapting an historic flow method for reviewing water license applications on British Columbia streams. Our recommendations for a standard-setting technique using historic flow data are presented in this report. The recommendations are based on a variety of analyses of historic flow data from around BC. The final recommendations should be subjected to a formal peer-review process. The recommended flow thresholds are based on fish-bearing status and historic flow data, which create two specific data requirements. The first is an adequate assessment of fish presence and absence; the second is an adequate time series of mean daily flows.

The recommended flow threshold for fishless streams is a minimum instream flow release equivalent to the median monthly flow during the low flow month. This value represents the minimum instream flow requirement through the diversion section at all times of the year. (*Note: additional important components of the recommendation are presented in the report.*)

The recommended flow threshold for fish-bearing streams is a seasonally-adjusted threshold for alterations to natural stream flows. The thresholds are calculated as percentiles of mean natural daily flows for each calendar month. These percentiles vary through the year to ensure higher protection during low flow months than during high flow months. As a result more water is available for diversion during high flow months than during low flow months. (*Note: additional important components of the recommendation are presented in the report.*)

The recommended flow thresholds have been devised primarily to satisfy the demands of screening level reviews of small hydropower projects. Yet, these same guidelines are also applicable to reviewing proposals for water withdrawals for irrigation, or domestic, municipal

or industrial uses. Minimum instream flows would be calculated using the same rules as those laid out above for fishless or fish-bearing streams

We propose two types of monitoring as part of the guidelines, compliance monitoring and biotic response monitoring. Compliance monitoring simply monitors water use to ensure that a user is complying with the conditions of a water license. This should be done through installation and maintenance of continuous recording flow gauges for measuring instream flows and diversions. Biotic response monitoring is also recommended; during the workshops and discussions held for this project there has been virtually unanimous support from resource managers for this type of monitoring. However, as highlighted in the Phase I report there remain a variety of policy-level questions that need to be resolved before a detailed monitoring program can be designed and implemented. We recommend using a general business case framework to support the design and evaluation of an effective monitoring program.

A summary of key recommendations is presented in Section 12.0.

2.0 INTRODUCTION

British Columbia has abundant water resources, which sustain productive aquatic ecosystems and many uses by humans (e.g., fishing, power generation, irrigation, drinking water, industrial uses, recreation, etc.). Determining how much water can be extracted from a river without negatively affecting fish and fish habitat is a daunting task, but one that is frequently asked of resource managers. The Ministry of Water, Land and Air Protection (MWLAP) and the Ministry of Sustainable Resource Management (MSRM) are developing the British Columbia Instream Flow Guidelines for Fish (referred to here as "the Guidelines") to aid in the process of setting instream flows in British Columbia streams.

The Guidelines are made up of two main components, Review Guidelines, and Assessment Methods. The main purpose of the Review Guidelines is to support a two-tiered review process for proposed water uses on BC streams. The first level is a scoping level process that provides instream flow reference points—seasonally-adjusted thresholds for alterations to natural stream flows that are expected to result in low risk to fish, fish habitat, and productive capacity. These thresholds are meant to act as a "coarse filter" during the review of proposed water uses; they are a general flow guideline to be used on BC streams when there is little or no biologically or physically relevant data available. Projects that propose to exceed these flow thresholds must collect additional data, which will be reviewed and used during a more detailed project review. The Assessment Methods are a set of endorsed techniques for assessing flow alterations on British Columbia streams, and ultimately for studying their ecological effects. The Assessment Methods include techniques for collecting data used in screening level reviews as well as data used during more intensive project reviews.

This document presents technical information used to support proposed instream flow thresholds as part of the Review Guidelines. The Assessment Methods are presented in a companion document. A third document is being prepared by MWLAP, which will describe the process that agencies will follow when reviewing proposed water uses.

2.1 What is a guideline?

We live in a complex society surrounded by standards and guidelines—speed limits, health and safety guidelines, financial principles, production standards, etc. Guidelines and standards are essentially a set of rules (not necessarily embedded in a legal framework), which guide collective decisions to reflect collective values. A "standard" is defined as follows:

> Quantifiable and measurable thresholds that are typically defined in law or regulation, and are mandatory. A statement that outlines how well something should be done, rather than how it should be done. A standard does not necessarily imply fairness or equity, nor an absolute knowledge of cause-and-effect linkages. Standards are typically established using a combination of best available scientific knowledge, tempered by cautious use of an established safety factor.
> (Dunster and Dunster 1996)

If done properly, standards and guidelines can have tremendous value: they indicate whether a product or decision meets specific criteria. As a result, we can judge whether that product or decision is acceptable without first having to become an expert on that topic. One of the more obvious examples is that, with appropriate guidelines in place, a consumer can purchase an electric appliance with a CSA label and be assured that it is safe to use. Another example is that of speed limits, which attempt a balance between safety and transportation efficiency, taking into account road engineering, prevailing automotive technologies, and human behaviour. In most cases, guidelines and standards like these have considerable margins of safety built in. Guidelines and standards are often adjusted through time as new information becomes available, or values change.

2.2 Why are the Guidelines needed?

Instream flows are directly related to natural water availability (e.g., rainfall, snow melt, etc.) and human water use. The legal right to extract and use water is governed by conditions set out in water licences. Authority for granting and administering water licences rests with the provincial government and its water resources agencies (currently Land and Water BC, Inc.), but conditions in the water license must comply with a variety of legislation, regulations, and policies (see Section 4.0).

At present, water licence applications are reviewed by staff in Land and Water BC and may be referred to other resource management agencies (federal and provincial) for comment. (Other licensees, applicants, or landowners, whose rights may be affected if the licence is granted, may also be notified.) If a review indicates that the fisheries resource is likely to be negatively affected by the proposed water use the application may be rejected. There is no formal procedure for determining which applications are referred, the extent of the review during the referral, or how instream flows for fish are ultimately determined. Thus, water use decisions vary among licence applications, streams, and regions, with the consequence that fisheries resources are not protected to the same level in all streams.

The Review Guidelines are intended to help in the process of setting instream flows in British Columbia streams. They present a set of seasonally-adjusted thresholds for alterations to natural stream flows. These alterations are expected to result in low risk to fish, fish habitat, and productive capacity. The thresholds are meant to act as a “coarse filter” during the review of proposed water uses – they are a general guideline to be used on BC streams when there is little or no biologically relevant data available. Good quality physical and biological data may indicate that it is safe to undertake water diversions in excess of the thresholds. In the absence of such information however, it cannot be assumed that exceeding the thresholds will be without risk. A conceptual diagram showing a hypothetical threshold relative to natural streamflows is presented in Figure 1. A general schematic of how the thresholds function as part of the review process is laid out in Figure 2. An in depth discussion of the conceptual framework for the thresholds is presented in Section 3.0.

2.3 Where will the Guidelines apply?

British Columbia is hydrologically and biologically diverse, but the thresholds are sufficiently flexible to guide the setting of instream flows in all streams in the province.

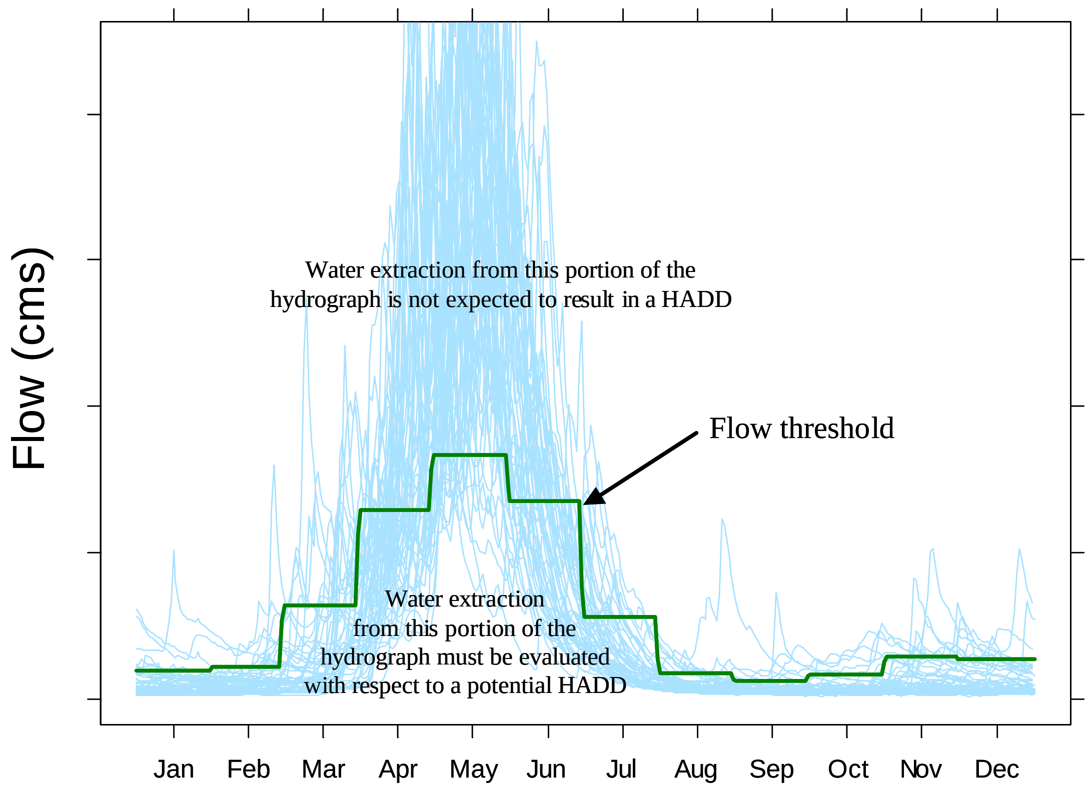

Figure 1. Concept of the flow threshold relative to observed natural streamflows and the streamflow level for Harmful Alteration, Disruption or Destruction (HADD) of fish habitat. In this example, the light blue lines trace mean daily flows with multiple years superimposed, for a hypothetical stream. The green line is the flow threshold proposed in the guidelines. Additional features of the guidelines, such as diversion capacity are discussed in the text. The flow threshold is conservative and represents the flow level to be retained in the stream. Below this threshold there is a reasonable likelihood of flow-related constraints on aquatic productivity and therefore the possibility that a HADD may result. The "true" HADD limit may be lower, but in the absence of more information it is not possible to tell whether exceeding the flow threshold will lead to a HADD.

2.4 Who will use the Guidelines?

The instream flow thresholds can be used by anyone wishing to determine flow requirements for fish in British Columbia streams, provided that they have basic information on biology and hydrology. The most likely users of the thresholds will be water licence applicants and regulatory agencies. The thresholds are meant to guide water use decisions by indicating diversion rates and timing that result in low risk to fish and fish habitat. In this way the thresholds can be used both as a scoping tool by water licence applicants and a formal review tool by regulators to assess the effects of a proposed water use.

A catalyst for developing the thresholds is the large number of applications for water use associated with small hydropower development. The design and presentation of the guidelines has therefore considered this need foremost. As a result, in this document discussion of the flow thresholds and how to apply them focuses primarily on issues surrounding small hydropower. The thresholds are nevertheless applicable to all streams in British Columbia, and for all uses, including consumptive uses (e.g., withdrawal for drinking water, agriculture, or industrial uses).

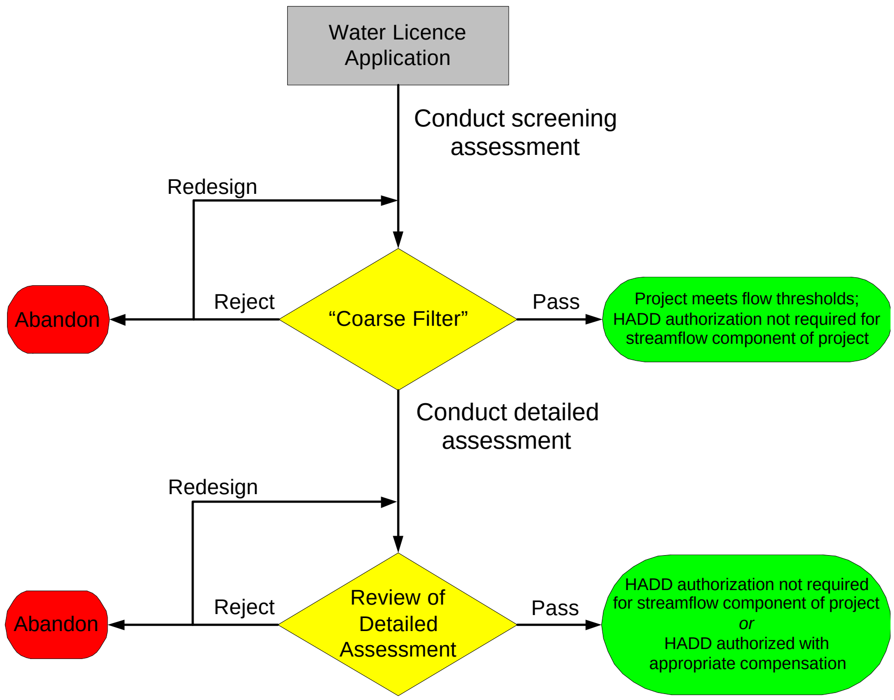

Figure 2. General decision schematic for a two-tiered review process. The “coarse filter” is first applied to a proposed water use. If the coarse filter indicates that fish-flow issues are not a concern the application would be approved subject to review of other fisheries concerns (e.g., intake screening, footprint issues, etc.). If the coarse filter indicated a potential fish-flow concern then the applicant has three options: abandon the project, redesign it to meet the flow thresholds (e.g., diversion rates or timing altered) or collect and present additional information to demonstrate that fish-flow concerns are adequately addressed within the proposed flow regime.

2.5 How have the Guidelines been developed?

The flow thresholds have been developed with the input of biologists, hydrologists and water managers from provincial, federal, and private sector groups. The thresholds make use of the best available technical and scientific information in order to be as rigorous and defensible as possible.

2.6 What are the Guidelines?

The Guidelines are intended to satisfy three critical needs: consistency in water licence applications, a process for making water allocation decisions with respect to fish and fish habitat, and a suite of flows that protect fish and fish habitat. The flow thresholds are presented in detail in Section 10.0, and focus on addressing the last of these three needs. (Representatives from MWLAP and LWBC are working on a process to streamline hydropower-related water licence applications.) Briefly, basic information on biology and hydrology is used to predict a schedule of instream flow requirements that protect available habitat for fish, and provide for necessary ecological functions. These flows relate to the natural availability of water in a stream and are, by design, low risk thresholds.

The flow thresholds address fish-flow issues only. They do not address issues such as instream construction impacts, transmission and road corridors, entrainment of organisms at water intakes, etc.

3.0 OBJECTIVES AND GUIDING PRINCIPLES

The fundamental objective during development of the flow guidelines was to ensure protection of fish and fish habitat, where the level of protection is consistent with current legislation and regulations. Since the thresholds are meant to be calculated in the absence of detailed physical and biological information any resulting alteration to flows based on the thresholds should be low risk to fish, fish habitat, and the productive capacity of a stream.

We attempted to meet the fundamental objective by developing the thresholds under several guiding principles:

1. Work within existing legal framework,
2. Develop guidelines from the perspective of protecting the fish resource,
3. Minimize review costs,
4. Maximize consistency and transparency, and
5. Implement a scientifically defensible approach.

These principles capture the motivation for the thresholds, the approach and philosophy to setting the thresholds, and their intended benefits. The principles are reviewed briefly below.

3.1 Work within existing legal framework

The guidelines propose no new legislation, regulations, or policies – they are meant to work entirely within the existing legislative and policy framework of the federal and provincial governments and their resource management agencies. Key pieces of environmental legislation that may apply to water extraction or diversion in British Columbia include, the British Columbia Environmental Assessment Act (BCEAA), the Canadian Environmental Assessment Act (CEAA), the Fisheries Act (Canada), the Fish Protection Act (British Columbia), the Species at Risk Act (Canada), and the Water Act (British Columbia). In addition to legislation, resource agencies have developed specific policies to guide decision makers (e.g., DFO 1986, 1995). (Relevant Acts and policies, as they relate to instream flow, are reviewed briefly in Section 4.0.) The guidelines have been developed with existing legislation and policy in mind, to minimize potential conflict between the guidelines and existing policies and laws. Where any such conflict arises, the existing legislative and policy framework supersedes the guidelines.

3.2 Develop guidelines from the perspective of protecting the fish resource

The flow thresholds assess only the needs of fish. Other natural resources (e.g., wildlife) or interests (e.g., public safety) may need to be considered during the development of water licence specifications. In some cases water use conflicts may arise where flow thresholds for fish indicate water levels that are suboptimal for other resources or interests. The guidelines cannot anticipate these cases, and we expect project proponents and the relevant agencies to undertake studies or negotiations to assess the appropriate trade-offs. Under the existing legal and policy framework, water licence applicants and fisheries agencies may wish to explore options for compensatory works or activities to offset some of these trade-offs.

3.3 Minimize review costs

There are multiple costs associated with preparing and reviewing water licence applications. These costs exist for project proponents, government reviewers, and society as a whole—costs associated with undertaking studies to gather background data, staff time, delays in project approvals, and the practicality of final decisions. We have developed the guidelines under the assumption that an ideal review process would be efficient (i.e., maximize attention for the most important aspects for fish, and minimize attention for the least important aspects), timely (i.e., a review should be conducted quickly), and produce a final decision that is practical (i.e., the decision should be clear and easy to implement). We expect the benefits of a clear application and review process to accrue to applicants and reviewers.

3.4 Maximize consistency and transparency

Water licence applicants expect a review process to be transparent and applied consistently throughout the province, and by constructing and adopting the guidelines resource agencies are attempting to provide such a process. The flow thresholds have been designed to be as objective as possible. That is, decisions based on the thresholds should not vary markedly among reviewers of water licence applications—all reviewers should reach a similar conclusion regarding instream flow needs for fish, as well as requirements for additional studies.

Yet, British Columbia is geoclimatically and biologically diverse. Fish species distributions, life history timing, precipitation and streamflow patterns, and stream characteristics vary considerably over the province. It is unreasonable to expect a single office-based review process to capture all nuances of each location within the province. The guidelines have therefore embraced a flexibility principle to allow individual reviewers to require additional studies as needed. The flexibility principle is aimed at allowing agency reviewers to mould the thresholds to the requirements of particular instances. The thresholds and their underlying philosophy should nevertheless form the foundation during each review.

3.5 Implement a scientifically defensible approach

The flow thresholds are built on the principle of using the best available scientific evidence to set stream flows in British Columbia. The science of river biology is young and evolving quickly, but there is a large body of literature relevant to British Columbia streams, and this has been used to develop the thresholds. The most salient features of a scientifically defensible approach are: habitat-based and risk-averse criteria, peer review of the guidelines, requirements for effective monitoring, and application of appropriate mitigation and compensation.

Habitat-based criteria. A habitat-based approach for the guidelines is defensible for three main reasons: the relevant environmental legislation is habitat-based (see Section 4.0), there is considerable evidence to indicate a general correlation between fish productivity and habitat (see Section 6.0), and alternatives to habitat-based assessment are unworkable in a guideline setting context (e.g., habitat is considerably easier to quantify than many other aspects of aquatic ecosystems).

Risk-averse criteria. The guidelines adopt a blended approach: they focus on setting flow thresholds that are risk averse for fish habitat, coupled with a commitment to effective monitoring (see Section 11.0). For fish-bearing stream reaches, the flow thresholds are based on the concept that, in general, risk for fish increases as water extraction or diversion increases, but that in many cases a balance is achievable between effective fisheries resource protection and water use development. The thresholds are risk-averse because of general uncertainties in fish-flow relationships, but also because they are to be used in situations where there is little or no site-specific information.

The available evidence indicates that there is not a simple 1 to 1 relationship between risk to the fish resource and amount of water used. At times water levels can be severely limiting for fish; in other instances large changes in flow appear to have little effect on fish production. This means that the "right balance" between water use and fish protection is difficult to predict, and may be different for each stream. Effective risk management of stream flows therefore requires the setting of conservative criteria, coupled with a commitment to a strong monitoring program to ensure that conservation goals are being met. Consistent with "results-based" management, flow criteria can be adjusted on a site-specific basis to reflect the local environment provided appropriate data are collected.

Peer review. One of the hallmarks of the scientific process is peer review of results. Components of the guidelines have been, or will be, subjected to a variety of peer review processes. Candidate flow criteria and standard-setting processes were first proposed to a technical working group and subjected to peer review prior to selecting a single "best" approach to setting the thresholds. The finalized guidelines should be distributed to stream flow experts for external review.

Effective Monitoring. Monitoring is the cornerstone of effective resource management, providing feedback to assess whether management is meeting its goals and objectives. Although the need for this feedback is widely recognized, monitoring is often accomplished in an *ad hoc* and qualitative manner. Usually most effort goes into making decisions, with few resources reserved for assessing decisions after they are made. Broad uncertainty in predictions of biological response to changes in the environment provides the strongest argument for monitoring (Ludwig et al. 1993; Castleberry 1996). Monitoring is discussed in more detail in Section 11.0.

Mitigation and compensation. Mitigation refers to intentional activities undertaken to avoid or reduce the likelihood of negative impacts of construction and operation of an intake or diversion. Compensation on the other hand, refers to intentional activities undertaken to offset inevitable impacts once they occur. Compensation offsets negative impacts by providing benefits elsewhere in the system. Thus, the purpose of mitigation is to avoid impacts, whereas the use of compensation implies acceptance of impacts. The requirement for mitigation and compensation stem primarily from DFO's "no net loss" principle (DFO 1986, 1995), which states that "the Department will strive to balance unavoidable habitat losses with habitat replacement on a project-by-project basis so that further reductions to Canada's fisheries resources due to habitat loss or damage may be prevented" (DFO 1986).

A guiding principle in the development of the guidelines is that mitigation is a superior option to compensation, and that compensation carries with it responsibilities to ensure its effectiveness. Under this principle water licence applicants would be encouraged to design their projects to ensure that the flow thresholds are not exceeded, and that the fish resource is protected. Where the thresholds are not met, some form of habitat compensation may be required. Whether habitat compensation is required, and the exact nature of the compensation, is for the most part, outside the scope of this document.

4.0 REGULATORY CONTEXT FOR INSTREAM FLOW REQUIREMENTS

The withdrawal of water from streams in British Columbia is governed by acts enforced by the Provincial and Federal governments. These include the provincial *Water Act*, *Fish Protection Act*, and *British Columbia Environmental Assessment Act*, and the federal *Fisheries Act* and *Canadian Environmental Assessment Act*. In addition, policies and guides support the application of these acts with respect to water withdrawal and consumption. A description of each act follows, along with their supporting policies and guidelines and the relevance of these to the British Columbia Instream Flow Guidelines for Fish. Although we have taken a comprehensive approach to reviewing relevant regulatory material and condensing it into the following discussion, readers are encouraged to consult the act, policies, and guides directly and should not rely on this document as a complete representation of regulatory requirements.

The British Columbia Instream Flow Guidelines for Fish are under development, thus their place in the regulatory framework has not yet been defined. The Guidelines are not intended to supersede or displace existing legislation, but rather have been designed to dovetail with the definitions, policies and guides currently used by regulators assessing impacts to fish and fish habitat. By design the guidelines allow the rapid assessment of potential effects, and encourage the planning of projects to meet levels of protection expected by fish habitat managers. The guidelines are intended to reduce the time required for review, since they encourage projects to meet existing legislative and policy requirements.

4.1 British Columbia Water Act

The *British Columbia Water Act* governs the use of water to serve the public interest and is key to the regulation of hydroelectric facilities and consumptive uses of water. The *Water Act* regulates diversion and storage of water, construction in and around streams, alterations of a stream or channel, or the installation of fish screens or guards. Anyone wishing to use, store, or divert water from a stream, or alter a water course must obtain an authorization administered by a system of licences and approvals. Even smaller projects for the diversion or use of water, such as the maintenance of culverts and construction of bridges, that are less than 12 months in duration, require an approval in writing.

To obtain a water licence, an applicant must follow Water Act regulations for filing the application, pay a fee, and give notice by posting on site and publication in a newspaper. Also, plans, specifications and details on location must be provided to the comptroller or the regional water manager (or present equivalent). Objections to water licences may be filed by existing water licence holders or applicants, as well as landowners potentially affected by the application. The comptroller or the regional water manager (or present equivalent) may hold a hearing to address any objections.

The comptroller or the regional water manager (or present equivalent) may grant an application or refuse it, amend the application, or ask for additional information. If granted, water licences impose restrictions on the quantity and rate of water use, but also on many aspects of the facilities that manage water, including structures and operating procedures to protect fish and habitat. Licences may include conditions that specify environmental protection measures for fish, both as conditions that must be met before the licence is finalized and as ongoing requirements. Security such as a performance bond may be required to obtain the licence.

The quick licensing procedure can benefit those applications for specified uses that do not exceed a maximum eligible quantity. The uses include domestic and irrigation uses, but may also include any use specified by regulation. In the context of instream flow guidelines, the regulation could be revised to include hydroelectric projects that meet the flow thresholds.

As a result of a water licence approval a proponent may, solely from a water use perspective, proceed with the project. However, both the construction and operation of the project must obey additional legislation. For example, the *Water Act* allows a licensee to make changes in and about a stream providing they exercise reasonable care to avoid damaging land and trees. It also allows the removal trees, rocks, or other features that endanger the water works. However, the *Fisheries Act* does not allow damage to fish habitat, so an authorization under the *Fisheries Act* would be required, as discussed in detail below. For most hydroelectric projects, where water withdrawal could affect fish habitat, a DFO authorization may be required, in addition to the water licence approval.

4.2 British Columbia Fish Protection Act

Provincial legislation of interest includes the relatively recently proclaimed *British Columbia Fish Protection Act*. In general, this Act does not limit the authority of the minister (MWLAP) under the *Water Act*, however, where regulatory conflict arises, the *Fish Protection Act* and regulations supersede the *Water Act*.

A key feature of the *Fish Protection Act* is Section 4, which prohibits new dams on 17 protected rivers[1], where dams are defined as bank to bank, or bank to instream feature structures capable

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[1] Protected rivers include the Adams, Alsek, Babine, Bell-Irving, Blackwater, Clearwater, Fraser, Nass, Skagit, Skeena, Stikine, Stuart, Taku, Tatshenshini, North Thompson, South Thompson, and Thompson rivers.

of impounding or storing water. This leaves open the opportunity to withdraw water from intakes placed within the channel.

In certain circumstances the *Fish Protection Act* directs the comptroller or regional water manager (or present equivalent) to consider the impact on fish and fish habitat, who may include conditions for fish and fish habitat (such as instream flow releases) in licence approvals or amendments, and to collect streamflow data to monitor water use and verify flow releases for fish. This responsibility is heightened on 'sensitive' streams, which are defined as those waterbodies with a "population of fish whose sustainability is at risk because of inadequate flow of water within the stream or degradation of fish habitat". Sensitive streams are designated by MWLAP in consultation with other regulatory agencies, the public, and First Nations. To date only 15 streams have been designated in the schedule of sensitive streams[2], however, it is expected that many other streams in the Province will be included in this schedule in the future. The sensitive stream designation directs water licence applicants to provide water flow and fish habitat information and develop mitigation or compensation measures.

The sensitive stream designation is complementary to the *Fisheries Act (Canada)* and requires many of the same actions by proponents, including impact assessment, mitigation, and compensation.

The *Fish Protection Act* gives authority to designate water management areas for the evaluation of water availability and the planning of water use when there is conflict among water users or between water users and instream flow requirements, risks to water quality (including those caused by water withdrawal), or concerns relating to fish or fish habitat. The minister may order water management plans for designated water management areas to address water use conflicts. For existing hydroelectric facilities operated by BC Hydro, Water Use Planning (WUP) will provide detailed operating orders for individual facilities with explicit considerations for fish and habitat protection. The WUP process, announced in November 1996, is currently underway across British Columbia at most BC Hydro facilities. The process is designed to define operations at each facility that consider all water use issues in the affected water bodies, particularly fish habitat. The process is described in detail in 'Water Use Plan Guidelines' (Province of British Columbia 1998). In summary, the *Fish Protection Act* can compel a WUP to occur where conflicts over water use warrant such an approach.

The instream flow thresholds proposed in this document are designed to provide a level of protection for fish and fish habitat that avoids conflict between water users and instream flow requirements for fish and habitat. Accordingly, these guidelines may be applied independent of water use plans on newly proposed project, or within an ongoing water use plan to provide operating regimes to restore fish and habitat. Indeed, prototype flow thresholds have already been applied within ongoing water use plans and for projects on streams not subject to water management plans.

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[2] Sensitive streams include Black Creek, Chapman Creek, Englishman River, French Creek, Fulford Creek, Goldstream River, Kanaka Creek, Lang Creek, Little Qualicum River, Little River, Nathan Creek, Salmon River, Silverdale Creek, West Creek, and Whonnock Creek.

The *Fish Protection Act* identifies specific fish and fish habitat considerations in water management plans, including measures to provide additional water for fish and fish habitat, and reduction of water rights. The Act therefore suggests that water management plans may contemplate reducing water rights to provide more water for fish and fish habitat. It is unlikely that projects that meet the guidelines would be subject to subsequent restrictions on their water licence for fish protection purposes.

The *Fish Protection Act* allows for the ordering of a temporary reduction in licensed water use in cases of drought. This has implications for consumptive users and hydroelectric developers in that "if because of a drought, the flow of water in a stream is or is likely to become so low that the survival of a population of fish in the stream may be or may become threatened, for the purposes of protecting the fish population, the minister may make temporary orders regulating the diversion, rate of diversion, time of diversion, storage, time of storage and use of water from the stream by holders of licences or approvals in relation to the stream, regardless of precedence under the *Water Act*." Fortunately, use of the instream flow guidelines would avoid the risk of temporary orders. During low flow conditions projects adopting the guidelines would probably not be operating because of the need to provide all natural flows as instream flows to meet instream flow requirements.

The *Fish Protection Act* includes the provision for streamflow protection licences, licences that may be obtained by third parties for the protection of fish and habitat.

4.3 British Columbia Environmental Assessment Act

The Environmental Assessment Office (EAO) is a neutral provincial agency that coordinates assessment of the impacts of major development proposals in British Columbia. The EAO administers an act to prevent or mitigate adverse effects of reviewable projects, providing a neutrally administered process that invites participation by the public, proponents, First Nations, and government agencies of all levels. The *British Columbia Environmental Assessment Act* (BCEAA) promotes sustainability by protecting the environment through the integrated assessment of the environmental, economic, social, cultural, heritage, and health effects of reviewable projects.

Reviewable projects are defined narrowly for the purposes of the Act by size, production, storage capacity, and other characteristics; however, the minister may designate a project as reviewable if there is a public interest in doing so or if a significant adverse effect on the environment is expected.

With respect to hydropower projects the Act defines reviewable projects as those that include dams, diversion works, water conduits, and all associated structures, machinery, appliances, fixtures and equipment. Reviewable projects include:

- electric transmission lines of 500 kV or greater than 40 km in length on a new right of way,
- new hydroelectric plants of 50 MW or more rated nameplate capacity,
- modified hydroelectric plants that increase by 50 MW or more the rated nameplate capacity, and

- dismantling or abandonment of an existing hydroelectric project with a dam of 10 m or higher, or has a maximum permitted rate of diversion of water under the *Water Act* that is 10 million m^3 or more per year.

These thresholds exclude most small hydroelectric projects, but may apply to some projects that propose to rebuild old sites.

BCEAA has three phases: an application phase in which detailed, but not exhaustive, information on the project is provided; a project report review phase where report specifications are designed by multi-stakeholder technical committees, and technical studies are undertaken (these studies can be intensive, even for small hydroelectric projects); and a public hearing phase. Following the completion of the three phases, a decision is made by the Cabinet of the British Columbia government.

4.4 Other British Columbia regulatory considerations

The Living Rivers Strategy is currently under development by the British Columbia government. The British Columbia Instream Flow Guidelines for Fish are consistent with the direction proposed by the Living Rivers Strategy.

Other relevant Provincial initiatives include the Freshwater Strategy for BC. The document produced for the Freshwater Strategy lays out general principles to govern MWLAP's approach to the management of freshwater resources. A key principle of the strategy is ecosystem integrity, which "requires taking a long-term, holistic approach to water management, to conserve and protect it for all its many uses and values." A second key principle is the precautionary principle, under which practices that may cause serious or irreversible damage to the environment are to be modified or curtailed. These two principles have been adopted by the British Columbia Instream Flow Guidelines for Fish. (The final strategic principle is stewardship, defined as: taking responsibility for resource use and getting involved in area-based planning, local stream clean-up activities, and other grass-roots initiatives.)

MWLAP maintains an Instream Flow Policy (from the Policy Manual August 1, 1986) that identifies instream flow needs as requiring action. The policy states that: "When, in the opinion of the Fisheries Branch or Waste Management Branch instream flows have reached a level where existing Provincial uses are in danger, the comptroller or regional water manager (or present equivalent) shall be advised so that he may consider whether regulatory action is required." The spirit of this policy has been followed in crafting the guidelines, in that Provincial fisheries personnel have helped define instream flow thresholds below which fish resources may be threatened.

4.5 Fisheries Act

The management of potential impacts to fish and habitat from water withdrawals for consumptive use or for the development of hydroelectric facilities is governed by several key pieces of federal legislation. The most well-used legislation is the *Fisheries Act* within which several sections define offences that may occur during withdrawal and release of instream flows. The key sections of the Act are section 22, wherein sufficient flow for flooding of spawning grounds and free passage of fish must be maintained during construction, section 35, which prohibits the harmful alteration, disruption or destruction of fish habitat (known as a HADD), and section 36, which prohibits the deposit of deleterious substances (Table 1). A less well-known section that acts as a catch-all is section 32, which prohibits destruction of fish by any means other than fishing.

Table 1. Sections of the Fisheries Act relevant to hydropower development.

Section 22	The Minister may require sufficient flow of water for the safety of fish and flooding of spawning grounds as well as free passage of fish during construction.
Section 32	Prohibits the destruction of fish by any means other than fishing.
Section 35	Prohibits works or undertakings that may result in harmful alteration, disruption or destruction of fish habitat (HADD), unless authorized by the Minister or under regulations.
Section 36	Prohibits the deposit of deleterious substances into waters frequented by fish, unless authorized under regulations.

A key part of the Act is the definition of fish habitat: "Spawning grounds and nursery, rearing, food supply and migration areas on which fish depend, directly or indirectly, in order to carry out their life processes." The reference to an indirect dependence of fish on habitat is critical to water withdrawal use proposals, particularly in fishless streams that may support fish habitats downstream.

4.6 DFO policy documents

4.6.1 Policy for the Management of Fish Habitat (the Habitat Policy)

The Habitat Policy document outlines DFO's long-term policy objective of an overall net gain of the productive capacity of fish habitats. This is to be accomplished through three actions: the conservation of the current productive capacity of habitats, the restoration of damaged fish habitats, and the development of habitats. For proposed water licence applications, the conservation of the current productive capacity of habitats is of direct relevance and great importance.

A key aspect of the Habitat Policy is that the level of protection given to habitats takes into consideration their actual or potential contribution to sustaining existing or potential fisheries. Protection may be given to fishless streams if they support fish by providing food or nutrients to habitats downstream that support an existing or potential fishery. The conservation of current productive capacity is implemented using the No Net Loss Guiding Principle. Unavoidable habitat losses are balanced with habitat replacement on a project-by-project basis to prevent a net habitat loss. The principle applies to proposed works and undertakings, and is not applied retroactively to approved or completed projects. However, proposals to rebuild existing projects would be reviewed with an eye to following the principle.

The key aspects of the 'no net loss' principle (condensed from the Policy) are as follows:

- The principle is intended as a guide, not a statutory requirement.
- Professional judgement by personnel experienced in habitat management is seen as playing a key role in most cases.
- Site-specific habitat requirements of fish are considered in assessing losses of habitats or habitat components that can limit the production of fisheries resources.
- The principle may be applied on a fish stock-specific basis or on a geographic basis, depending on how particular fisheries are managed and harvested. Salmon may be treated differently than freshwater resident species.
- Where affected fish stocks and habitats are adjacent to Aboriginal communities, it will be important that any habitat replacement be undertaken in the immediate area to avoid any negative effects on Aboriginal fishing rights.
- In other circumstances, such as for resident freshwater species, the principle may be applied on a broader, geographic area basis, rather than on stock-specific management.
- Local fish habitat management plans, where available, will guide the application of the principle in specific cases.
- The principle offers flexibility through a hierarchy of preferences and other procedures that include mitigation and compensation.
- Various other techniques, including those used to restore and develop habitat, may be employed by proponents to achieve no net loss and the conservation goal.
- In cases where the productive capacity of habitats is very high, no loss of habitat will be permitted, in accordance with the local fish habitat management plan, wherever available.

4.6.2 Decision Framework for the Determination and Authorization of Harmful Alteration, Disruption or Destruction of Fish Habitat (HADD);

A HADD is any change in fish habitat that reduces its capacity to support one or more life processes of fish. This includes: 1) harmful alteration, an indefinite reduction in capacity while maintaining some of the habitat; 2) disruption, a short term reduction in capacity; and 3) destruction, permanent loss of capacity.

Projects that may cause a HADD include those that change hydrology, hydraulics or geomorphology of a waterbody. Therefore hydroelectric projects or diversion for consumptive use may cause a HADD.

Damage to fish habitat is legal if authorized by regulation or by the Minister. The decision to authorize a HADD is made through a decision framework that identifies the information needed to answer a series of questions that clearly link to a decision on whether a section 35(2) authorization can be granted. Although the determination of a HADD may be technically complex, the questions are quite simple:

1. Is fish habitat present at the project site or in an area affected by the project?
2. Could the proposed project cause a HADD of fish habitat?
3. Can the impacts to fish habitat be fully mitigated?

4. Should the HADD be authorized?
5. Can the HADD be compensated?

The presence of a potential HADD is ultimately defined by the DFO habitat managers who must "determine if, in their professional judgement, such effects would be expected to result in a reduction in the habitat's capacity to produce fish, relative to the fishery or potential fishery in question." Consistent with the Policy for the Management of Fish Habitat, professional judgement plays a large role in assessing a HADD. This feature of HADD determination has a parallel in the design of instream flow thresholds for this project, which has been based partly on a review of available scientific information, but largely on the collective professional judgement of a group of instream flow practitioners.

The HADD framework identifies the role of mitigation in avoiding a HADD and the role of compensation. Mitigation can avoid a HADD and the need for a section 35(2) authorization whereas compensation necessarily indicates a HADD has taken place (although hopefully not a net loss of habitat, once compensation is provided).

4.6.3 Habitat Conservation and Protection Guidelines (the C&P Guidelines)

DFO has developed Habitat Conservation and Protection Guidelines based on the No Net Loss Guiding Principle. The goals of these guidelines are to ensure that proposals for projects that could affect fish or the productive capacity of fish habitat are assessed and treated in a fair and predictable manner across Canada.

The guidelines identify a hierarchy of options to protect habitat from adverse effects in accordance with the No Net Loss Guiding Principle. The hierarchy of options is as follows (in order of preference):

1. Relocation or physically moving a project, or part of a project, to eliminate adverse impacts on fish habitat.
2. Redesign of a project so that it no longer has negative impacts on fish habitat.
3. Compensation, developed following a hierarchy of preferred compensation options and included in a Fisheries Act authorization (Subsection 35(2)) for implementation. Note that conditions regarding compensation measures must be formalized through legal agreement.

Project proponents are expected to provide to DFO mitigation and/or compensation measures sufficient to alleviate potential impacts and/or compensate for any loss in the capacity of habitat to produce fish. These measures must be generally effective and for each project must be assessed to ensure that objectives are met.

In the context of the British Columbia Instream Flow Guidelines for Fish, relocation, redesign and compensation are possible on most projects. Relocation of project facilities may reduce impacts: for example, moving a powerhouse tailrace upstream from anadromous fish habitat into an impassable canyon may eliminate direct impacts to fish habitat. Projects can be redesigned: refining project flow requirements to meet the flow thresholds is effectively design of a project to avoid impacts to fish. So too can flow management practices and flow management technology (pressure release valves to allow continuous flow) offset potential impacts.

Compensation is DFO's least preferred option and is considered only when relocation and redesign prove impractical and where mitigation is ineffective. Compensation for habitat losses caused by instream flow withdrawal is problematic and will be carefully and critically reviewed by DFO. However, where instream flow thresholds cannot be met, there are options for habitat compensation. The hierarchy of preferred compensation options (taken directly from the C&P Guidelines) is:

- create similar habitat at or near the development site within the same ecological unit;
- create similar habitat in a different ecological unit that supports the same stock or species;
- increase the productive capacity of existing habitat at or near the development site and within the same ecological unit;
- increase the productive capacity of a different ecological unit that supports the same stock or species;
- increase the productive capacity of existing habitat for a different stock or a different species of fish either on or off site.

Compensation involves replacing damaged habitat with newly created habitat or improving the productive capacity of some other natural habitat. However, compensation may not be an option for particularly valuable habitat.

In the context of the guidelines, compensation may not be acceptable for water allocations that exceed instream flow criteria. Some streams will be unable to withstand instream flow reductions and maintain productive capacity. This will depend on the factors defining productive capacity for the habitat and fish species in question.

Detailed multi-year studies may be required to define the compensatory needs. If accepted and built, compensation habitats require ongoing monitoring and maintenance and may require redesign to ensure effectiveness. Given the significant risks to fish habitat when compensation is required, and the difficulty in designing and maintaining effective compensation habitat and the costs therein, proponents should view compensation as a last resort.

4.6.4 Directive on the Issuance of Subsection 35(2) Authorizations

DFO issues authorizations to harmfully alter, disrupt or destroy fish habitat only when other options are unworkable. "Unworkable" has no strict definition, but demands that a proponent give specific reasons why mitigation or design changes cannot reasonably be made. Changes in project design or implementation are preferred by DFO, including the relocation of the project or parts thereof. In the case of water licence applications, the proposed site of water intake and discharge may be moved to avoid a HADD. If a project is redesigned such that no HADD occurs, the project will then be in compliance with the *Fisheries Act* and no authorization will be needed. On the other hand, if it is impossible to avoid a HADD, an authorization under Subsection 35(2) will be required. Although it is legal to proceed with a project without such an authorization, any resulting damage to fish habitat will be liable to prosecution under the

Fisheries Act. Necessary permits from other regulatory agencies may not be issued until an authorization is received. An authorization covers only fish habitat related aspects of a project and does not in and of itself allow the project to proceed because other regulatory agencies may also have specific requirements.

4.7 Canadian Environmental Assessment Act (CEAA)

Although Canadian Environmental Assessment Agency does not have legislation directed specifically at hydroelectric projects or water use, the Guide to the Implementation of CEAA describes how to classify projects and when to consider a project reviewable under the Act. The first consideration in determining if the *Canadian Environmental Assessment Ac*t applies is to evaluate whether a particular operational change constitutes a project as defined under the Act, defined as either 1) an undertaking in relation to a physical work or 2) a proposed physical activity not relating to a physical work that is listed in the CEAA Inclusion List Regulation. The Inclusion List Regulation includes "…the harmful alteration, disruption or destruction of fish habitat by means of draining or altering the water levels of a water body that require the authorization of the Minister of Fisheries and Oceans under subsection 35(2) of the *Fisheries Act*." Thus any change to a flow regime in a stream or lake (i.e., operation at levels below the existing regime) that created a HADD would meet the definition of a project under CEAA.

Under the *Canadian Environmental Assessment Act*, federal departments and agencies must undertake an environmental assessment before they issue an authorization to a project. Thus DFO must undertake a CEAA assessment prior to issuing an authorization (i.e., a HADD authorization triggers a CEAA review). A CEAA review may be relatively brief if the project has minimal environmental impacts, requiring only a "screening review" that documents predicted environmental effects, specifies redesign options or mitigation, and identifies additional studies required. A screening review may be sufficient if, after review, the impacts are considered insignificant (i.e. there may be impacts but they are small in the context of the population or habitat): note that this does not mean that there will be no impact. Projects with greater potential environmental impacts may require a comprehensive study that can lead to detailed assessment. If environmental effects of a project are uncertain or potentially significant, or if public concern warrants, a review by an independent EA review panel or mediator may be required.

The British Columbia and Federal governments coordinate environmental review activities on projects such that proponents can avoid separate CEAA and BCEAA reviews. The reviews are harmonized such that the proponent can deal with the BCEAA review alone. The Federal government may conduct a CEAA review in parallel without involving the proponent directly in a second review process.

An important focus of CEAA is cumulative effects. Projects proposed for streams and watersheds with other licensed users must consider the cumulative effect of water withdrawal. Cumulative water withdrawals for hydroelectric and/or consumptive use increase the potential for impacts to fish and habitat and may impose requirements for additional study over that required for a single project. This issue has been considered in the drafting of the flow guidelines, which are calculated relative to the natural flow of a stream and so factor in existing uses, providing a guideline that allows incremental allocation up to a fixed level. By requiring a naturalized flow as a reference point, the guidelines consider cumulative effects at the site of withdrawal. However, downstream impacts still need to be considered. For example, diversion for consumptive use creates impacts downstream to saltwater, therefore the cumulative effects of multiple diversions in the lower reaches must be considered by calculating the flow thresholds based on naturalized flows in the lower river. Similarly, rivers with multiple small hydroelectric projects may experience a cumulative environmental effect beyond the individual effects attributable to each project. Cumulative effects arising from activities other than water use must also be considered where such impacts could contribute to the effects of water withdrawal. For example, thermal effects from small hydro projects are typically minimal and can be avoided by adherence to the guidelines, however, in the case of river basins where natural vegetation has been largely removed, any change in temperature may be detrimental, requiring an assessment.

4.8 Species at Risk Act

The Species at Risk Act (SARA) received Royal Assent in December 2002, and Proclamation is expected to occur in 2003. SARA will be the first Act in Canada to provide legal protection for species designated by The Committee on the Status of Endangered Wildlife in Canada (COSEWIC). More detailed information is available at www.speciesatrisk.gc.ca.

SARA is founded on and formalizes the principles laid out in the Accord for the Protection of Species at Risk , which was drafted in the spring of 1995, following public workshops to determine what should be included in a national approach to protecting species at risk. In October 1996, wildlife ministers agreed in principle to the Accord and committed to a national approach to protect species at risk. SARA aims to protect wildlife at risk from becoming extinct or lost from the wild, with the ultimate objective of helping their numbers to recover. The Act will cover all wildlife species listed as being at risk nationally and their critical habitats.

Until SARA's regulations are developed and the Act is proclaimed, water use project proponents should seek guidance from regulators regarding the implications of the Act for their project.

5.0 HYDROLOGY AND CHANNEL MORPHOLOGY

5.1 Hydrologic diversity in British Columbia

There are three broad climatic gradients in British Columbia: latitudinal, longitudinal, and elevational. Northern regions are cooler than southern regions, western regions are wetter than eastern regions, and high elevations are cooler than low elevations. Since BC is topographically diverse, these gradients combine to create a climatically and hydrologically diverse province.

Classifying this hydrologic diversity requires defining regions of relative homogeneity (e.g., similar magnitude, frequency and duration flows). Using streamflow data from Water Survey of Canada, British Columbia has been separated into 41 homogeneous hydrologic zones (Province of British Columbia 1995). Classification was based on mean annual discharge, month with the greatest total discharge, percentage of annual runoff within that month, and other hydrologic factors. The zones and their characteristics are presented in Table 2 and Table 3.

It is clear from examining these tables that BC is hydrologically diverse. It should therefore be kept in mind that while hydrologic classifications may be useful, homogeneity is a function of scale, and within each region there may still be significant variability in hydrologic regimes. This "residual variance" can be relevant to the distribution and abundance of fish in streams within a region.

Differences in annual hydrographs have implications for fish and habitat, and should be considered when developing a recommended schedule of instream flows. Figure 3 illustrates the annual hydrographs of two streams: Lingfield Creek in the Chilcotin, and Carnation Creek on Vancouver Island. The shape of the hydrographs differ in magnitude and timing of the peak and low flows—Lingfield Creek shows an extended late spring and summer freshet, whereas Carnation Creek flows peak in the fall and spring. These divergent patterns exist despite similar amounts of annual flow, and highlight how a single summary statistic like MAD cannot capture patterns of streamflow. Hydrographs and hydrometric summary statistics are presented for a variety of BC streams in Appendix A.

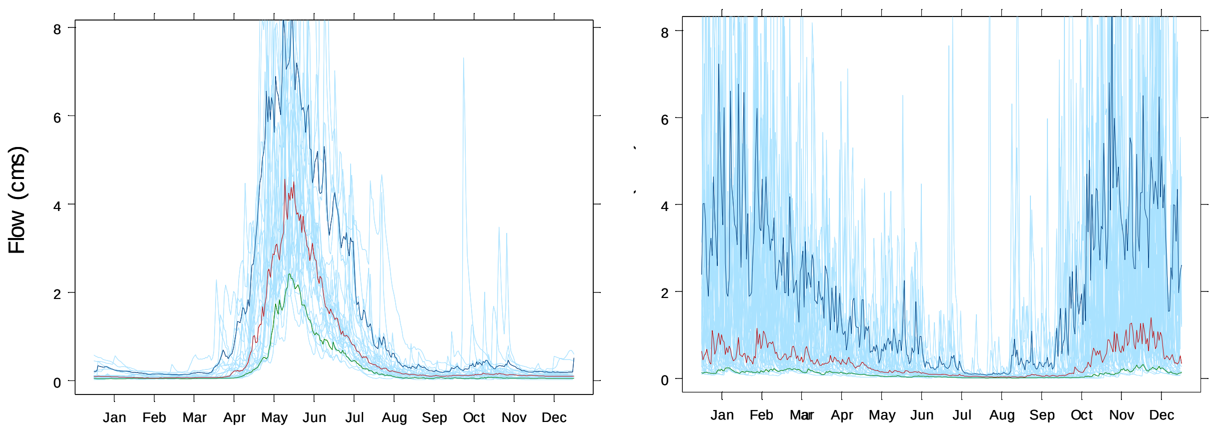

Figure 3. Hydrographs for Lingfield Creek (left) and Carnation Creek (right). The two streams have approximately the same annual discharge, MAD ˜ 0.8 $m^3 s^{-1}$. The light blue lines trace mean daily flows with years superimposed. The dark blue lines are 90th percentiles of daily flows, the red line is the 50th percentile (i.e., median) of daily flows, and the green line is the 10th percentile of daily flows.

BC's hydrologic diversity has considerable relevance for instream flow standard-setting techniques. The diversity underscores the difficulty of developing a single simple set of flow guidelines that can apply across the province. To demonstrate this, one can apply Tennant's criteria (see Section 9.2) to natural hydrographs in different regions and compare the "fit" between observed flows and recommended flow. Figure 4 presents examples of such comparisons for four streams from different regions.

There are notable discrepancies between Tennant's flow recommendations for "good" stream conditions and the natural hydrographs in several of BC's hydrologic zones. The largest discrepancies occur in zones where peak streamflows are not dominated by snowmelt. For example, rain-dominated systems exhibit winter runoff peaks, and summer minima, a temporal pattern that is reversed relative to Tennant's criteria. In some cases the recommended flows are well above those naturally occurring in a stream. (It should be noted that, while it may be important to protect flows during this time of year, this type of discrepancy was deemed to be unreasonable and undesirable by a number of agency staff.) Tennant's original criteria clearly fail in some hydrologic zones.

Table 2. British Columbia's hydrologic zones (from Summit 1998).

			Mean Annual Runoff		Mean annual peak flow per 100 km^2		Yearly Distribution	
Zone	Name	Number of Observations	(mm)	rank	(m^3/s)	rank	Peak Month	% of Annual Runoff
1	Northern Coast Mountains	15	1278	14	36	15	June, July	28 - 20
2	Tahltan Highlands	3	506	26	11	26	June, July, August	26 - 25
3	Stikine Plateau	20	432	29	7	34	June, July	33 - 24
4	Cassiar Ranges	8	342	32	8	32	June	32 - 29
5	Liard Plain	11	341	33	7	36	May, June	32 - 14
6	Muskwa Ranges	13	393	31	15	24	June, July	29 - 14
7	Fort Nelson Plains	15	195	38	10	30	May, June	43 - 22
8	Peace Plains	17	200	37	7	37	May, June	38 - 17
9	Central Rocky Mountains	7	559	24	19	21	May, June	31 - 24
10	Northern Interior Plateau	9	393	30	46	11	May, June	35 - 21
11	Skeena Mountains	3	2045	6	43	13	July	27 - 22
12	Nass Basin	2	1709	11	36	14	June	22 - 23
13	Queen Charlotte Ranges	1	927	17	n/a		Nov, Dec, Jan	17
14	Skidegate Plateau	3	2003	9	81	8	Oct, Nov, Dec	22 - 14
15	Queen Charlotte Lowland	1	933	16	66	9	Nov, Dec, Jan	16
16	Hecate Lowland	4	2056	5	93	5	Oct, Nov	17 - 15
17	Exposed Fjords	3	2144	2	105	2	May, June	32 - 16
18	Central Coast Mountains	22	1354	12	20	20	June, July	29 - 17
19	Central Interior Plateau	27	268	36	6	39	May, June	43 - 21
20	Nechako Lowland	10	336	34	10	29	May, June	41 - 23
21	McGregor Ranges	7	625	21	22	18	May, June	27 - 20
22	West Cariboo Mountains	19	614	22	9	31	May, June	34 - 22
23	Columbia Mountains	29	1161	15	27	17	June, July	33 - 21
24	Northern Park Ranges	17	733	18	17	22	June, July	31 - 23
25	Shuswap Highland	18	571	23	10	28	May, June	44 - 23
26	Southern Park Ranges	29	542	25	16	23	May, June	36 - 23
27	Cranbrook Plateau	15	496	27	14	25	May, June	41 - 21
28	Southern Selkirk Mountains	17	688	20	21	19	May, June	40 - 29
29	Okanagan Dry Belt	6	169	40	6	38	May	42 - 31
30	Okanagan Range	3	180	39	7	35	May, June	40 - 32
31	Thompson-Okanagan	39	144	41	4	40	May, June	51 - 24
32	Cascade Mountains	13	283	35	11	27	May, June	43 - 29
33	Chilcotin Ranges	6	470	28	8	33	June	29 -18
34	Garibaldi Mountains	6	2013	7	45	12	June, July	21 -17
35	North Shore Ranges	29	2117	3	91	6	Nov, Dec, Jan /May, June	29 - 12
36	Bute Inlets	4	2110	4	59	10	June/Nov	20 - 13
37	Owikeno Ranges	3	2012	8	36	16	Feb/ June	21 - 13
38	Windward Island Mountains	11	2884	1	267	1	Nov, Dec	19 - 13
39	Leeward Island Mountains	28	1892	10	100	3	Nov, Jan	27 - 13
40	Georgia Basin	13	1282	13	96	4	Dec, Jan	32 - 14
41	Puget Basin	5	724	19	90	7	Dec, Jan	38 - 18

Table 3. Characteristics of British Columbia's hydrologic zones (summarized from Summit 1998).

Geographic Region	Hydrologic Zones (no.)	Characteristics
Northern British Columbia	Northern Coastal Mountains (1) Tahltan Highlands (2) Stikine Plateau (3) Cassiar Ranges (4) Liard Plain (5) Muskwa Ranges (6) Fort Nelson Plains (7)	• Annual runoff decreases steadily from west to east • max = 1278 mm (zone 1); min = 195 (zone 7) • Peak flows are relatively low, generated by snowmelt, latitude affects timing • Typically, 30% of annual discharge occurs in the month of highest flow. • Low flows occur in winter.
North Central British Columbia	Peace Plains (8) Central Rocky Mountains (9) Northern Interior Plateau (10) Skeena Mountains (11) Nass Basin (12)	• Annual runoff is variable: relatively high for zones 1, 11, and 12, drops sharply across zone 10, rises again through zone 9 then drops again in zone 8 • Zones 7 & 8 among the lowest annual runoff in BC • Runoff peaks are generated by snowmelt, with about 30% of the annual runoff occurring in the peak month. Timing is variable. • Peak flows are highest for zones 10, 11, and 12 • Low flows occur in winter.
Central British Columbia	Hecate Lowland (16) Exposed Fjords (17) Central Coast Mountains (18) Central Interior Plateau (19) Nechako Lowland (20) McGregor Ranges (21)	• Annual runoff is variable: relatively high in zones 16, 17, 18, falling off dramatically within zones 19 and 20, and increasing again in zone 21. • Peak runoff is associated with spring snowmelt for all zones except 16, in which it is associated with rainfall often accompanied by melting snow. • peak flow month in this zone accounts for only 17% of the total annual runoff • Peak flows are highest in zones 16 and 17. • In zone 16 July and August are the months with lowest flow, but in all the other zones the lowest flows occur in winter.
Queen Charlotte Islands	Queen Charlotte Ranges (13) Skidegate Plateau (14) Queen Charlotte Lowland (15)	• very high annual runoffs • Monthly and daily peak discharges occur in response to winter storm events, and typically the month of highest flow accounts for about 18% of the total annual runoff. • Low flows occur in July and August
South coastal British Columbia	Hecate Lowland (16) North Shore Ranges (35) Bute lnlets (36) Owikeno Ranges (37) Windward Island Mountains (38) Leeward Island Mountains (39) Georgia Basin (40)	• All have very high annual runoff values with the exception of zone 41. • highest annual flows are produced by fall and winter storms, though high snowmelt-generated peak flows in spring occur in zones 35, 36 and 37. • The month with the highest runoff typically accounts for about 20% of the total annual runoff

	Puget Basin (41)	
Southwestern British Columbia	Central Coast Mountains (18) Okanagan Ranges (30) Cascade Mountains (32) Chilcotin Ranges (33) Garibaldi Mountains (34)	• annual runoff varies greatly, with variations reflecting distance inland of each of the ranges. • Peak flows are vary; typically generated by snowmelt; timing varies • Lowest flows of the year occur in winter, except for zone 32 where low flows occur in winter and in late summer.
South central British Columbia	Central Interior Plateau (19) Okanagan Dry Belt (29) Thompson-Okanagan Plateau (31)	• These zones are quite dry, with very low annual runoff • Peak flows are associated with snowmelt in May or June • flows in the highest month account for about 30% of the total annual runoff. • Average annual peak flow levels tend to be quite modest • Low flows occur in early winter.
Southeastern British Columbia	West Cariboo Mountains (22) Shuswap Highland (25) Southern Selkirk Mountains (28) Cranbrook Plateau (27)	• annual runoff is higher than for the three south central zones • Snowmelt generates the peak flows during May or June, and flow in the highest month accounts for upwards of 35% of the total annual discharge
	Columbia Mountains (23) Northern Park Ranges (24) Southern Park Ranges (26)	• Annual runoff is fairly high • Peak flows are snowmelt generated; relatively low peak flows for mountainous regions; timing is variable: late spring through early summer • The lowest flows in all the southeastern BC zones occur in winter.

Additional discrepancies are reviewed in Summit (1998). For example, in the Northern half of the province, where cold winter temperatures contribute to low winter flows, mean monthly flow tends to fall below the "good" Tennant coefficient during the winter. In other hydrologic zones (1 – 12) the general hydrologic characteristics are similar to those in the geographic region investigated by Tennant, but the month-to-month range is greater than assumed by the original Tennant system. There may also be notable elevational effects causing shifts in streamflow timing relative to Tennant's criteria. These discrepancies underscore the difficulty in developing a "one-size-fits-all" approach for streamflow thresholds in BC, as well as the general difficulty of developing regional corrections for the Tennant approach.

5.2 Cross-sectional channel form and hydraulic geometry

During the review process of the Phase I report and the "Rationale" document (Ptolemy and Lewis 2002) there were requests to examine existing information on stream geometry to see whether it was possible to develop instream flow guidelines based on morphological "first principles." This section presents background to the general field of channel geometry and an assessment of the applicability of channel geometry relationships to instream flow guideline setting for BC streams. It is excerpted from a letter report written by Scott Babakaiff, Regional Hydrologist, Ministry of Water Land and Air Protection, Surrey, British Columbia (Babakaiff 2002).

The dominant controls on cross-sectional channel form are discharge, the absolute and relative amounts of bedload transport, and the composition of channel boundary, particularly as it relates to bank stability (Knighton 1998). Although absolute channel dimensions are scale-dependent and depend on the discharge regime imposed by the upstream catchment (Yu and Wolman 1987), the main control of channel shape is boundary composition (Richards 1982). In general, channels with silty banks tend to be narrow and deep in cross-section, (i.e., small width/depth, or w/d, ratio), whereas those with sandy erodible banks tend to be wide and shallow (i.e., large w/d ratio). Many studies have also shown that removal of intact mature vegetation will increase the likelihood of a greater w/d ratio (e.g., Zimmerman et al. 1967), most notably in banks with low cohesion, or a low proportion of silt and clay. These and other relations may be considered in an integrated manner via hydraulic geometry.

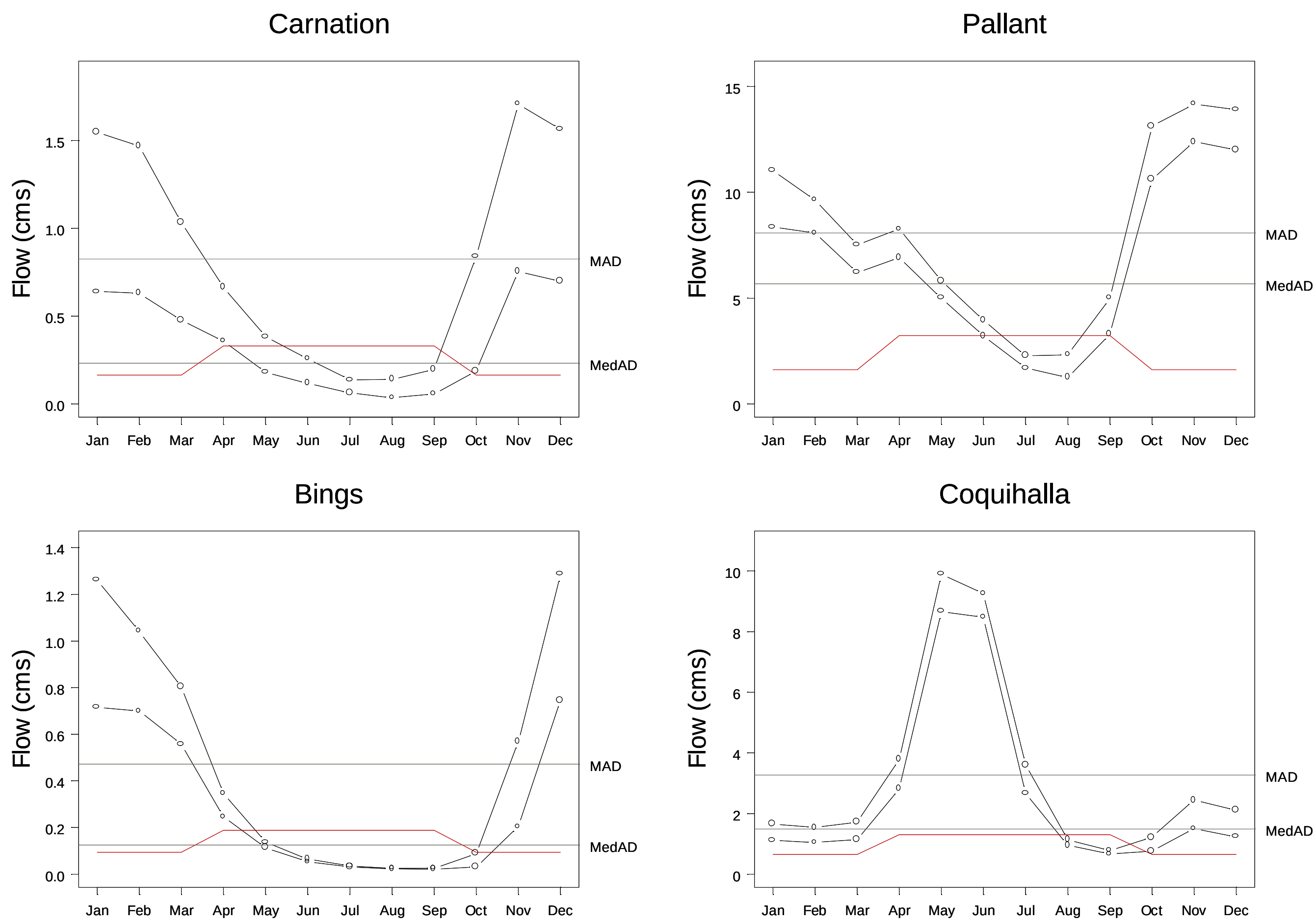

Figure 4. Hydrographs from streams in different regions of BC. Tennant's recommended instream flows for "good" stream conditions are plotted in red.

Hydraulic geometry is a quantitative description of how river width, depth, velocity and related properties vary with changing discharge (Leopold and Maddock 1953). Such relations have been used as a component of hydraulic modelling for instream habitat simulation (e.g. Hogan and Church 1989), and have been compared favourably to more costly and time-consuming methods such as the Incremental Flow Instream Method (IFIM). Several studies have concluded that hydraulic geometry provides a promising method for making an initial assessment of environmental impacts of proposed flow changes, *provided habitat requirements can be specified in terms of mean velocity and depth relations in habitat assessment*. Jowett (1998) developed at-a-station hydraulic geometry relations, and compared predicted mean depths and velocities to the results of IFIM: mean depths and velocities were within 15% of values predicted by IFIM surveys. Milhous et al. (1989) had similar results, concluding that the weighted usable area derived from relations of hydraulic geometry versus those derived from IFIM were usually within 20% of each other. However, a broadly-accepted methodology of habitat simulation based on hydraulic geometry has remained elusive, and alternate methods (e.g., Tennant 1976) have gained wide appeal.

Relations of hydraulic geometry may be considered over time at one site ("at-a-station") or between various sites at a comparable discharge frequency ("downstream"). At any one time and place, mean width (w), mean depth (d) and mean velocity (v) are interrelated by the continuity equation (discharge Q= wdv), so it follows that at any spatial or temporal change in discharge must be accommodated by a suitable combination of changes in width, depth and velocity. At-a-station hydraulic geometry has been found to provide "a valuable means of describing and analysing flow behaviour at the cross-sectional scale, with implications for instream ecology and river management" (Knighton 1998).

The seminal paper of Leopold and Maddock (1953) introduced logarithmic plots of river properties against discharge, with trends described by the power laws:

$$\text{Width (w)} = aQ^b$$
$$\text{Depth (d)} = cQ^f$$
$$\text{Velocity (v)} = kQ^m$$

The exponents of these relations (b, f, and m) describe the rate of change of the respective variables with changing discharge. Since continuity must be maintained, these relations are linked (b+f+m=1). For example, any constraint on b (i.e., the rate of change of width with discharge) will affect f and m (the respective rates of change of depth and velocity with discharge). Initial studies found that at-a-station relations were well-fitted by linear regression once log-transformed (or plotted on logarithmic graph paper), and that the exponents b, f, and m (i.e., the slopes of the fitted linear relations) were reasonably consistent between cross-sections of various streams (Table 4).

These initial studies were often limited to channels sharing common geomorphic characteristics; work in the past three decades indicates that the hydraulic response to changes in discharge is quite variable. Knighton (1975) found great scatter in b, f and m depending on channel planform and bank materials. Park (1977) and Rhodes (1977) collated available results, and found huge scatter in the exponents: $0 < b < 0.6$; $0 < f , m < 0.7$. Rhodes (1977) partitioned the scatter by differentiating data according to channel planform (i.e., straight, meandering,

Table 4. Summary of at-a-station hydraulic geometry studies (1953-1975). (Reproduced from Heede (1972) and Knighton (1998)).

Source	Location	b	f	m	# sites
Leopold & Maddock (1953)	Mid-western United States	0.26	0.40	0.34	20
Wolman (1955)	Brandywine Creek, Pennsylvania	0.04	0.41	0.55	7
Leopold & Miller (1956)	Ephemeral streams, semi-arid United States	0.25	0.41	0.33	10
Leopold, Wolman & Miller (1964)	Ephemeral streams in semiarid United States	0.21	0.36	0.43	
Leopold, Wolman & Miller (1964)	Stream gauges sites in United States	0.12	0.45	0.43	158
Lewis (1969)	Rio Manati, Puerto Rico	0.17	0.33	0.49	10
Wilcock (1971)	River Hodder (coarse bed, cohesive banks)	0.09	0.36	0.53	9
Heede (1972)	Fool Creek, central Rocky Mountains	0.05	0.43	0.52	
Knighton (1975)	River Bollin-Dean (coarse bed, cohesive banks)	0.12	0.40	0.48	12
Harvey (1975)	River Ter (cohesive banks)	0.14	0.42	0.43	8

braided), but this was likely also a function of channel cross-section shape. Despite broad variability in these exponents, Ferguson (1986) proposed that the relations are determinate, based on laws of hydraulics and relations of flow resistance. Standard flow resistance equations determine the rate of change of velocity with depth, and channel geometry (i.e., cross-section shape) determines the rate of change of width with depth. However, the wide range of frictional characteristics and channel shapes will not allow a universally-applicable set of at-a-station hydraulic geometry relations.

Recent work has also raised uncertainty regarding functions used to fit relations of hydraulic geometry at individual cross-sections. Ferguson (1986) proposes that the relations of hydraulic geometry are not necessarily power functions, and does not expect all log-transformed relations to be well-described by linear equations. This notion is supported by numerous studies (Richards 1973; Knighton 1979), but several processes may be responsible for non-linear responses:

Complex channel shapes. In many natural channels, flow at low discharge may be confined to a narrow channel inset into the stream bed, and the width-discharge curve will display a discontinuity in the plotted (linear) relation at the discharge where the inset channel capacity is exceeded (Lewis 1966). Variability in bank slope caused by sediment accumulations such as bars and bank slumps will also affect the hydraulic relations. For instance, Hogan and Church (1989) found that the relations of at-a-station hydraulic geometry for Hangover Creek were well described by power functions, but the plots displayed a break in slope at a discharge ~ 1 $m^3 s^{-1}$. This response is caused by channel shape: a sharp change in bank angle occurs at the stage when discharge ~ 1 $m^3 s^{-1}$. Below this threshold, increases in discharge are attributable primarily to increases in mean velocity and channel width, with little change in mean depth. Above this threshold, increases in discharge are attributable primarily to increases in mean depth and velocity, with little change in channel width. Based on one year of flow monitoring, this "threshold" flow was 200% MAD, and was exceeded ~ 34% of the year, but such values will vary depending on the channel shape. The value for this threshold discharge is a function of the topography of inset channel features (e.g., width and elevation of bars). The threshold discharge in Hangover Creek occurs at a relatively high flow, attributable to a bar occupying a large proportion of the bankfull width; the threshold discharge occurs at the stage when the bar is inundated.

Changes to channel shape. Knighton (1998) differentiated the response of at-a-station hydraulic variables to changes in discharge into multiple phases, depending upon whether discharge exceeds the threshold discharge (Q_t) required for mobilization of channel bed sediment, or exceeds the overbank discharge (Q_b). He proposed that most studies of at-a-station hydraulic geometry have implicitly assumed that $Q_t \sim Q_b$, and that data has been collected at discharges less than the threshold discharge. Such relations of hydraulic geometry are determined largely by the cross-sectional form relic from the previous bed-mobilizing discharge.

Variability of flow resistance. Many factors influence flow resistance, including cross-section irregularities, channel shape, obstructions, vegetation, channel meandering, sediment load, floodplain conditions, etc. Several equations have been developed to quantify flow resistance. The most commonly applied are the Darcy-Weisbach, Manning, and Chezy equations, and their respective resistance coefficients (friction factor ff, Manning's n, and Chezy's C). Many studies have found an inverse relation between the resistance coefficient and discharge (i.e., resistance decreases with increasing discharge, as grain roughness is drowned out), but the relations display a wide scatter in the relations, and may not obey a power law. Some researchers have reduced the scatter in such relations by considering a narrow range of hydraulic condition, but discontinuities in relations of hydraulic geometry persist (Ferguson 1986), as there are complexities associated with sediment transport and free surface resistance.

Knighton (1998) concludes that the variability of at-a-station geometry inhibits the drawing of simple conclusions: "…the width exponent (b) appears to be largely a function of channel geometry and therefore boundary composition, while the rates of change of depth (f) and velocity (m) are dependent partly on cross-sectional form and partly on transport- and resistance-related factors which tend to be more variable". The wide range in b, f and m found in datasets integrated from a wide variety of fluvial environments is not surprising given the variability in channel shape and flow resistance within the cross-sections. Datasets that minimize this variety (e.g., Wolman, 1955; Andrews, 1984) will display a narrower range in the exponents. For example, Castro and Jackson (2001) differentiated Washington State into several hydrologic regions on the basis of hydraulic geometry relations. Likewise, the likelihood of a well-fit suite of log-linear relations will increase as the difference between the bankfull discharge and threshold discharge decreases.

Despite these complexities, Jowett (1998) developed relations of hydraulic geometry for 73 river reaches in New Zealand and concluded that "hydraulic geometry can be used as a preliminary means of indicating whether mean hydraulic conditions that result from a change in flow are 'safe' or approaching a threshold such as minimum acceptable depth or velocity, thus predicating the need for a more extensive habitat survey and analysis." This suggests that relations of at-a-station hydraulic geometry are not constant, but that trends may be apparent in datasets that have been differentiated on the basis of channel shape and flow resistance. Jowett (1998) concluded that "the relationship between mean annual discharge and hydraulic habitat (depth and velocity) varies with river size…water depths at 10% of the mean annual flow in a small stream will be less than water depths at 10% of the mean flow of a large river". This issue is addressed further in Section 6.4.

Church (1996) proposed that the most fundamental division of river channels should be made between 'small channels', where channel scale is comparable with the scale of individual sediment grains, and 'larger channels' on which the boundary is made up of aggregate structures of grains. He differentiated channels into one of three classes, based generally on bank material calibre and relative roughness (bed material diameter/bankfull depth):

1. **Small channels** generally have relative roughness > 1.0 and flow through cobble-sized material or larger. Individual clasts (grain roughness) are significant elements of flow resistance. Small channels generally have gradient > 4% and bankfull width < 20 m.

2. **Intermediate channels** have a bankfull width much greater than bed material size, but a significant portion of channel cross-section may be occupied by fallen trees or sediment accumulations (i.e., bars). This criterion places an upper width limit on intermediate channels of ~ 20-30 m, and an upper gradient limit of ~ 5%. The pool-riffle-bar unit is a primary physical element, and bars generally require relative roughness < 0.5. Church (1996) claims that intermediate channels constitute optimum spawning and rearing habitat for a range of fish.

3. **Large channels** have their morphology determined by fluvial processes and geological constraints, rather than individual structural components. The transition from intermediate channels occurs at width ~ 20-30 m, and bankfull discharge ~ 20-50 $m^3 s^{-1}$. Channel gradient is typically < 2%, and often < 0.5%.

The components of these definitions are inter-related. For example, gradient generally decreases as stream size increases. Mean depth varies inversely with slope when flow is uniform, so a steep river will be shallower and swifter than a low gradient river for the same channel shape and discharge (Jowett 1998). The b, f, and m components of hydraulic geometry vary inversely with gradient (Church 1996); despite mean velocity being greater (and mean depth being less) in steep channels, the relative rate of change in mean velocity with increasing discharge (m) is greater in flat channels. In intermediate channels, where steep and flat sections are respectively represented by riffles and pools, the relative differences in m can result in mean velocity in the pools exceeding that of riffles at high discharges[3].

As previously described, studies summarizing relations of at-a-station hydraulic geometry found a wide scatter in the values of b, f and m; Park (1977) found modal values of 0.0-0.1, 0.3-0.4, and 0.4-0.5 respectively (i.e. m>f>b). Rhodes (1977) also found that f>b at 90% of sites, but observed two commonly occurring channel conditions:

[3] This 'velocity reversal' has been noted by several researchers (e.g. Richards, 1977; Hogan and Church, 1989), and although a definitive explanation remains elusive, it is likely a function of reduced stream gradient along the downstream side of riffles as discharge increases and the riffles are backwatered.

1. the rate of change of velocity with discharge was much higher than the other components: **m>f>b** (and m> f+b),
2. the rate of change of depth with discharge was slightly greater than the rate of change of velocity with discharge, but both components are greater than the rate of change of width with discharge: **f>m>b** (and m ˜ 0.67-1.0 f).

The cause for such differentiation in the two channel conditions (and their exponents) is uncertain. Cross-section shape would seem an obvious candidate, but recent studies do not support this hypothesis. Ferguson (1986) calculated theoretical hydraulic geometry relations for four (rectangular, triangular, parabolic and bend) channel shapes, and found that m>f>b for *all four* shapes. However, ratios of the various components (e.g., b/f, m/f) varied as a function of channel shape and relative roughness. Miller (1991) found that components of at-a-station hydraulic geometry were affected by channel size and bed roughness. Variables representing channel size (MAD, channel width, width/depth ratio) were found to constrain b, and streams with a high % silt-clay in the bed[4] constrained m. In the most detailed study of hydraulic geometry in recent decades, Jowett (1998) found that U-shaped channels ("parabolic" in Ferguson 1986) tended to have higher b and lower m components than V-shaped channels ("triangular" in Ferguson 1986), but concluded there were "poor relationships between channel shape and hydraulic geometry, especially depth and velocity, and this would make it difficult to estimate habitat response to flow changes from the appearance of the river alone." These findings imply that a key aspect is the variance of flow resistance as a function of changes in discharge. This is most critical in small to intermediate-sized channels where relative roughness varies widely with over low to moderate flows.

There have been few studies of hydraulic geometry in small to intermediate channels where relative roughness varies widely over low to moderate flows (i.e., cobble or greater sized material in streambed). The data sets of Castro and Jackson (2001), and Jowett (1998) included some reaches that may be defined as such, but the components of hydraulic geometry were not provided for each reach: only average values (and associated standard deviations for Jowett 1998) are included. Hogan and Church (1989) found that m>f>b (0.60, 0.22 and 0.18, respectively), but noted that the response of width and velocity is not proportional across the range in discharge: a small change in discharge at low flows results in a relatively large change in width and velocity. As described above, the width response is merely a function of channel shape, but the rapid changes in velocity are attributable to a drop in flow resistance as roughness elements are drowned out. Inspection of hydraulic data collected in New Zealand streams suggests that this effect is most apparent in streams having a w/d ratio of 10 or greater and a D50 exceeding 30 mm (Hicks and Mason 1998). Hogan and Church (1989) also warn that there may some bias in discharge measurement at low flows where "a significant portion of flow may occur through the streambed gravels below the bed surface. This would result in overestimates of open water discharges at these sites." Theoretical work by Ferguson (1986) suggested that the power law approximation of traditional flow resistance equations cease to apply when relative roughness < 3. Field studies completed by the New Zealand National Institute of Water and Atmospheric Research suggest that when water depth is similar to the

[4] Streams with a high %silt-clay in the bed have roughness characteristics controlled by bed configuration (i.e. bedforms), not particle size as in gravel-bed streams. So as discharge increases in streams with high %silt-clay in the bed, roughness is *increased* by changes in bed configuration, and the proportional increase in velocity ("m") is constrained.

bed-material size, the roughness sublayer extends to the water surface and traditional hydraulic parameters are not clearly defined (Smart 1999 and unpublished data[5]). There are few detailed data on the hydraulic response of small to intermediate gravel/cobble-bed streams at low to moderate flows.

Small to intermediate sized gravel- and cobble-bed streams likely constitute the majority of BC stream types that will undergo instream flow assessment. With the aim of developing at-a-station hydraulic geometry equations for such streams, a field monitoring program was established in July 2002 on five BC streams. The study program has been expanded by MWLAP Region 2 to include researchers at Simon Fraser University, and preliminary results are expected by April 2004.

5.3 Use of channel geometry for habitat assessment and standard-setting

Two strategies for employing at-a-station hydraulic geometry to assess instream flow needs have been presented in the literature. Both assume that fish habitat can be quantified in terms of velocity and depth, such that a minimum desirable discharge to provide these conditions may be calculated. Hogan and Church (1989) recommend a complex strategy using a "disaggregated bivariate distribution of velocities and depths (e.g., Mosely, 1982)" for assessing instream flow needs. Jowett (1998) developed average hydraulic geometry relations to estimate flows required to meet specific velocity and depth criteria. Jowett (1998) proposed the following methodology to apply average at-a-station hydraulic geometry to instream flow assessments:

1. Measure width and average depth at five cross-sections in intermediate (run) habitats. (Note: recent work summarized in Stewardson (2003) supports use of five cross-sections. He found that the variability in hydraulic geometry exponents (as fitted by regression) decrease as the number of cross-sections increases to five, but that reach-averaged values were relatively unaffected by additional cross-sections),
2. Establish temporary staff gauges on each cross-section and record water levels (l_1),
3. Measure flow (Q_1) at the cross-section with the most uniform flow characteristics,
4. Calculate mean depth (d_1) and width (w_1) for reach,
5. When flow has changed, measure flow again (Q_2) at the most uniform cross-section, measure widths (w_2) and water levels (l_2) at each cross-section from staff gauges,
6. Calculate mean depth (d_2):

$$d_2 = \frac{(w \times [d_1 + \Delta l]) + \frac{1}{2}(\Delta l \times [w_2 - w_1])}{w_2}$$

if w_2˜ w_1, $d_2 = d_1 + ?l$

7. Calculate components a, b, f and c:

$$a = \frac{w_1}{Q_1^b}$$

[5] Study updates are provided at http://www.niwa.cri.nz/rc/prog/eh3/news.

$$b = \frac{\log(\frac{w_1}{w_2})}{\log(\frac{Q_1}{Q_2})}$$

$$f = \frac{\log(\frac{d_1}{d_2})}{\log(\frac{Q_1}{Q_2})}$$

$$c = \frac{d_1}{Q_1{}^f}$$

8. Use calculated values of a, b, f and c in the hydraulic geometry equations to give depth vs. discharge and velocity vs. discharge relationships,
9. Determine mean depth and velocity habitat requirements for the reach by increasing the target depth habitat requirement by 25% and target velocity habitat requirement by 10% to compensate for positively skewed distributions about the mean, and
10. Calculate the discharge required to provide mean depth and velocity for habitat requirements.

Jowett's (1998) methodology should be considered for BC streams. However, significant effort may be required to develop the average equations of hydraulic geometry[6] and to develop reliable relationships between fish habitat and average hydraulic conditions in a stream. The issue deserves consideration as a research priority, but it may be some time before the information is available as a decision-making tool.

Channel geometry is also considered in the context of setting minimum flows through the use of the wetted perimeter method, a relatively low-effort assessment method. The method is usually applied to riffle mesohabitats, and is most often used to develop a reference point for protecting wetted instream habitat. The reference point used to prescribe flows is usually the flow corresponding to the "point of maximum curvature" (PMC) , or an "inflection point" that describes a rapid change in at-a-station channel geometry. The wetted perimeter method is most often used to wet riffle width. Tennant (1976) specified 10% MAD as a threshold flow

[6] Efforts to utilize existing flow data to provide discrete sets of hydraulic geometry relations for particular regions or channel types in B.C. have not proved fruitful. Bachman and Hamilton (2003) developed relations of at-a-station hydraulic geometry based on data collected at Water Survey of Canada (WSC) discharge monitoring stations, but found "no spatial coherence" in the relations. Singh and Broeren (1989) had similar conclusions based on data collected at United States Geological Survey (USGS) discharge monitoring stations, and suggested that cross-sections selected for long-term discharge monitoring are biased towards 'riffle-like' conditions.

below which streams in his study area were subject to severe degradation or rapid dewatering, and this value has often been used as a guideline for macroinvertebrates.

Some experiences on BC streams indicate that, based on wetted perimeter data and PMC analysis, 10% MAD is adequate for wetting riffle habitat, and the method may be important as an indicator for icing or dessication of riffle-inhabiting life (Ptolemy and Lewis 2002). It should be noted however, that others have found that the PMC is highly subjective and the flow corresponding to it does not fully protect habitat for the macroinvertebrate community, particularly since portions of the wetted width may not provide adequate depths and velocities (Gippel and Stewardson 1998). Finally, it should be noted that there is nothing magical about the PMC value, it is merely a point on the hydraulic geometry relation where slope is equal to 1. There is no assurance that it is a biologically relevant index for stream management.

As a means of exploring wetted width relationships further we undertook some simple calculations based on the at-a-station hydraulic equation,

$$W = aQ^b$$

In the literature, values for b vary among studies, but generally are less than 0.25. In a detailed examination of 73 reaches on 68 streams in New Zealand Jowett (1998) measured mean and standard deviation of b as 0.176 and 0.066 respectively. Values from BC streams are scant but appear to be within this range (e.g., Hogan and Church 1989; Bachman and Hamilton 2003).

The hydraulic equation above describes the wetted width (also called the “top width”) of a stream as water levels rise and fall, so we can ask how much of the stream channel is wetted at a particular flow relative to some reference flow. We used MAD as the reference flow because the flow is usually fairly large (see quantile plots in Appendix A) and therefore most of the potential channel width is wetted at that flow, and because scaling relative to this flow is common in standard-setting approaches. We conducted a brief Monte Carlo simulation in which 10,000 values were drawn at random to represent the population of parameter values for b, calculated W for each value of b, and then solved for Q after setting W to a fixed proportion of that obtained at the reference flow. In this analysis we ignore the effect of the a parameter.

Results are presented in Table 5, and indicate for example that a flow of 20% MAD would wet approximately 2/3 of the average channel width in about 90% of streams. This table of values can be used to understand the implications of selecting a particular value for incorporation into the guidelines. Use of such information assumes a strong correlation between wetted width and macroinvertebrate production or equivalent biological production parameter. Selection of an “appropriate” criteria from this table would necessarily rely on subjective criteria. However, the results indicate that since hydraulic geometry is variable one would need to select a high proportion of MAD to have reasonable certainty of achieving even a modest level of protection such as 2/3 of channel width. On the other hand the results indicate that flows as low as ~7% MAD will wet half the channel width in 90% of streams, which provides some comfort that low flows may still provide ecological function. Nevertheless, the results indicate that hydraulic geometry relationships are a relatively coarse tool for stream management.

Table 5. The %MAD required to wet a set proportion of the channel width. Results are from a simple Monte Carlo simulation (see text) based on a standard hydraulic equation of channel width vs. flow.

% wetted width	% MAD required (80th percentile)	% MAD required (90th percentile)	% MAD required (95th percentile)
95%	80.46%	82.18%	83.53%
90%	63.98%	66.83%	69.09%
80%	38.83%	42.59%	45.70%
70%	22.05%	25.56%	28.61%
66.7%	17.93%	21.21%	24.11%
60%	11.47%	14.17%	16.66%
50%	5.30%	7.06%	8.79%
40%	2.06%	3.01%	4.02%
33.3%	0.95%	1.50%	2.12%
30%	0.61%	1.00%	1.46%
20%	0.11%	0.21%	0.35%
10%	0.01%	0.01%	0.03%

An alternative method for examining the applicability of stream geometry for instream flow standard-setting is to simulate channel geometry relationships over the range of parameter values, and to calculate PMC values for each relationship. To do this we used parameter values from Jowett (1998) and calculated 10,000 at-a-station curves. We assumed that parameter values varied normally, and that Q varied from 0 to 100 flow units. We then calculated PMC values for each curve and summarized them using percentiles and a density plot (Figure 5). The results indicate that PMC values tend to occur at relatively low flows, but that there is considerable variance in the PMCs over the parameter range indicated in Jowett (1998). The variance is sufficiently high that managers should be wary about selecting a single value (such as the 10% MAD value suggested by Tennant) as a management guideline. Our conclusion is that stream geometry parameter values are presently too variable for standard setting. Additional research seems warranted to investigate whether parameters are sufficiently less variable within well-defined stream morphology types. Such research should be undertaken on BC streams if a flow threshold is to be developed based on stream geometry.

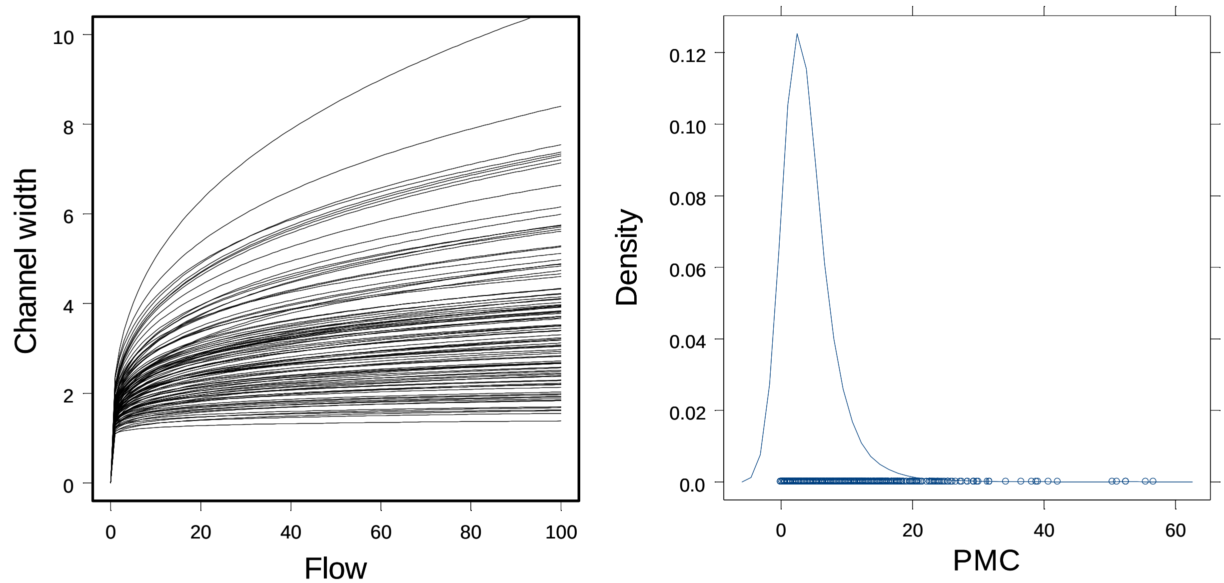

Figure 5. Left: 100 simulated at-a-station curves based on parameter values in Jowett (1998). Right: Distribution of PMC values calculated from 10,000 simulations of at-a-station curves based on parameter values in Jowett (1998).

6.0 Effect of Stream Flow on Fish Production

Construction of dams and the resulting regulation of streamflows has been massively replicated over a broad range of geographic, physical, and biological scales (Dynesius and Nilsson 1994). The influence of dams and flow regulation on fish and aquatic and riparian habitats has been intensively studied over the full range of scales. Effects of flow regulation are often profound (e.g., Grand Canyon, (Walters et al. 2000); Columbia and Snake River (Peters and Marmorek 2001); Big Qualicum River (Fraser et al. 1983)), yet in some senses we still appear to have little understanding of how to manage flows for fish. Our ability to predict biotic responses to changes in flow regime remains very limited (Castleberry et al. 1996).

Fluvial systems are physically and biologically complex, and consequently understanding instream flow needs for fish can be a daunting task. Fish abundance and biomass are the parameters that managers are usually most concerned with, but population estimation is difficult and abundance is variable, which makes it difficult to measure relationships between flow and abundance. In their attempts to understand relationships between fish production and flow, scientists have often turned to simpler surrogate measures rather than direct population estimates. For example, fish habitat is often quantified under different flow scenarios because it is relatively easy to measure and is more stable than population abundance.

In assessing the link between stream flow and fish production it is common to think rather linearly (Figure 6). In doing so, many managers appear to amalgamate two logical relationships: the link between fish habitat and fish production, and the link between flow and fish habitat. These two relationships get merged into a third: a causal link between flow and fish production (Figure 7). Difficulties in synthesizing and implementing the information

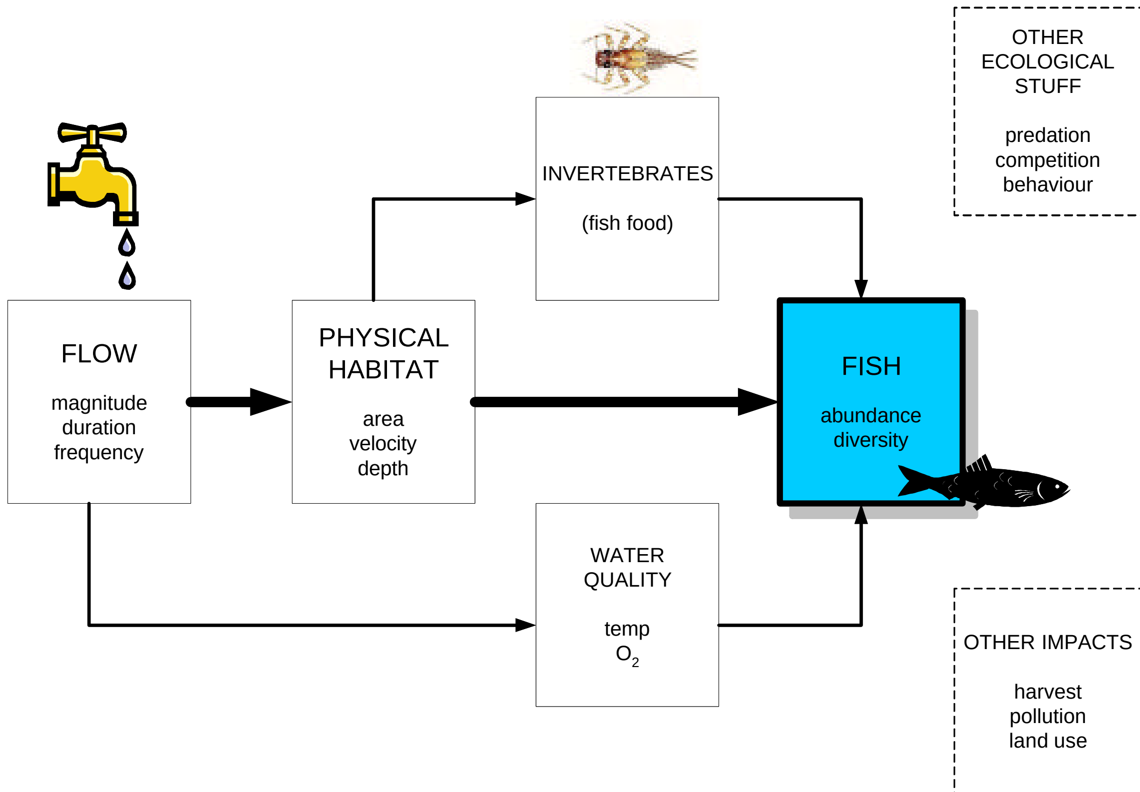

Figure 6. Influence diagram showing how fish production in streams is often thought to be a function of flow. In this diagram fish abundance and diversity is driven primarily by physical habitat availability, which is directly related to flow. Water quality and invertebrate production, also directly related to flow, may have a lesser impact on fish. Other influences may be acknowledged, but are seldom treated explicitly in instream flow assessments.

appear to arise in part because the relationships have often been investigated at quite different physical and temporal scales. For example, the link between fish habitat and fish production is often investigated at a regional or "macro" scale, whereas the link between flow and fish habitat is usually investigated at a stream reach or "micro" scale. Integrating these relationships to assess the link between flow and fish production is thus difficult.

A related problem is that "flow," while the fundamental abiotic factor controlling ecological processes in streams (Poff et al. 1997; Hart and Finelli 1999), is often referred to simplistically. Flow can be summarized readily by measures such as mean daily discharge, yet these obscure some of the highly variable nature of flow (Nowell and Jumars 1984; Heede and Rinne 1990; Whitfield 1998; Hart and Finelli 1999; Kondolf et al. 2000). Flow characteristics vary over a broad range of space and time scales, and the scale of organism-flow interactions can span more than six orders of magnitude (Hart and Finelli 1999). Determining which scale(s) is (are) the most important to organismal distribution and abundance is a central challenge for stream ecologists. For example, Hart et al. (1996) measured velocity time series at 2mm and 10mm above the substrate and found virtually no statistical relationship. Benthic organisms responded to flow variation at 2mm, but not at 10mm. A study measuring flow at only the 10mm height would have found "no effect." Adding to this scale issue, are acute empirical difficulties in measuring and characterizing streamflows for assessing changes to streamflows

(Kondolf et al. 2000). Conceptually, it is probably better to refer to "flow regimes," to underscore that organisms are often exposed to a suite of flow characteristics over reasonably large spatial and temporal scales.

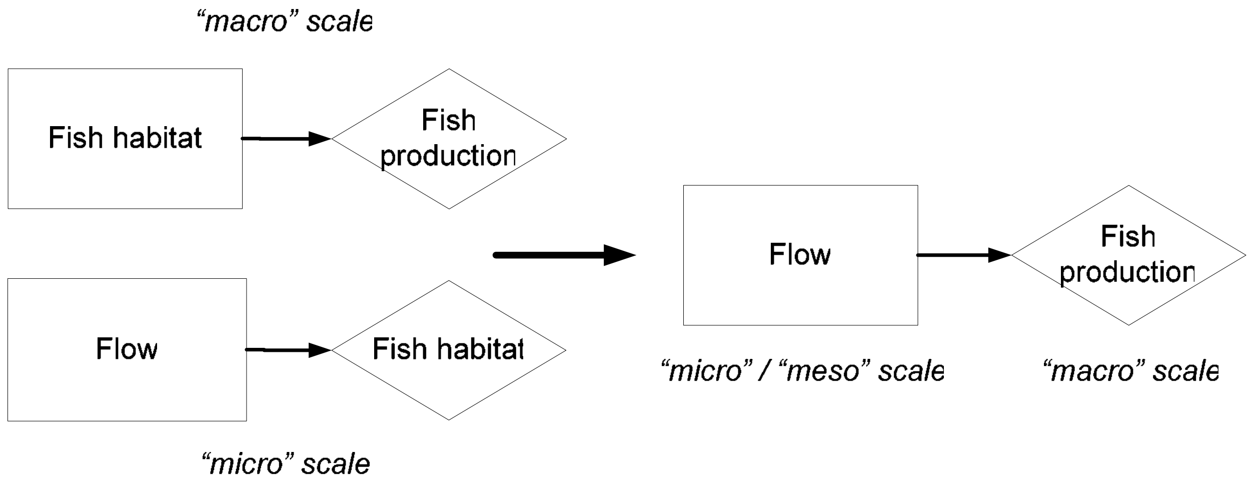

Figure 7. The link between stream flow and fish production often implies two underlying logical relationships. The different physical and temporal scales of these underlying relationships may make the link between flow and fish production difficult to measure.

6.1 Fish production vs. habitat

Fish habitat is the physical space used directly by fish or relied upon indirectly by fish for survival. The Fisheries Act defines fish habitat as: "Spawning grounds and nursery, rearing, food supply and migration areas on which fish depend, directly or indirectly, in order to carry out their life processes." The no net loss principle of the Policy for the Management of Fish and Fish Habitat demands no net loss of "productive capacity of fish habitats," defined as "the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support aquatic organisms on which fish depend." A clear definition of productive capacity has been elusive. Minns (1997) adopts Ricker's (1975) definition of production (new body mass per unit time, per unit area) and refines this for fish as "the sum of all production rates for all co-occurring fish stocks within a defined area of ecosystem."

Fish production is generally assumed to be positively correlated with amount of fish habitat, and indeed this is the logical underpinnings of much legislation and policy, particularly the Fisheries Act. There are many excellent examples of fish production versus habitat relationships. For example, sockeye escapements are greater in systems with larger lakes than those with smaller lakes (Figure 8), and chinook escapements are greater in larger streams than in smaller streams (Figure 9). Both of these relationships presumably exist because larger lakes and streams tend to have more habitat than smaller ones. Another example is that of Marshall and Britton (1990) and Bradford et al. (1997) who found a good correlation between stream length and mean coho smolt abundance: more stream means more fish. Summarizing this and related work, Bradford et al. (2000) state that "the production of [coho] smolts from freshwater habitats appears strongly limited by the availability of suitable physical habitat." This is likely a common working assumption for biologists working on fish in streams.

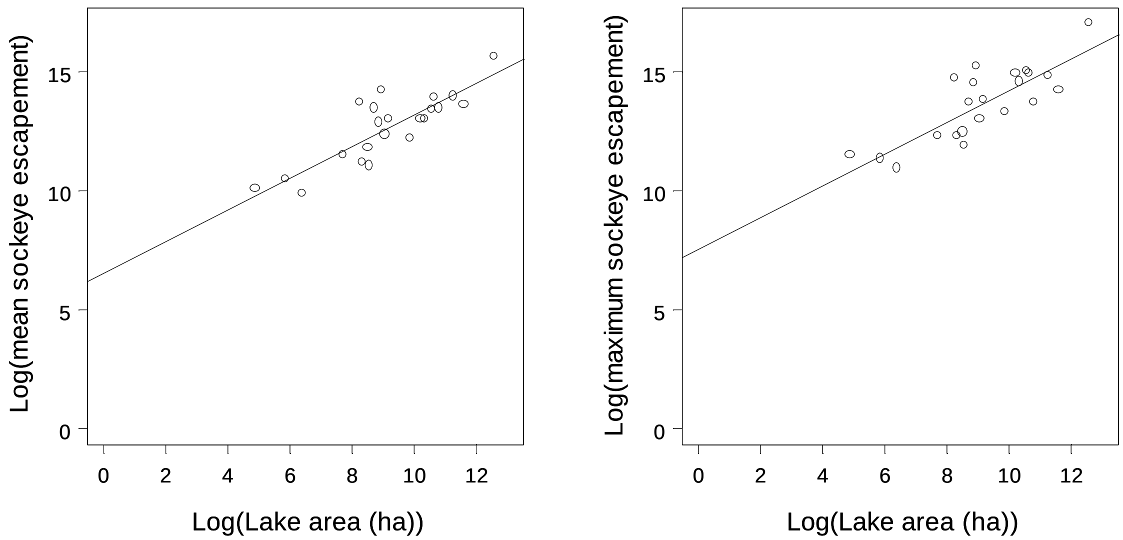

Figure 8. Sockeye escapements in relation to rearing lake size (data from Burgner 1991).

Relationships between fish habitat and fish production (assumed or empirical) led to quests for predictive tools useful in fisheries management. There are numerous productive capacity models that essentially create a predictive relationship between some measure of habitat and the number of fish produced per unit of habitat. Examples of these range from simple models, such as the morphoedaphic index (Ryder 1965) and euphotic volume (Koenings and Burkett 1987) for lake rearing capacity, to more complex methods, such as those that take into account primary and secondary productivity (Oglesby 1977; Downing et al. 1990; Hume et al. 1996). These types of simple predictive models have also been produced for stream habitats. For example, Burns (1971) correlated ($r = 0.898$) salmonid biomass with stream surface area in seven streams in northern California; Bradford et al. (1997) present regression equations for coho smolt capacity vs. stream length; and Binns and Eiserman (1979) provide predictive relationships for trout standing stocks using habitat variables in Wyoming streams.

6.2 Habitat vs. flow

Stream habitat tends to be classified at three scales: the watershed- or reach-level “macro” scale (e.g., elevation, gradient, channel width, etc.), the stream segment-level “meso” scale (e.g., riffle, run, pool, etc.), and the hydraulic-level or “micro” scale (e.g., depth, velocity, substrate, etc.). Strong associations often exist between fish presence or abundance and indexes of habitat at these different scales. For example, at the macro scale cutthroat trout density was found to be strongly and inversely correlated with bankfull channel width in coastal BC streams (Rosenfeld et al. 2000), and coho smolt density was significantly correlated with stream gradient in western Washington streams (Sharma and Hilborn 2001). At the meso scale, fish are often associated with particular habitat types such as pools, although growth rates and densities may be correlated with invertebrate production in riffles (Hartman et al. 1982). At the micro scale, fish are often associated with specific hydraulic conditions such as water depth and velocity (Beecher et al. 1993, 1995).

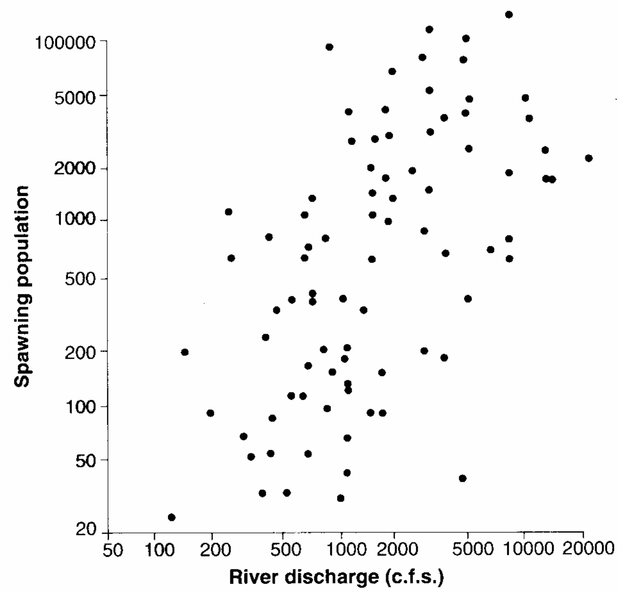

Figure 9. Relationship between river flow and chinook salmon spawning population size in British Columbia (from Healey 1991).

When defining and quantifying habitats in a stream, there is a greater dependence on flow at the micro scale than at the macro scale. For example, elevation and stream gradient are insensitive to flow except over geological time scales. Mesohabitats are affected by changes to flow because habitat boundaries and habitat types shift with changes in flow; at low flows a particular site may be a pool, while at higher flows it may be a riffle (Herger et al. 1996; Hilderbrand et al. 1999; Parasiewicz 2001), but they change little over small to moderate flow increments. Distribution and abundance of microhabitats are especially sensitive to changes in flow since depths and velocities at any particular site will change with flow, sometimes quite substantially over relatively small flow changes.

Streamflow regulation affects habitat at the micro scale instantly and somewhat predictably, and it is therefore at this scale that most biological assessments take place. A fundamental precept of the methods used in these assessment is that there will be a predictable biological response to changes in total habitat area and quality.

Although there are some assessment methods that focus specifically on mesohabitats (Parasiewicz 2001), most of the methods used for conducting detailed instream flow assessments focus on aspects of microhabitat. These methods are well reviewed in Instream Flow Council (2002). More recently, methods have been developed (Lamouroux et al. 1998; Hatfield and Bruce 2000; Lamouroux and Capra 2002) to predict microhabitat vs. flow relationships using data that can be collected more easily than those obtained from in detailed field assessments.

6.3 Fish production vs. flow

Fish production has been measured in British Columbia and other jurisdictions by a variety of methods. Estimates of adult spawning populations of salmon and steelhead are essentially estimates of freshwater and marine production, minus harvest. Unfortunately, more direct estimates, such as counts of smolts, or multi-year studies of resident salmonid growth and abundance, are few in number, making it difficult to explore fish production vs. flow relationships.

Some studies have found remarkably strong correlations between flow and fish production. For example, Smoker (1955) found a correlation between the commercial catch of coho salmon and annual runoff, summer flow, and lowest monthly flow in 21 western Washington basins. Mathews and Olson (1980) analysed data from Washington and showed that summer baseflows were correlated with total coho production for Puget Sound streams. Rushton (2000) reported a remarkably strong fit (R^2 = 98%) between numbers of coho smolts produced in Bingham Creek, Washington and 60-day mean summer low flows. Wolff et al. (1990) found that resident trout responded to flow increases in Douglas Creek with a four-to-six fold increase in biomass. A multi-year study (1973-1999) was conducted on Carnation Creek, BC measuring coho salmon growth, survival and biomass. The lowest recorded flow period was in August 1994 (0.007 cms, 0.8% MAD), and the lowest coho smolt yield was observed the following spring. Coho abundance in September was also positively correlated with mean flows during the preceding 30-day period, though only 25% of total variance in abundance was explained by this relationship (R^2 = 0.25, df = 18).

More water is not always better. For example, Smith (2000) suggested that wild steelhead abundance is lower in more northern, snow-melt driven watersheds where high summer flows reduce juvenile habitat. This suggestion seems plausible when comparing streams from biogeoclimatic zones with different hydrology (Smith examined streams influenced by snowmelt and rainfall type hydrology). His results suggest a dome-shaped function, where fish production is depressed at higher levels of flow.

More commonly studies show only a weak correlation between flow and fish production, or no correlation at all. For example, Conder and Annear (1987) found no correlation between microhabitat characteristics (WUA) and trout standing crop in Wyoming streams. Similarly, Irvine et al. (1987) found no correlation between WUA and trout abundance in New Zealand streams. Lewis and Mitchell (1994) reviewed studies from 28 hydropower facilities that had released water to enhance fish habitat. Of these only 12 judged the releases effective. It is interesting that less than half of the releases were deemed effective since presumably there was sufficient expectation of a benefit sufficient to justify the release. The lack of correlation between flow and fish production is probably more common than one might infer from the literature given the substantial bias toward publishing results that are statistically significant (Carver 1978; Murtaugh 2002).

There are in fact many possible explanations for poor correlations between streamflows and fish abundance; Bovee et al. (1994) list several:

1. there may be several consecutive and independent habitat events that can affect fish populations (e.g., harvest, spawning habitat, fry and parr rearing habitat, temperature regime, feeding territories, etc.),
2. limiting events often occur multiple times over variable time scales,

3. habitat may be co-limited at both high and low flows and by the rate of change of flow events,
4. the smallest amount of habitat available during the year may not be limiting productive capacity (such as during the winter when fish are inactive and not defending territories), and
5. mesohabitat types not directly utilized by the fish species (such as macroinvertebrate habitat as it affects downstream food supply for fish) may be more important than the habitat directly used by the species.

Other factors that obscure fish-flow relationships include the complex life histories of salmonids, multiple habitat-bottlenecks, inaccuracy of reach-level surveys, non-linear biotic responses to flow, and the many factors that influence abundance (e.g., critical seeding rates, complex food webs, density-independent factors such as floods). Since fish are relatively long-lived organisms they integrate multiple and potentially conflicting ecological influences over long time periods. For this reason alone it is perhaps not surprising that fish production vs. flow relationships are difficult to detect.

Implementing decisions based on microhabitat studies. There may be considerable risk from implementing decisions based solely or primarily on studies of microhabitat. Certainly there have been some spectacular failures from this approach. On the Trinity River in northern California river managers implemented a single release of 4.2 $m^3 s^{-1}$ from Lewiston Dam, believing this would maximize spawning habitat for chinook salmon. The chain of events that followed resulted in a narrow, armoured channel, cut off from the floodplain, with disastrous effects for fish and a variety of other species (Trush et al. 2000). In BC, on the Big Qualicum River a dam was constructed specifically to regulate flows to enhance fish production. Although there was an initial positive biotic response to changes in the flow regime, longer term trends were decidedly negative as the streambed became infiltrated with fines (Lewis and Mitchell 1994).

There are many sound critiques of methods that rely primarily on microhabitat assessments. For example, the techniques are time consuming, expensive and technical (Armour and Taylor 1991); ecological interactions (e.g., competition and predation) are ignored (Studley et al. 1996); results are user dependent (K. Bovee, personal communication; Railsback 1999); statistical uncertainty can be large (Williams 1996); many of the underlying assumptions are rarely tested (EA Engineering Science and Technology 1986); and results are almost never verified or monitored (Mathur et al. 1985; Scott and Shirvell 1987). Perhaps even more importantly, is the fact that results are based on the present condition of a stream (Bovee et al. 1998), yet morphology, sediment conditions, and water quality may change when flow becomes regulated, which in turn affects the quantity and quality of available habitat (Church 1995; Bovee et al. 1998; Trush et al. 2000).

The above examples and many others have led some scientists to recommend a more holistic approach that incorporates key physical and ecological functions of the natural hydrograph (Poff et al. 1997; Richter et al. 1996, 1997; Trush et al. 2000). In developing the flow thresholds presented here we acknowledge that there are uncertainties and difficulties associated with microhabitat-based flow assessment methods (Jowett 1997). As a result, we have recommended thresholds that focus on preserving key features of the natural hydrograph, since it is these features that are responsible for maintaining fish habitat in alluvial streams (Trush et al. 2000).

6.4 Effect of stream size

Stream size can be defined in several ways. It can be defined using relative roughness (see Section 5.2), physical dimensions such as channel width or depth, or by size of some reference flow such as MAD or a flood flow. Regardless of how stream size is measured, there is a variety of evidence indicating that small streams are more sensitive to water withdrawals than larger streams. Some jurisdictions (e.g., New Zealand, Germany) have responded to this evidence by implementing guidelines that give small streams a greater degree of protection than larger rivers (Dunbar et al. 1998), however, most jurisdictions do not explicitly give special management status to small streams. Beecher (1990) suggests that such a strategy would be appropriate for Washington State (a jurisdiction with similar fish communities and stream types to those in BC), although to our knowledge the policy has not been implemented.

Studies of physical habitat consistently indicate an effect of stream size on relationships between flow and habitat availability. For example, the recommended flow for spawning salmonids in BC streams follows a curvilinear function (Figure 10) indicating that smaller channels require higher relative flows than do larger streams in order to reach management targets for spawning (Ptolemy and Lewis 2002). Habitat availability for juvenile salmonids shows a similar pattern (Figure 10; Hatfield and Bruce 2000). When examining the relationship between negotiated instream flow release (i.e., the licensed minimum flow) and stream size, Smith and Sale (1993) found a highly curvilinear function for a set of streams in Washington State (Figure 11). The relationship indicates that decision makers allowed relatively more water to be extracted from larger streams than from the smaller streams. Decisions were apparently based on detailed physical habitat studies in each of the streams. These types of curvilinear patterns have been found by others (e.g., Annear and Conder 1984; Orth and Leonard 1990; Jowett 1997) in a variety of geographic locations.

A stream size effect would be predicted from an understanding of channel geometry (see Section 5.2). For example, if we assume (as do most instream flow habitat-based assessment methods) that target fish species are restricted to or prefer a certain range of depths and velocities, then it follows that smaller streams have proportionately more habitat than larger streams (Figure 12). Water withdrawals therefore have a greater effect on small streams, and even small withdrawals have the potential to reduce water depths below those inhabitable by fish. It should also be pointed out that base flows in small streams are often measured in L s^{-1} so any significant surface water diversion would be more pronounced in small streams than larger rivers. Many small streams within British Columbia are reduced to zero flow in drought years as a result of flow regulation or abstraction (R. Ptolemy, personal communication).

A stream size effect is also consistent with observations of fish distribution and abundance in streams. In large systems salmonid juveniles and fry are restricted to the margins of the channel, whereas they are distributed across the full channel width in smaller systems (e.g., Mundie 1969 cited in Bradford et al. 1997; Lister and Genoe 1970). Given this distribution, water withdrawals are expected to have a greater effect on small streams because useable width would be immediately affected, whereas margin areas in large streams would continue to exist except under drastic diversion scenarios. (It should be noted, that the distribution of fish across a channel may also be explained as an artefact of sampling efficacy (Sawada et al. 2002), but this seems unlikely to be a complete explanation, particularly for early life stages of fish.) Smaller streams often have greater fish abundance per unit area (Rosenfeld et al. 2000) than larger streams, but this relationship may be sharply asymptotic. For example, rearing area may be relatively constant in relation to stream width beyond a threshold stream width, which may explain in part the near linear relationship between coho smolt production and stream length reported in Marshall and Britton (1990) and Bradford et al. (1997).

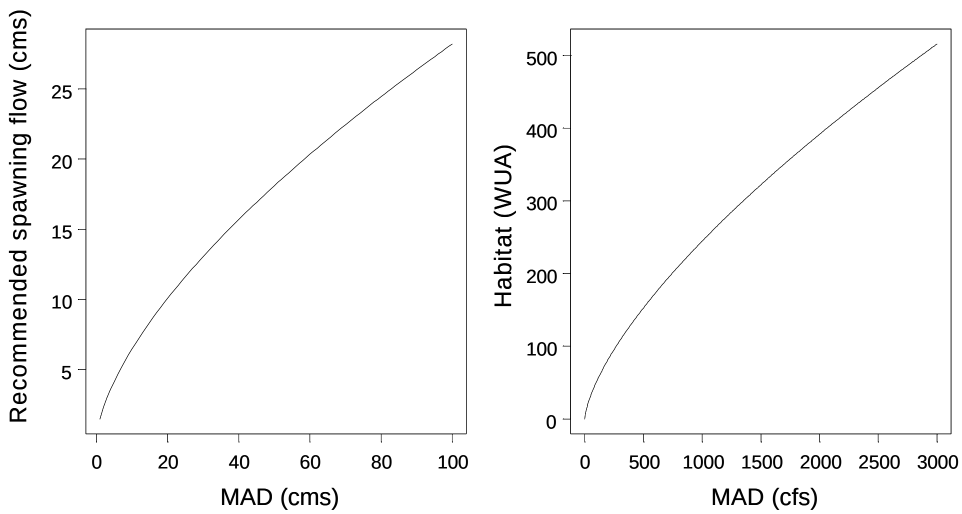

Figure 10. Left: relationship between recommended spawning flows and stream size for BC streams (from Ptolemy and Lewis 2002). Right: predicted habitat availability for juvenile salmonids as a function of stream size (from Hatfield and Bruce 2000).

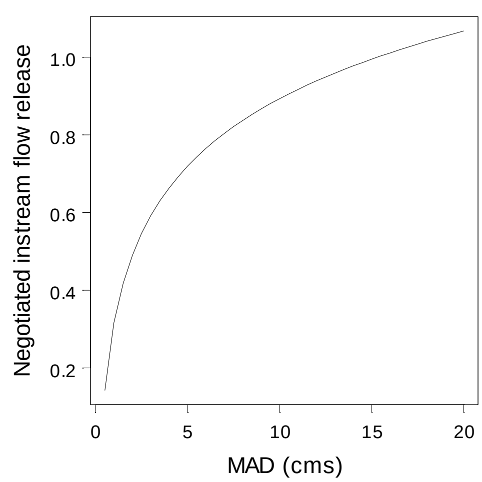

Figure 11. Relationship between licensed minimum instream flow and stream size in a set of northwest Washington streams (from Smith and Sale 1993).

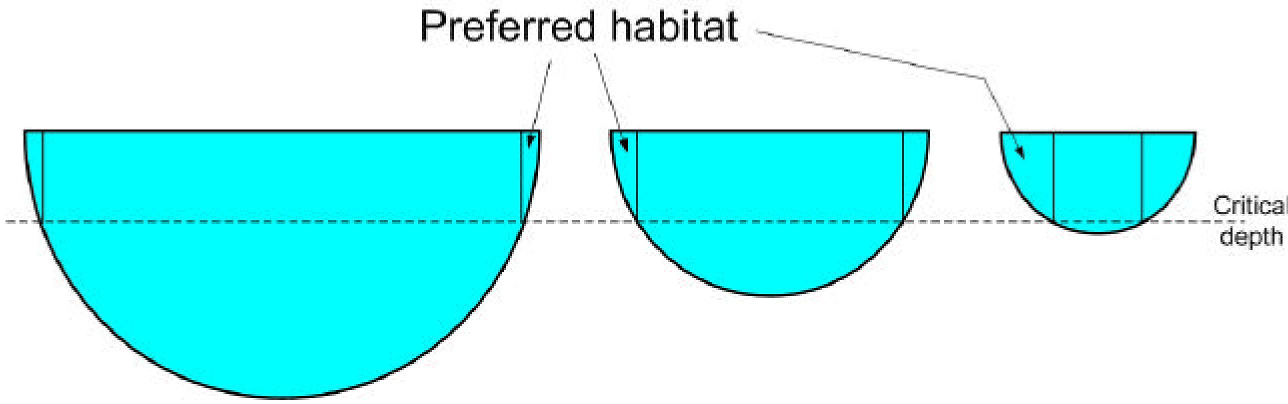

Figure 12. Using an idealized shape of a semi-circle, the effect of stream size can be seen on cross-sectional area available for fish; smaller streams have a greater proportion of cross-sectional area that is preferred habitat. This effect would hold for most real channel shapes.

These patterns are directly relevant to the development of instream flow thresholds for British Columbia streams, and streamflow management in general. The thresholds should be conservative enough so as to not endanger fish production in smaller streams. Since many of the applications for hydropower production are on small to intermediate-sized streams, resource managers should be aware of the potential sensitivity of these systems, particularly if they are systems with high fish abundance.

6.5 Fishless streams

Virtually all fish-bearing streams in British Columbia have fishless tributaries that contribute inflows. These tributaries include headwater streams and small sub-basins over the full length of a fish-bearing stream. Fishless streams tend to be lower-order systems, but they can range from small ephemeral drainages to considerably larger perennial streams.

Fishless streams by definition do not directly provide habitat for fish. However, they do contribute to downstream fish productivity through the export of invertebrates (i.e., food for fish) and detritus (i.e., food for aquatic invertebrates). The scientific literature indicates that, with the exception of fish presence, fishless streams are ecologically similar to fish-bearing streams. For example, invertebrate abundance can be high in both fishless and fish-bearing streams (e.g., Minshall and Minshall 1977; Delucchi 1988; Halwas et al. 2002), abundance and community structure is closely-linked with habitat type (e.g., Minshall and Minshall 1977; Cummins and Klug 1979; Huryn and Wallace 1987; Schlosser and Ebel 1989; Jowett and Richardson 1990; Wohl et al. 1995), and aquatic invertebrate production is highly dependent on terrestrial energy inputs (Fisher and Likens 1973; Richardson 1991; Wallace et al. 1997; Wipfli 1997; Piccolo and Wipfli 2002; but see also Minshall 1978).

Recent evidence suggests that contributions from fishless streams to fish-bearing streams may be higher than previously appreciated. Wipfli and Gregovich (2002) studied 52 fishless headwater streams in southeast Alaska—streams that are biogeoclimatically similar to many in coastal BC—and found that high rates of insect and detritus export occurred throughout the year. Using a simple model they estimate that each kilometre of their fishless headwater streams produces enough insect drift to support 100 to 2000 young-of-the-year salmonids. Estimates of the total number of downstream fish supported would likely be higher if detritus export was also taken into account. Insect drift and detritus export to downstream reaches is common to all streams (Vannote et al. 1980).

Wipfli and Gregovich's (2002) study is consistent with other observations, such as the observation of a general productivity gradient in BC streams that extends from oligotrophic headwaters to more productive lowland streams. Likewise, the majority of fish feed on invertebrates and other organic matter that "drift" by from upstream. What is more debateable is the extent to which local fish production is driven by inputs far upstream. One would expect that distance would attenuate the productivity connection between sites, but this question is only just beginning to be addressed by biologists as new study techniques become available. At present, existing data are not sufficient to know with reasonable certainty where the bulk of biological productivity originates in different systems, the extent to which productivity at different sites is interdependent, and what effects hydrologic changes have on that productivity.

7.0 EFFECT OF STREAM FLOW ON INVERTEBRATE PRODUCTION

Macroinvertebrate habitats are often considered in instream flow decisions in an effort to preserve food sources for fish, since many fish species depend on drift of invertebrates from upstream areas (e.g., Allan 1978; Nielsen 1992; Wipfli 1997). Over the short term, drift itself is often a function of flow characteristics (Irvine 1985; McLay 1970; Waters 1972; Brittain and Eikeland 1988), but flow can also affect abundance of invertebrates more directly through effects on habitat (Gore and Judy 1981; Gore et al. 2001). Evidence for a link between macroinvertebrate abundance and fish production has been reviewed in Section 6.0.

Like fish, stream-dwelling invertebrates have ecological niches that result in habitat associations over a range of scales. At a microhabitat scale invertebrate habitat preferences can be described using standard measures (e.g., depth, velocity, substrate type) and summarized using habitat preference curves (Gore and Judy 1981; Jowett and Richardson 1990). At a mesohabitat scale invertebrates are known to be distributed differently among riffles, pools, and other habitat types (Cummins and Klug 1979; Schlosser and Ebel 1989; Richardson and Mackay 1991). At an even greater scale, invertebrate abundance, distribution, and species composition vary with stream order (Spence and Hynes 1971; Vannote et al. 1980; Hauer and Stanford 1982; Ward and Stanford 1983).

Flow regulation affects habitat at each of these scales. Since depths and velocities at any particular site will change with flow, the streamwide abundance and distribution of invertebrate-supporting microhabitats will also change with flow. Macrohabitats are affected by changes to flow because habitat boundaries and habitat types shift with changes in flow; at low flows a particular site may be a pool, while at higher flows it may be a riffle (Herger et al. 1996; Hilderbrand et al. 1999; Parasiewicz 2001). Streamflow regulation can also determine effective stream order by altering temperature and detritus inputs, thereby altering the continuum from headwater to lowland stream (Spence and Hynes 1971; Hauer and Stanford 1982; Ward and Stanford 1983). A fundamental precept of many flow assessment methods is that there will be a concomitant biological response to changes in habitat quality and quantity.

Numerous studies have shown changes in invertebrate abundance and distribution in response to flow regulation, although the magnitude of biological response varies among locations and with characteristics of the regulated flow. Taxonomic shifts are common. For example, Spence and Hynes (1971) showed a large taxonomic shift in the invertebrate community when comparing riffle habitats upstream and downstream of an impoundment on the Grand River, Ontario. Zhang et al. (1998) found distinct differences in invertebrate community structure between regulated and unregulated rivers in northern Sweden. Similarly, on the Upper Kennebec River, Maine, Trotzky and Gregory (1974) found that a number of swift-water insect species were present above a hydropeaking plant, but absent below the dam. Williams and Winget (1979) showed a large change in invertebrate species composition in response to lower more stable flows following regulation of the Strawberry River in Utah. Hauer and Stanford (1982) noted a similar shift in functional feeding groups on the upper Flathead River, British Columbia. This kind of response is sufficiently common that Ward and Stanford (1983) proposed the Serial Discontinuity Concept to incorporate impoundments into riverine ecological concepts; within this concept taxonomic shifts are interpreted as a resetting of the river continuum at the point of regulation.

In addition to changes in species composition, these and other studies have noted invertebrate abundance changes in response to changes in flow. In many cases the shift is a change in the relative abundance, such that some species increase and others decrease, though overall diversity may stay the same. In other cases flow changes have produced a profound response in total abundance. For example, Morgan et al. (1991) recorded a doubling in macroinvertebrate density when regulated flows on the Patuxent River, Maryland, were stabilized. The authors attributed the response to higher base flows. Likewise, under experimental flow augmentation Schlosser and Ebel (1989) noted a tripling in macroinvertebrate abundance in Gould Creek, Minnesota. Particularly noteworthy was that the large numeric response occurred though habitat area increased only 10 – 20%, and despite an increase in predator density. Gislason (1985) described several effects of diel flow fluctuations for insect abundance in the Skagit River, Washington. Dewatered areas had substantially lower insect abundance, but deeper areas were also affected relative to control sites. When hydropeaking was curtailed the benthic insect density increased 1.8 – 59 times. It cannot be assumed that absolute or relative abundance changes are beneficial or detrimental for fish production. Rader (1997) provides a functional classification of drift invertebrates, which can be used to assess whether changes are likely to affect fish.

Not all studies show strong effects of flow on invertebrate production. For example, Wipfli and Gregovich (2002) found only a weak correlation between hydrologic factors and export of insects and detritus in southeastern Alaska streams. Delucchi (1988) found that benthic invertebrate community structure in small streams was related to temporal flow regime, but that differences in community structure between permanent and temporary riffles are minimized by general adaptations of benthic fauna, such as high migration rates, drought-resistant eggs, and the tendency to take refuge in the hyporheic zone. Although the effects of flow regime on community structure were apparently small, she did not study the effect on invertebrate abundance. It seems likely that although the hyporheic zone is typically productive at all flows and provides a refuge during low flows, there would be less substrate available and fewer organic inputs during times of no surface flow. One would therefore expect severe low flows to restrict invertebrate production and drift.

There are two common methods used to determine flow recommendations for stream invertebrates in regulated rivers: PHABSIM using habitat suitability curves developed specifically for invertebrates, and the wetted perimeter method. At present, too few PHABSIM studies have been completed for stream invertebrates to permit a meta-analysis of the combined studies. However, Gore et al. (2001) provide an historical perspective and suggest that targeting macroinvertebrates in PHABSIM studies will often lead to recommendations of higher streamflows than if benthic fish are used as a proxy.

Wetted perimeter data are often used to produce recommendations for protecting macroinvertebrate habitats. In cases where the performance of this method has been independently assessed, the PMC has not performed well in protecting habitat for macroinvertebrates (Gippel and Stewardson 1998). This occurs in part because portions of the wetted width may not provide adequate depths and velocities. The wetted perimeter method is reviewed in more detail in Section 9.2.

8.0 ENTRAINMENT

When water is diverted from a stream for consumptive use or power production there is a risk of entraining fish, invertebrates, and detritus, all of which contribute to the biological productivity of a stream. Risk of entrainment depends on the effectiveness of intake screens and the volume of water diverted. The guidelines do not explicitly consider the issue of intake screening (this is covered by existing guidelines and regulations), but they do consider the issue of entrainment in the broader context of removing productive capacity from a stream. For example, entrainment and removal of invertebrates and detritus is considered and presented as a motivating factor for precluding full diversion, even on fishless streams. The issue of entrainment is therefore briefly reviewed in this section.

8.1 Consumptive uses

When water is diverted from a stream for consumptive use (e.g., irrigation, drinking water, industrial use, etc.) it may carry with it portions of the biological productivity of the stream (e.g., fish, invertebrates, detritus, etc.). In some cases some of the productivity may be returned to the stream in waste water or runoff, however, it is probably safe to assume that in the great majority of cases the productivity is permanently lost. Since this "entrained" productivity is difficult to quantify we assume that the lost productivity is directly proportional to the amount of streamflow diverted.

8.2 Hydropower production - penstock and turbine passage

When water is diverted from a stream for power production it passes through a penstock and turbine before being released back into the stream. An entrained organism may experience three general types of physical stress: (1) positive and negative pressure changes, (2) contact with turbine blades (depending on the type of turbine), and (3) shear forces and turbulence

(Cada 1990). We discuss the physical stresses and their biological consequences below, in order. In the discussion we assume that turbines are of the bulb, Kaplan, or Francis type; Pelton type turbines are assumed to cause full mortality of virtually all fish and macroinvertebrates (Cada 2001).

From the point of entrainment pressure will increase, reaching a maximum just upstream from the turbine runner. After passing the runner there is an almost instantaneous decrease in pressure to < 1 atm for some brief period. Water is usually discharged to a shallow tailrace where pressure is ~1 atm. Cada (1990) provides graphical presentations of characteristic time series of pressures observed during passage through a typical bulb turbine.

For organisms with gas-filled structures (e.g., fish with a swim bladder) the primary cause of injury and mortality from turbine passage is usually the very rapid pressure changes that occur during transit. The most harmful effects are rapid pressure decreases, an effect that is analogous to a SCUBA diver decompressing too quickly. Injuries due to sudden pressure decreases may include haemorrhaged, burst or distended swim bladder, and embolisms (formation of gas bubbles) in the body fluids. Passage through the turbine is generally rapid so there is insufficient time for an organism to physiologically adjust to pressure changes during transit. Acclimation history is therefore an important determinant of effects, since an organism acclimated to high pressures will experience a greater pressure drop through a turbine than one acclimated to lower pressures. (A high pressure differential may occur when water intakes are located at depth in a reservoir. A smaller pressure differential would occur when intakes are located at the surface.) Organisms without gas-filled organs (e.g., most invertebrates) would presumably not experience physiological effects from pressure changes that are as acute as those in organisms with such organs. Because passage times tend to be rapid there is not a significant correlation between direct mortality and power plant head (Bell 1990).

The probability of contact with turbine blades depends on size of the particle, with larger particles more likely to be struck by a runner blade (Bell 1990). For large organisms such as juvenile and adult fish this may be a significant source of mortality, however, for small organisms it may be less important. Cada (1990) estimated that a 4 cm long organism would have a probability of runner contact in a bulb turbine of 5% or less; probabilities for most larval fish are 2% or less. It is unlikely that all organisms would die if contacted by a runner, so rates of mortality induced by runner contact would presumably be less than these values.

Shear forces occur when two contiguous bodies of water are moving at different velocities. Accelerative forces occur from fluctuations in overall water velocity, small-scale velocity changes in turbulent eddies, and collisions with solid surfaces (Cada 1990). If penstocks are long and velocities are high then physical stress during transit will likely come primarily from abrasion, shear forces, and turbulence in the penstock rather than in the turbine, although shear forces within the turbine may also be important. Abrasion may be a lesser concern for invertebrates than for fish, since they have chitinous exoskeletons, but long penstocks may nevertheless expose them to considerable risk. The effect of shear stress and turbulence likely depends also on the fragility of an organism. For example, a relatively streamlined, compact insect like a chironomid may be at less risk from high-intensity, small scale turbulence than a mayfly nymph, which has long delicate appendages and external gills.

Survival of small fish through turbines is commonly 70% or greater (Cada 2001), and for some systems such as the large Columbia River facilities, survival has been about 88% including latent effects such as predation (Bickford and Skalski 2000; Skalski et al. 2002). Direct mortality estimates reviewed by Skalski et al. (2002) indicate a range in mortality of 0 – 15%. In general, latent effects of passage have been less rigorously studied than direct effects (Cada 2001), but there is evidence that these effects can be substantial (Bickford and Skalski 2000). Studies of latent effects are relevant beyond passage through turbines. For example, direct mortality estimates indicate that fish have higher mortality when passing through turbines than when passing over dam spillways, but studies of indirect effects may show that entrainment over spillways is also a large source of mortality. Few of these studies have been done.

There are only a small number of direct studies of invertebrate passage through hydropower plants, but studies from thermal power cooling stations indicate a large variance in mechanical damage and mortality rates that is likely related to differences in physical works and species susceptibilities (Marcy et al. 1978; Capuzzo 1980; Cada 1990). Mortalities or mechanical damage vary tremendously from system to system and among taxa (e.g., 0 to 100% in Marcy et al. 1978; 28% in Gaudy 1981; 70% in Carpenter et al. 1974 cited in Capuzzo 1980; 70% in Standke and Monroe 1981).

Preventing entrainment of fish is likely to be a strict condition of water licence approval, but even where fish screening is adequate there may be residual ecological effects of entrainment — direct effects on macroinvertebrates and downstream effects on fish. The ecological consequences of entrainment will vary among streams, project configurations, and operations (i.e., amount of water diverted, length of penstock, turbine type, etc.). For example, high head projects with Pelton-type turbines will likely have very high mortality of macroinvertebrates. For projects with other turbine types there is risk of injury and mortality to invertebrates from penstock and turbine passage, but the risk is likely lower than published values for fish undergoing similar passage.

As variable as the effects on invertebrates are, the ecological effect of injury and mortality are even less clear. Anecdotal evidence indicates that fish will feed on dead or injured organisms after they pass through turbines, so an injured or mutilated insect is not necessarily lost as "fish food," provided it remains in pieces of sufficient size to attract a feeding fish. On the other hand, high mortality during passage may limit recolonization of invertebrates below the tailrace (Marchant and Hehir 2002) and lead to lower invertebrate abundance for some distance downstream of the tailrace. This is in contrast to outlets of lakes and impoundments, which are "hot spots" of invertebrate production (Richardson and Mackay 1991).

9.0 SETTING INSTREAM FLOW REQUIREMENTS FOR FISH

This section summarizes the evaluation of a variety of instream flow assessment methods as potential "coarse filters" for reviewing water license applications on British Columbia streams. Parts of this evaluation took place during Phase I of this project, but are briefly reviewed again here for sake of completeness.

Discussion and evaluation of potential standard-setting methods varied depending on the method. Some evaluations were informal, based either on professional judgement of the consultants, a review of relevant literature, or input received from technical experts during a series of instream flow workshops held specifically for this project. Other evaluations were more formal and involved peer-review of a written rationale. A common theme emerged when participants reviewed recommended flows produced by different methods: there should be a reasonable match between the recommendation and flows that naturally occur in a stream. Responsibility for final recommendations for selecting a standard-setting technique rest with the consultants and any resulting guidelines should be subjected to a peer-review process.

9.1 Methods available for determining instream flow requirements

A 1986 literature review (EA Engineering Science and Technology 1986) lists a total of 54 instream flow assessment techniques. Many more techniques or adjustments to existing methods have been added to this list in the last 15 years (cf. Jowett 1997). The sheer number of assessment techniques available, and the fact that the list continues to grow, is testament both to the urgency of the need and the frustration with the present set of tools.

Available instream flow assessment techniques can be categorized in different ways (e.g., Jowett 1997; Summit 1998; Sawada et al. 2002). For the purposes of this discussion we draw a distinction between what we call "standard-setting methods," and "empirical methods." Standard-setting methods are primarily office-based scoping exercises that make use of existing information to predict an appropriate schedule of instream flow requirements. Empirical methods require an investigator to visit the stream of interest and collect biological and physical data. These data are then used to determine a schedule of instream flow requirements, often in a negotiation context. In both cases the objective is to protect aquatic resources, but the level of information required and the time and cost needed to undertake the tasks may be substantially different.

The dichotomy of empirical vs. standard-setting methods is useful here because our ultimate task is to develop both a set of conservative flow thresholds that can be calculated quickly and a set of accepted empirical methods for investigating flow-related issues on British Columbia streams (see Figure 2). Such two-tiered processes are common in many jurisdictions (Kulik 1990; Dunbar et al. 1998). In general, level two studies move away from standard setting and towards an incremental approach (i.e., quantification of varying instream requirements), enabling various management options to be assessed (Dunbar et al. 1998).

In practise the division between empirical and standard-setting methods may be less clear since empirical methods may utilize existing information, and standard-setting methods may require collection of information not already available. But the dichotomy is nevertheless useful for eliminating a variety of data-intensive techniques as suitable for standard setting. Examples of empirical methods are one-, two- and three-dimensional hydraulic modeling (e.g., PHABSIM, River2D), and direct study of biological response to flow manipulations. Standard-setting methods include, the Tennant Method and its variants, the Wetted Perimeter Method, the Habitat Quality Index, the Toe-Width Method, PHABSIM prediction, and a variety of hydrologically-based methods. The dominant standard-setting methods are presented briefly below, along with results of evaluations as to whether it is an appropriate scoping tool for BC. Readers interested in a more comprehensive review of instream flow assessment methods should consult other documents (e.g., EA Engineering, Science and Technology 1986; Jowett 1997; Instream Flow Council 2002).

9.2 Standard-setting methods

Tennant Method.—One of the original techniques for determining instream flow needs for fish, the Tennant Method (Tennant 1976; also known as the Montana Method) has been especially influential and is still widely used throughout the world (Reiser et al. 1989; Jowett 1997). According to Tennant (1976), the method is based on 17 years of experience on hundreds of coldwater and warmwater streams, and tested with field studies on 11 streams in Nebraska, Wyoming and Montana. The test used empirical hydraulic data from cross-sectional transects combined with repeated subjective assessments of habitat quality. From these measurements Tennant defined relationships between flow and aquatic habitat quality, and found that they were similar for each of his study streams. He therefore developed stream flow recommendations based on percentages of MAD (Table 6).

Table 6. Instream flow regimens for fish, wildlife, recreation and related environmental resources, as described in Tennant (1976). Flows are expressed as percentages of MAD.

	October-March	**April-September**
Flushing or Maximum	200%	200%
Optimum Range	60-100%	60-100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	0-10%	0-10%

Advantages. The Tennant Method is easy to implement; it is a desktop method requiring no field work. The method is based on a single hydrologic statistic (MAD) that is easy to obtain. Decisions based on the Tennant Method have withstood numerous court challenges in the US (Christopher Estes, pers. comm.).

Disadvantages. Critiques of the Tennant Method are numerous, but tend to focus on two aspects: the high degree of professional judgement embedded in the method and the lack of biological validation. Tennant (1976) indicates that his methods have been tested, but many would argue that his "test" has been only vaguely described, and to our knowledge there has been no measurement of fish response to flow changes using his standards. These criticisms are, in fact, valid for most instream flow methods—all techniques require subjective judgements during the collection of data and in the final recommendation of an instream flow schedule, and in practise exceedingly few decisions are adequately assessed after they are implemented.

The method also raises a general concern: there is potential doubt over the relevance of MAD as a basis for a standard-setting index (Dunbar et al. 1998). While the mean flow is of considerable use in some aspects of hydrology (e.g., hydropower estimation), it is influenced by extreme flow events, especially high flows. Dunbar et al. (1998) note that the use of indices derived from the flow duration curve (i.e., percentiles) may be more appropriate and allow guidelines to be better adapted for different regions. A significant disadvantage for use of the Tennant Method in BC is that it was developed for the mid-western US, east of the Rockies. The streams in that area are similar to one another in their hydrologic regimes, and may therefore be more consistently characterized using %MAD statistics than streamflow patterns in BC.

Recommendation. The method is not recommended as a review guideline tool for BC streams due to its poor fit to natural streamflow patterns on a wide variety of BC streams (see Section 5.1). For example, there are notable discrepancies between Tennant's flow recommendations and the natural hydrographs in several of BC's hydrologic zones. The largest discrepancies occur in zones where peak streamflows are not dominated by snowmelt, such as rain-dominated coastal systems. In some cases the recommended flows are well above those naturally occurring in a stream, and this type of discrepancy was deemed to be unreasonable and undesirable by a number of agency staff. Given the poor fit between Tennant's flow recommendations and the natural hydrographs it would likely be difficult to specify a relationship between his criteria and a "no HADD" threshold. Lastly, due to the diversity of hydrologic regimes in BC it will be generally difficult to implement a single method that makes recommendations based on MAD.

Modified-Tennant Method.—It was quickly recognized that the original Tennant Method may not apply to geographic locations outside the region for which it was originally devised. Various modifications have made the technique more applicable to other regions. For example, the Texas Method makes modifications to account for the flashy streamflows common in that region. The method is conceptually similar to the original Tennant Method, but uses median annual discharge (MedAD) rather than mean.

Another weakness in Tennant's original method is addressed with the Tessman (1980) modification, which incorporates consideration of natural variations in flow on a monthly basis. This type of modification is common, and has led to modifications that make the original Tennant Method more applicable to regions with different hydrological and biological cycles (e.g., see Estes [1995] for modifications appropriate for Alaska, and Locke [1999] for modifications appropriate for Alberta).

Advantages. Modified Tennant Methods have the same advantages as the original method: they are easy to implement desktop methods requiring no field work. They are based on a single hydrologic statistic or set of statistics that are easy to obtain. The modified methods provide a better "fit" to different geographic regions.

Disadvantages. The disadvantages of modified Tennant Methods are similar to the original method: the high degree of professional judgement embedded in the method and the lack of biological validation. Any one of the existing modifications will not reflect natural streamflow patterns on a broad variety of BC streams, and different modifications may be necessary for different regions within BC.

Recommendation. The modifications developed for other jurisdictions are not recommended for BC due to their potentially poor fit to natural streamflow patterns on a wide variety of BC streams (see Section 5.1). Due to the diversity of hydrologic regimes in BC it will be difficult to implement a single method that makes recommendations based on MAD. Although regional corrections may be possible, such an approach may have problems associated with defining which modification should apply to which stream. As noted in Section 5.1, even after hydrologic classifications of BC there may be considerable "residual variance" in hydrology, which can be relevant to the distribution and abundance of fish in streams within a region.

BC Modified-Tennant Method.—Biologists working for the BC Fisheries Branch have developed a "made in British Columbia" modification to the original Tennant Method, incorporating local biological and physical information to develop Tennant-like streamflow criteria to satisfy biological requirements of fish throughout the region. The method has evolved over the past 30 years and continues to be updated. The method and its technical rationale are presented in Ptolemy and Lewis (2002). A summary of BC modified-Tennant flow criteria is presented in Table 7.

Table 7. Summary of BC modified-Tennant recommended flows to satisfy biological and physical needs in British Columbia streams.

Biological or Physical Requirement	Flow Recommendation (% MAD)	Duration
A. Rearing	20%	Months
Juvenile	20%	Months
Adult	> 55%	Months
B. Over-wintering	20%	Months
C. Incubation	20%	Months
D. Migration and Spawning	30-200%	Days-weeks
Summer Steelhead passage	50-100%	Days
Spawning	equation: $1.56 * MAD^{0.63}$	Days-Weeks
Smolt Migration	50%	Weeks
E. Short-term Maintenance	10%	Days to a Week
F. Channel maintenance	> 400%	Days
E. Wetland linkage	100%	Weeks

The BC modified-Tennant method diverges from the original Tennant method in one key element. The method allows regionalization of its implementation by focussing on fish life history and ecological information for the target stream. Biological information including species and life stages present, timing of key biological activities such as spawning, incubation, migration, active rearing, overwintering, and specific ecological needs, such as geomorphological considerations, are compiled into a species periodicity chart. This approach is described by Estes and Orsborn (1986).

A schedule of instream flow requirements is developed after referring to the species periodicity chart, the natural flow data, and any site-specific ecological needs. Appropriate flows are then assigned to week-long time blocks in a summary table. The range of "appropriate" flows is determined by the ecological requirements at the time, and the choice of flow criteria for each ecological requirement (i.e., values in Table 7). At any one time, different needs may need to be met. For example, fish rearing may require only 20% MAD, whereas migration may require much higher flows. Conflicting requirements are presently resolved by defaulting to the highest flow within each time block.

The natural annual hydrologic cycle should be considered when determining the ecological requirements. For example, wetland linkage may occur naturally during certain periods of the year when stream flows are at or above 100% MAD. Examining the natural hydrograph for the stream in question allows one to identify the periods when, historically, wetlands were linked to the stream. Other ecological needs can be addressed in a similar manner. This type of information can then be incorporated into the final schedule of instream flow requirements.

Advantages. The BC modified-Tennant method is more difficult to implement than the original Tennant Method, but it is still a desktop method requiring little or no field work. The method is based on a single hydrologic statistic (MAD) that is easy to obtain. The method represents a direct attempt to develop relevant flow guidelines for BC, and there is a history of using the method on BC streams.

Disadvantages. Critiques of BC modified-Tennant method are essentially the same as for other standard-setting techniques: the extensive use of professional opinion and the lack of biological validation. The criteria and rationale have been subjected to peer review and performed poorly. The review noted that the criteria are not necessarily wrong, but at this point cannot be adequately supported with existing data. Because the method relies on a single hydrologic statistic (MAD) there is a concern that the criteria may not transfer well among different hydrologic regimes in BC.

The method requires considerable subjective judgement during the flow setting process. For example, it remains up to the user to define which species and life stages should be given priority, and during which times of the year. It may be possible to standardize such decisions with policy, but different users may develop different recommendations using the same method and information base.

Recommendation. The method is presently not recommended for calculating flow thresholds during initial review of proposed water uses. This recommendation is based largely on two considerations: its performance during peer review, and a potentially poor fit to natural streamflow patterns on some BC streams. The province may wish to fund additional research to overcome the technical issues raised during the peer review. Alternatively, the method may be used as a check on any guidelines that are developed using other methods. Any proposed changes to the method should consider that due to the diversity of hydrologic regimes in BC it can be difficult to implement a single method that makes recommendations based on MAD.

Historic flow methods.—These methods, as the name implies, rely entirely or mostly on a long-term time series of recorded or estimated flows in the target stream. A fixed percentage of flow, or some other derived flow index is selected as a flow recommendation to maintain an ecosystem feature at a predetermined acceptable level. The recommended flows may be set at an annual, seasonal or, less often, monthly, biweekly, or weekly time steps. The indices are generally derived using one of two broad methods. Firstly, expert opinion, or secondly, more structured observations of the health of a group of rivers deemed to be of a similar type, combined with statistical analysis.

The Tennant Method is the best known method in this category, but there are other methods that also rely on this general approach to produce an instream flow guideline. King et al. (1999) noted that there are at least 15 frequently referenced, hydrology-based methodologies, but many are region- and/or context-specific in their application. Jowett (1997), Dunbar et al. (1998), King et al. (1999) and Instream Flow Council (2002) review a variety of these methods (e.g., Hoppe, New England aquatic base flow, Northern Great Plains, Lyon, 7Q10, and Basque methods).

The Range of Variability Approach (RVA; see Richter et al. 1996, 1997) is a more sophisticated historic flow methodology, developed as part of the movement by resource managers toward "naturalizing" hydrographs. The RVA tools provide a method to statistically characterize a flow regime. The characterization includes description of hydrologic variability, which is assumed to be crucial for sustaining riverine ecosystems.

Advantages. Methods based on flow records are typically inexpensive, rapid, desktop exercises, requiring only historic flow records, or synthesized data. As such, they are highly appropriate at the reconnaissance level of water-resource development. A particular strength of many methods in this class is that they are not fixed levels, but instead respond to natural patterns of water availability. More sophisticated methods, like RVA, have the potential to be modified to produce regionalization methods or to provide a useful evaluation function.

Disadvantages. Weaknesses and limitations of historic flow methods depend in part on the method to which one is referring. For example, shortcomings of the Tennant Method are discussed above. In general, there is considerable risk that the criteria developed by historic flow methods will be applied across different geographic regions and river types, without sufficient understanding of their ecological implications. Historic flow methods are most appropriate at a reconnaissance level, and in cases where no negotiation is involved in the decision-making process.

Recommendation. We recommend that the existing historic flow methods be treated with caution, and not be used as the primary method to set flow thresholds for scoping-level reviews of proposed water uses in BC streams. However, there is considerable validity to this class of methods as "coarse filters," particularly if one is adopting a naturalized hydrograph approach to flow management. Methods such as the RVA statistics may be used as a check on any guidelines that are developed. We recommend that this class of methods be thoroughly investigated as potential coarse filters for BC streams.

Wetted Perimeter Method.—This is part of a class of methods also referred to as "hydraulic methods" (Jowett 1997), which determine instream flow needs based on relationships between discharge and some hydraulic measure of a stream (e.g., wetted width, depth, etc.). The relationships are assumed to be indicative of ecological requirements.

The Wetted Perimeter Method uses transects across a stream to develop a relationship between wetted perimeter (i.e., stream width as measured by the cross-sectional profile of the wetted streambed) and discharge. A point on the curve is selected to represent a threshold flow below which habitat is assumed to decline rapidly with decreasing flow. Although it is possible to select alternate points, the one usually used is the point of maximum curvature, or an "inflection point" that describes a rapid change in at-a-station channel geometry.

The Wetted Perimeter Method is not technically a standard-setting method, but it would be straightforward to mould it for that purpose. For example, policy can set the proportion of wetted width as the threshold and set the appropriate locations for placement of transects (e.g., in riffle habitats), thus making the method quick and efficient. Alternatively, one could set a flow threshold based on analysis of wetted width data from many streams in BC.

Advantages. A guideline based on clear methodologies (e.g., how and where to set transects) would be relatively easy to implement, and require only minimal data collection effort.

Disadvantages. The method can be highly subjective (EA Engineering Science and Technology 1986; Gippel and Stewardson 1998), and therefore error prone. Preliminary results from BC streams do not support the notion of a consistent "inflection point" (see Section 5.2). The biological importance of the hydraulic threshold is assumed, and has generally not been validated (Jowett 1997). In cases where it has been independently assessed, the PMC has not fully protect habitat for the macroinvertebrate community, particularly since portions of the wetted width may not provide adequate depths and velocities (Gippel and Stewardson 1998). "Translating" wetted width relationships to "no HADD" thresholds would likely be difficult.

Recommendation. We recommend that this method not be used as the primary standard-setting method for BC streams. The method may nevertheless be useful for providing relevant information during detailed assessments, as part of hydraulic geometry assessments.

Toe-Width Method.—The Toe-Width Method, also known as the Swift Method (Swift 1976, 1979), was developed in the 1970s by federal and state agencies at the request of the Washington state legislature in response to the need to determine minimum instream flows for fish (Rushton 2000). Water depths and velocities were measured at transects over known spawning areas and combined with criteria for salmonid spawning and rearing. Data were collected at 8 to 10 different flows at a total of 336 transects in 28 streams in eastern and western Washington. The data were used to create fish habitat versus streamflow relationships in a manner similar to that of PHABSIM.

Habitat-flow relationships were compared to many different variables in the watershed to determine if there were correlations that could be used as a proxy to empirical measurement, and thus avoid having to do so many flow measurements to calculate spawning or rearing flows for different fish species. Toe-width (distance across the stream channel, from the toe of one streambank to the other) was the only variable found to have a high correlation. This width of the stream is used in a power function equation to derive the flow needed for spawning and rearing salmon and steelhead. The method is still widely used in Washington State, particularly for assessing applications for use of small water volumes (Hal Beecher, Washington Department of Fish and Wildlife, personal communication).

The method is conceptually sound for predicting flow-habitat relationships, but we could find no studies assessing the biological validity of the model's predictions.

Advantages. A guideline based on this method would require only minimal data collection effort.

Disadvantages. The model was developed for streams in Washington State and there is no assurance the method would perform similarly in BC.

Recommendation. We recommend that this method not be used as the primary standard-setting method for BC streams due to the large effort required to collect relevant data and the lack of assurance that such research would produce a reliable guideline.

Habitat Quality Index.—This method (Binns and Eiserman 1979) was developed as a habitat evaluation tool for use in Wyoming, but has also been used as a flow evaluation method (Courtney 1995). A multitude of habitat variables were measured at a variety of locations in late summer, along with standing crop of fish. Multiple regression models were developed for predicting standing crop from habitat predictor variables.

Advantages. If suitably validated, the method has the capacity to perform well (Conder and Annear 1987) and can be applied as an office-based task.

Disadvantages. The method is not likely suitable in its present form for standard-setting in British Columbia streams for two main reasons: the regression models would likely have to be developed *de novo* for streams in the province, and effort required to collect the habitat data for prediction purposes could be extensive. For example, the Binns and Eiserman model was tested for Alberta and performed poorly (Griffiths 1981 cited in Courtenay 1995).

Recommendation. We recommend that this method not be used as the primary standard-setting method for BC streams due to the large effort required to collect relevant data and the uncertain outcome of that research.

PHABSIM prediction.—One of the main attractions of PHABSIM and similar methods is that they produce an incremental relationship of habitat vs. flow. Incremental relationships are especially useful when trade-offs are required (e.g., among species, life stages, or other interests). PHABSIM normally requires substantial effort to collect and analyse data, a process that makes it impossible for use in a standard-setting context.

Recently, a method to predict habitat vs. flow relationships has been developed by Hatfield and Bruce (2000) and Bruce and Hatfield (unpublished manuscript). The predictions are based on a meta-analysis of previous streamflow studies. Briefly, the work analysed previously conducted

PHABSIM-based instream flow studies throughout western North America, and used regression analysis to develop predictions of habitat vs. flow relationships. There are separate prediction equations for several salmonid species (or all salmonids as a group) at each of four life stages. The equations can be used to predict habitat vs. flow relationships in streams of different sizes and geographical locations.

The required inputs for the meta-analysis are MAD (in cms or cfs), latitude (in decimal degrees), and longitude (in decimal degrees). The predictions can be used to develop recommendations for instream flows.

Advantages. The method is one of only a few office-based exercises that produce incremental relationships rather than single recommendations. The method has been used on several rivers on Vancouver Island. It is a substantially cheaper alternative to PHABSIM.

Disadvantages. The weaknesses of the meta-analysis for standard-setting in British Columbia streams are similar to those of other methods. For example, there has been no validation of the biological response to flow changes recommended by PHABSIM or the meta-analysis, so the risks of using the tool for standard setting are largely unknown. The underlying data for the meta-analysis are derived from PHABSIM, which is itself a controversial method (see e.g., Mathur et al. 1985; Scott and Shirvell 1987; Williams 1996). The meta-analysis speaks only to habitat needs of rearing and spawning salmonids and does not incorporate other requirements for instream flows (e.g., other species, or geomorphic and substrate issues). Flows to satisfy such needs would need to be calculated using another method. Although the meta-analysis is quite objective at one level, it still requires considerable subjective judgement during the flow setting process. For example, it remains up to the user to define which species and life stages should be given priority, and during which times of the year. It may be possible to standardize such decisions with policy, but different users may develop substantially different recommendations using the same set of risk functions, if given the freedom to do so.

Recommendation. The method is more suitable to a negotiation setting than for standard setting. We recommend that this method not be used as the primary standard-setting method for BC streams due to the potentially variable recommendations that would arise from its use. The method may be used as a check on any guidelines that are developed using other methods.

10.0 RECOMMENDED INSTREAM FLOW THRESHOLDS FOR BRITISH COLUMBIA

Based on a variety of formal and informal evaluations (summarized in Section 9.0) we pursued the possibility of adapting an historic flow method for use as a potential “coarse filter” for reviewing water license applications on British Columbia streams. Our recommendations for a standard-setting technique using historic flow data are presented in this section. The recommendations are based on a variety of analyses of historic flow data from around BC, which are presented in Appendices A through F. The final recommendations are those of the consultants and should be subjected to a formal peer-review process.

10.1 Data requirements for calculating the flow thresholds

The recommended flow thresholds are based on fish-bearing status and historic flow data, which create two specific data requirements. The first is an adequate assessment of fish presence and absence; the second is an adequate time series of mean daily flows.

Fish-bearing status. Determining the fish-bearing status of all streams in the project area is perhaps the most basic of biological information needs. In the absence of reliable data these streams will be considered fish-bearing. Appropriate methods for determining fish presence and absence are detailed in the Assessment Methods guidebook. It should be noted that these methods may differ from those used for other industries.

Historic flow records. A more complete description of hydrology data requirements is presented in the Assessment Methods guidebook. Briefly, preferred hydrologic data are empirical historic flows, obtained from gauged sites with appropriate validation. However, geographic coverage is incomplete in British Columbia, so empirical historic flow records are often not available for streams of interest. There are numerous techniques for estimating natural flows (i.e., corrected for existing water and land uses) at ungauged sites. Where flow records must be synthesized we expect that a reasonable attempt at validation will be made, and measurement biases and errors will be described. Since operations will be defined relative to natural flows, it is essential to understand potential effects of hydrologic modeling and measurement error. **It is in the interest of all project proponents to establish new gauging stations when none exist on the affected streams.**

To calculate the instream flow threshold for a target stream the entire period of record should be used if the data are reliable. Whether synthetic or empirical data are used, a minimum 20-year continuous record should form the baseline. Records of this length will more accurately reflect natural flow variation than shorter time series. A long hydrologic record will also allow for accurate exploration of project alternatives, if required as part of the review process.

The primary location of interest for hydrologic analysis is the stream segment immediately below the point of diversion. Impacts from a project will likely attenuate as tributary and groundwater inflows enter the stream below the water intake. However, proposed water uses may interact with other uses to produce a combined impact that is considered high risk. For example, water diversions in two or more tributaries may affect water quantity and quality in a particular mainstem stream.

10.2 Recommended flow threshold for fishless streams

The recommended flow threshold for fishless streams is a minimum instream flow release equivalent to the median monthly flow during the low flow month. This value represents the minimum instream flow requirement through the diversion section at all times of the year. The low flow month is defined as the calendar month with the lowest median flow, based on natural mean daily flows. Several examples of pre- and post-project hydrographs using this diversion rule are presented in Appendix E.

The flow threshold must be based on data that meet requirements as described in Section 10.1. For example, non-fish bearing status must be demonstrated using techniques as described in the

Assessment Methods guidebook, calculations must be based on a minimum of 20 years of continuous natural daily flow records, and maximum diversion rates are less than or equal to the 80th percentile of daily flows over the period of record. Table 8 shows a summary of diversion and instream flows based on this rule when modeled for a set of test streams.

Table 8. Summary of diversion and instream flows when the recommended fishless stream threshold is applied to a set of test streams. (Note: the purpose is to understand the effects of the diversion rule; in reality each of these streams is likely fish-bearing.) Sum natural flow, sum regulated flow, and sum diverted flow are totals of mean daily flows for the period of record. Units of flow are cms days; multiply by 86400 (i.e., no. of seconds in a day) to obtain total volume over period of record. Sum diverted flow / sum natural flow is the proportion of total flow that is available for diversion. Thus, under this rule diversion as a proportion of available flow ranges from 30% to 69% with a mean of 48% for our group of test streams.

Region	Gauge no.	Gauge name	Period of record	sum natural flow	sum regulated flow	sum diverted flow	sum diverted / sum natural
Coastal, Dry	08HA016	Bings Creek near mouth	1961 - 2000	5683	2824	2859	50.3%
Coastal, Dry	08HA001	Chemainus River near Westholme	1914 - 2000	318000	121000	197000	62.1%
Coastal, Dry	08HB025	Browns River near Courtenay	1960 - 2000	31011	10757	20254	65.3%
Coastal, Wet	BCH inflow file	Heber River u/s of diversion	1959 – 1999	74040	32238	41802	56.5%
Coastal, Wet	08HB048	Carnation Creek at the mouth	1973 - 2000	8436	4487	3949	46.8%
Coastal, Wet	08MH056	Sleese Creek near Vedder Crossing	1957 - 2000	129000	62100	67100	51.9%
Coastal, Wet	08OB002	Pallant Creek near Queen Charlotte	1962 - 2000	76712	23849	52863	68.9%
Interior, Dry	08LB072	Louis Creek at mouth	1971 - 1996	23867	15250	8617	36.1%
Interior, Dry	08LB078	Lemieux Creek at mouth	1977 - 2000	24786	14445	10341	41.7%
Interior, Dry	08NL070	Similkameen River above Goodfellow	1974 - 2000	72122	40922	31200	43.3%
Interior, Dry	08NL007	Similkameen River near Princeton	1914 - 2000	516000	312000	204000	39.5%
Interior, Dry	08NM173	Greata Creek near mouth	1970 - 2000	961	669	292	30.3%
Interior, Dry	08NM171	Vaseux Creek above Solco Creek	1970 - 2000	10444	6718	3726	35.7%
Interior, Dry	08MA006	Lingfield Creek at mouth	1974 - 2000	7406	4659	2748	37.1%
Interior, Wet	08NE039	Big Sheep Creek near Rossland	1929 - 2000	107000	56400	50600	47.3%
Interior, Wet	08NH006	Moyie River at Eastport	1915 - 2000	512000	279000	233000	45.5%
Interior, Wet	08PA001	Skagit River near Hope	1915 - 1955	259000	130000	129000	49.9%
Interior, Wet	08MF062	Coquihalla River below Needle Creek	1965 - 2000	33407	16011	17396	52.1%
Interior, Wet	08MF003	Coquihalla River near Hope	1911 - 1983	258000	115000	143000	55.5%

The steps in calculating this flow threshold are as follows:

1. determine non-fish bearing status of streams in the impact area,
2. obtain 20 or more years of continuous **natural** daily flow records,
3. calculate the 80th percentile flow over the period of record to set the maximum diversion rate,
4. calculate the median of mean daily flows during each calendar month,
5. set the annual flow threshold by selecting the lowest value from step 4.

This threshold does not apply where data requirements cannot be met. In such cases, appropriate assessment methodologies must be determined in consultation with regulatory agency representatives. Where proponents propose to divert greater amounts of water (either by decreasing the minimum flow requirement or increasing the maximum diversion rate), specific detailed assessments must be undertaken to evaluate the risk to fish and fish habitat (see Assessment Methods).

This flow threshold is intended to maintain connectivity through the diversion section, and to provide occasional high flow events to maintain gross stream morphology. We recommend that projects using this guideline be assessed to ensure these objectives are met. We also recommend that, where synthesized data are used, the diversion rules be annually adjusted during a period of at least five years, based on continuous discharge data collected from a gauge installed on the target stream.

The fishless stream diversion rule allows a substantial volume of water to be diverted. When modeled for a set of BC streams diversion ranged from 30% to 69% of total annual stream flow, and on average allowed almost 50% of flows to be diverted (Table 8). The rule can be calculated or approximated (see Section 10.7) with relatively simple data requirements. Where detailed physical and biological information is collected, it may be possible to exceed these diversion rates.

10.3 Rationale for recommended flow threshold for fishless streams

The recommended flow threshold for fishless streams is based on several considerations:

1. non-fish bearing status,
2. existing regulations and policies,
3. existing understanding of downstream fish benefits from continuous flow, and
4. consideration of naturally occurring low flows.

We have assumed that risk to fish production is lower on a fishless stream than on a fish-bearing stream, and therefore recommend that flow thresholds be more risk-averse on fish-bearing streams than on fishless streams. The rationale for different thresholds based on fish-bearing status is straightforward: a project on a fishless stream would have no direct effects on fish (e.g., entrainment, stranding, habitat alteration, etc.) within the fishless stream sections, there are precedents in other land use regulations for discriminating between streams with and without fish (e.g., The Forest Practises Code of BC), and the recommendation is consistent with past water use decisions.

The proposed minimum flow of median monthly flow during the low flow month, is based on the knowledge that this is a frequently observed naturally occurring low flow. Given the aim of protecting invertebrate production for downstream fish populations, the flow threshold should not drastically impinge on flows during naturally low flow periods, an often hypothesized bottleneck in invertebrate production in streams. We assume that the minimum flow will provide sufficient connectivity to maintain local invertebrate production and export of drift and detritus. Finally, the threshold assumes that run-of-river water use projects will utilize a maximum diversion equivalent to no greater than the 80th percentile of mean daily flows over the period of record. If this assumption is satisfied then flows in excess of this amount will remain in the diversion section and provide (albeit with lower frequency and duration) physical forces necessary to maintain overall stream morphology, and instream and riparian habitat.

The maximum diversion rate is usually an economic decision based on the cost of physical diversion works (e.g., penstock) in relation to the frequency of available flows. In practice, the maximum diversion rate is considerably less than the maximum available flow. As a rule of thumb we assumed that maximum diversion for run of river hydropower projects is roughly 100 – 150% of mean annual discharge. After examining flow duration curves for our test streams (see Appendix A) we set maximum diversion capacity equivalent to the 80th percentile flow over the period of record, which is always greater than MAD, at least on our test streams. We assume that this flow is a reasonable approximation for most projects.

Water extraction from a fishless stream has no direct effect on fish, but there are downstream effects that must be considered under current legislation and regulations. The Fisheries Act and supporting policies define fish habitat as water occupied by fish and "areas on which fish depend directly or indirectly in order to carry out their life processes." DFO's Habitat Conservation and Protection Guidelines (1998) interpret fish habitat to include areas that "although not directly supporting fish, provides nutrients and/or food supply to adjacent or downstream habitat or contribute to water quality for fish." This legal definition creates the imperative to treat fishless streams as habitat requiring some level of protection because doing so reduces risk to fish populations. In other words, based on these guidelines full diversion is not a valid option anywhere in the province.

Based on reviews in Sections 6.0 and 8.0 it is reasonable to assume that water use projects on fishless streams have the capacity to influence downstream fish production. Benefits to downstream fish producing areas include export of detritus and invertebrate drift, important components of food webs in streams. We therefore recommend against full diversion.

10.4 Recommended flow threshold for fish-bearing streams

The recommended flow threshold for fish-bearing streams is a seasonally-adjusted threshold for alterations to natural stream flows. The thresholds are calculated as percentiles of natural mean daily flows for each calendar month. These percentiles vary through the year to ensure higher protection during low flow months than during high flow months. As a result more water is available for diversion during high flow months than during low flow months. Several examples of pre- and post-project hydrographs based on the proposed diversion rule are presented in Appendix C.

The flow threshold must be based on data that meet requirements as described in Section 10.1. For example, calculations must be based on a minimum of 20 years of continuous natural daily flow records, and maximum diversion rates are less than or equal to the 80th percentile of mean natural daily flows over the period of record. Table 9 shows a summary of diversion and instream flows based on this rule when modeled for a set of test streams.

The maximum diversion rate is usually an economic decision based on the cost the physical diversion works (e.g., penstock) in relation to the frequency of available flows. In practice, the maximum diversion rate is considerably less than the maximum available flow. As a rule of thumb we assumed that maximum diversion for run of river hydropower projects is roughly 100 – 150% of mean annual discharge. After examining flow duration curves for our test streams (see Appendix A) we set maximum diversion capacity equivalent to 80th percentile flow over the period of record, which is always greater than MAD, at least on our test streams. We assume that this flow is a reasonable approximation for most projects.

Table 9. Summary of diversion and instream flows when the fish-bearing stream flow threshold is applied to a set of test streams. Sum natural flow, sum regulated flow, and sum diverted flow are total mean daily flows for the period of record. Units of flow are cms days; multiply by 86400 (i.e., no. of seconds in a day) to obtain total volume over period of record. Sum diverted flow / sum natural flow is the proportion of total flow that is available for diversion. Thus, under this rule diversion flow ranges from 12% to 32% for our group of test streams, and on average allows approximately 22% of flows to be diverted.

Region	Gauge no.	Gauge name	Period of record	sum natural flow	sum regulated flow	sum diverted flow	sum diverted / sum natural
Coastal, Dry	08HA016	Bings Creek near mouth	1961 - 2000	5683	4125	1558	27.4%
Coastal, Dry	08HA001	Chemainus River near Westholme	1914 - 2000	318000	217000	101000	31.8%
Coastal, Dry	08HB025	Browns River near Courtenay	1960 - 2000	31011	21857	9154	29.5%
Coastal, Wet	BCH inflow file	Heber River u/s of diversion	1959 – 1999	74040	54199	19841	26.8%
Coastal, Wet	08HB048	Carnation Creek at the mouth	1973 - 2000	8436	5784	2652	31.4%
Coastal, Wet	08MH056	Sleese Creek near Vedder Crossing	1957 - 2000	129000	103000	25700	19.9%
Coastal, Wet	08OB002	Pallant Creek near Queen Charlotte	1962 - 2000	76712	52544	24168	31.5%
Interior, Dry	08LB072	Louis Creek at mouth	1971 - 1996	23867	20567	3300	13.8%
Interior, Dry	08LB078	Lemieux Creek at mouth	1977 - 2000	24786	21064	3722	15.0%
Interior, Dry	08NL070	Similkameen River above Goodfellow	1974 - 2000	72122	57439	14683	20.4%
Interior, Dry	08NL007	Similkameen River near Princeton	1914 - 2000	516000	419000	96600	18.7%
Interior, Dry	08NM173	Greata Creek near mouth	1970 - 2000	961	842	119	12.4%
Interior, Dry	08NM171	Vaseux Creek above Solco Creek	1970 - 2000	10444	8828	1616	15.5%
Interior, Dry	08MA006	Lingfield Creek at mouth	1974 - 2000	7406	6020	1386	18.7%
Interior, Wet	08NE039	Big Sheep Creek near Rossland	1929 - 2000	107000	88200	18900	17.6%
Interior, Wet	08NH006	Moyie River at Eastport	1915 - 2000	512000	421000	91100	17.8%
Interior, Wet	08PA001	Skagit River near Hope	1915 - 1955	259000	207000	51400	19.9%
Interior, Wet	08MF062	Coquihalla River below Needle Creek	1965 - 2000	33407	25739	7668	23.0%
Interior, Wet	08MF003	Coquihalla River near Hope	1911 - 1983	258000	200000	57600	22.3%

The steps in calculating the proposed flow threshold are as follows:

1. determine fish-bearing status of streams in the impact area,
2. obtain 20 or more years of continuous **natural** daily flow records,
3. calculate the 80th percentile flow over the period of record to set the maximum diversion rate,
4. calculate the median of mean daily flows during each calendar month,
5. order monthly values from step 4 in sequence from lowest to highest,
6. set the flow threshold in the lowest flow month to 90th percentile of mean daily flows in that month,
7. set the flow threshold in the highest flow month to 20th percentile of mean daily flows in that month,
8. set the flow threshold for all other months as a percentile of mean daily flows in that month, where the percentile is calculated according to the formula:

$$90 - \left[\left(\frac{median_i - median_{\min}}{median_{\max} - median_{\min}} \right) \times (90 - 20) \right]$$

where
$median_i$ is the median of mean daily flows for month i,
$median_{min}$ is the month of lowest median flows,
$median_{max}$ is the month of highest median flows.

Using this formula the percentile for each month will vary between 20th and 90th (Figure 13).

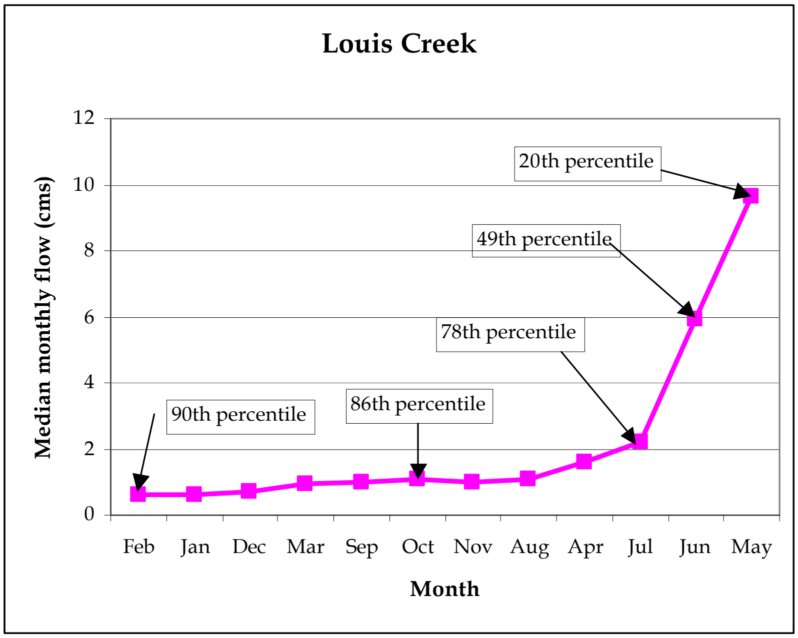

Figure 13. An example of median monthly flows plotted in ascending order, showing the percentiles that would be calculated and used for diversion criteria.

This flow threshold does not apply where data requirements cannot be met. In such cases, appropriate assessment methodologies must be determined in consultation with regulatory agency representatives. Where proponents propose to divert greater amounts of water (either by decreasing the minimum flow requirement or increasing the maximum diversion rate), specific detailed assessments must be undertaken to evaluate the risk to fish and fish habitat (see Assessment Methods).

This guideline is intended to maintain the most important features of a natural hydrograph from a biological and physical perspective. For example, the resulting flows are intended to maintain connectivity through the diversion section at all times, protect low flow periods regardless of season (e.g., protect rearing habitat during summer low flows, and overwintering habitat and ice free refuges in winter low flows), and to provide high flow events to maintain gross stream morphology and instream and riparian habitat. We recommend that projects using this guideline be assessed to ensure these objectives are met. We also recommend that, where synthesized data are used, the diversion rules be annually adjusted during a period of at least five years, based on continuous discharge data collected from a gauge installed on the target stream.

The fish-bearing stream diversion rule allows a substantial volume of water to be diverted, though less than the fishless stream rule. When modeled for a set of BC streams diversion volumes ranged from 12% to 32% of total stream flow, and on average allowed approximately 22% of flows to be diverted (Table 9). The rule can be calculated or approximated (see Section 10.7) with relatively simple data requirements. Where detailed physical and biological information is collected, it may be possible to exceed these diversion rates.

10.5 Rationale for recommended flow threshold for fish-bearing streams

The recommended flow threshold for fish-bearing streams is based on several considerations:

1. high variability in hydrologic regimes (e.g., snowmelt, rainfall, or combination),
2. high variability in fish communities (e.g., diversity, abundance, and fisheries values),
3. uncertainty in ecological response to flow changes,
4. existing regulations and policies, and
5. naturally occurring flow regimes and their ecological functions.

As discussed at length in previous sections of this report, British Columbia is hydrologically and biologically diverse. As a result, it is difficult to develop meaningful generalizations regarding streams in the province and their biological resources. Adding to this difficulty is the general uncertainty in ecological response to flow changes. This makes the task of setting instream flow thresholds difficult.

Relevant regulations and policies are discussed in detail in Section 4.0, but the primary consideration with respect to stream flows and fish has been the Fisheries Act and supporting policies. Of particular importance is the determination of whether an altered flow regime constitutes a harmful alteration, disruption or destruction (HADD) of fish habitat. It is this component of the act that is usually used to assess proposed water use projects, yet it became apparent during this project that determining HADD thresholds in relation to flow is not yet possible prior to the collection of considerable site-specific information.

We therefore adopted the "natural flow regime" approach in which one tries to quantitatively describe and then preserve key aspects of the natural hydrograph (Poff et al. 1997; Richter et al. 1996, 1997; Trush et al. 2000) . The approach does not deny that there may be certain regulated flow regimes that are superior in some respects than a natural hydrograph at some sites. Instead it merely implies that predicting the biological response to different types of alteration are likely to be difficult, and preserving key aspects of the natural hydrograph is most likely to maintain the physical aspects of streams on which fish and other ecosystem components depend.

The proposed minimum flow threshold of 90th percentile flow during the low flow month is based on the knowledge that this is a frequently observed naturally occurring low flow. The threshold will not drastically impinge on flows during naturally low flow periods, an often hypothesized bottleneck in fish production in streams. The threshold will more accurately reflect true low flow values than a percentage of MAD, since it will vary among streams depending on hydrologic region (i.e., hydrograph type). Finally, the guideline assumes that run-of-river water use projects will utilize a maximum diversion no greater than the 80th percentile of daily flows over the period of record. If this assumption is satisfied then flows in excess of this amount will remain in the diversion section and provide (albeit with lower frequency and duration) physical forces necessary to maintain overall stream morphology, and instream and riparian habitat. Specifying both a minimum and a maximum diversion amount is an important component of preserving key components of the natural hydrograph.

10.6 Consumptive uses

As noted earlier, the recommended flow thresholds have been devised primarily to satisfy the demands of screening level reviews of small hydropower projects. Yet, these same guidelines are also applicable to reviewing proposals for water withdrawals for irrigation, or domestic, municipal or industrial uses. Minimum instream flows would be calculated using the same rules as those laid out above for fishless or fish-bearing streams; the flows would be based on percentiles of mean daily flows during each calendar month. Maximum diversion rates should also be constrained in the same manner as discussed above: the installed diversion capacity should be less than or equal to the 80th percentile of natural daily flows over the period of record. By constraining maximum diversion rates, flows in excess of this maximum combine with the minimum instream flows to help maintain a natural hydrograph.

The recommended thresholds may diverge from rules of thumb currently used to determine whether a stream is fully allocated. However, we suggest that the proposed diversion rules are reasonable as a "coarse filter" when there is no biological or physical information to help in the assessment of water use applications. This is especially the case since consumptive uses by definition do not return water to the channel, and therefore may have a larger area of impact downstream of the intake. The "coarse filter" may encourage proponents to consider off channel water storage to satisfy water demands during low flow periods when surface water extraction should be restricted. Additionally, the thresholds may help direct study effort toward the collection of relevant data to resolve conflicts between proposed water uses and instream flows for fish (e.g., site-specific detailed assessments).

10.7 Simplifying the Review Guideline thresholds

The guidelines as proposed depend on an accurate long-term historic flow record; a flow record that must be compiled from a gauge on the stream of interest or synthesized from nearby gauges. Once a good flow record is obtained, there are a series of steps that must be taken to calculate the thresholds for a given site. Although the calculations are not complex they do require some comfort with numbers and a familiarity with computers and historic flow data. There would likely be some benefit to simplifying the calculations, providing automation through a software application, or to providing methods to approximate the thresholds in the absence of a long-term flow record.

One of our initial attempts at simplifying the guidelines was to create diversion rules that rely on fewer data. Examples of these alternate rules are presented and discussed in Appendix B. These alternatives performed considerably less well than the proposed thresholds, and are therefore not discussed further.

Another straightforward way to simplify the guidelines would be to express the minimum and maximum diversion rates in terms of % MAD or a similar statistic such as MedAD. These summary statistics are easy to calculate from historic flow records or to model from nearby gauges. A guideline expressed in these terms would have the benefit of being quick to calculate by hand or by pocket calculator. The downside to expressing a threshold in these terms has been discussed at several points throughout this document: MAD is insensitive to hydrologic regime and BC is represented by streams of diverse hydrologic type.

We nevertheless examined whether it was possible to express the proposed thresholds in terms of annual summary statistics. We used the flow records from a set of BC streams (see Appendix A), calculated the proposed flow thresholds, and then asked whether there were correlations between the monthly flow threshold and the annual summary statistics, MAD and MedAD. Relationships between the monthly flow threshold and MAD or MedAD varied widely both within and among streams indicating that the thresholds would be poorly represented using proportion of MAD or MedAD.

During this analysis we also examined whether there were consistent relationships between the monthly flow thresholds and mean monthly flows. The relationships were not consistent among streams, but there were strong correlations between monthly percentiles and mean monthly flows (Figure 14). These relationships indicate that it may often be possible to predict with reasonable accuracy the monthly flow thresholds in ungauged systems using data from nearby gauges. This may be particularly useful for calculating the fishless stream threshold. This type of modeling has been completed for some regions in BC and may even allow prediction of the monthly flow thresholds for fish-bearing streams as percentages of MAD within specified hydrologic zones (e.g., Barr et al. 2001).

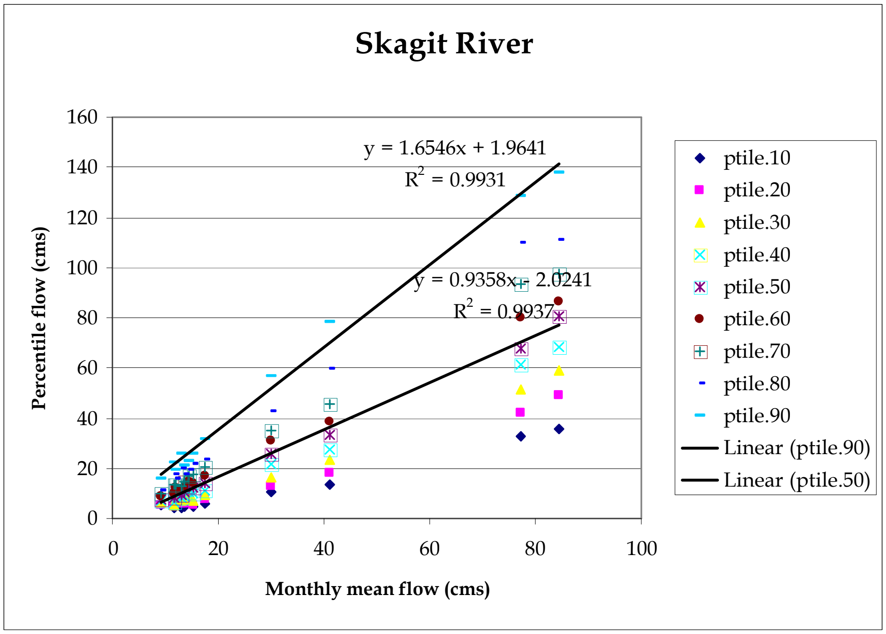

Figure 14. Monthly percentiles may be well predicted from monthly means. Such relationships may facilitate accurate modeling of the flow thresholds for ungauged systems, based on data from nearby gauges. It should be noted that while most of these relationships were quite strong for our group of test streams, some were not.

It should be noted however that although one may be able to predict some of the flow thresholds using data from nearby gauges, the prediction is subject to modeling error. We recommend that the guideline be expressed in terms the mean daily flow data, but to leave the door open for alternatives that can do a similar job on a site-specific basis. Since optimal methods for synthesizing flow data may vary among regions we do not specify a single recommended method. We do recommend however, that any synthesizing of flow records be done by a certified professional and that continuous recording flow gauges be installed for all hydropower projects, and where other water demands are high. Where synthesized data are used to calculate diversion rules, the rules should be annually adjusted during a period of at least five years, based on continuous discharge data collected from the target stream.

Finally, to facilitate water planning within resource agencies we recommend that the Review Guidelines, if adopted, be accompanied by a dedicated software application to automate aspects of the flow setting determinations. Alternatively, the thresholds can be calculated for a set of reference systems throughout the province, and the results can be made available on a web site. There may be sufficient benefit to undertaking both of these tasks.

11.0 MONITORING

Monitoring is the cornerstone of effective resource management, providing the feedback mechanism that allows post implementation assessment of management decisions and programs. Monitoring is a vital element of the guidelines because it either demonstrates compliance, demonstrates the effectiveness of flow decisions, or identifies how the flow thresholds should be revised to increase effectiveness.

The mandate to undertake effective monitoring is emphasized in the provincial government's stated environmental stewardship objective of "improving the use of science for the development of standards and for effective monitoring and reporting" (MWLAP Service Plan, 2003/04 – 2005/06). Stated strategies for this objective are to:

- Acquire the data, information and knowledge to support a science-based approach to the conservation of biodiversity.
- Implement monitoring and reporting programs to track the status of species and ecosystems and their responses to management actions.

We note however, that monitoring should not be the responsibility of provincial agencies only. There are benefits to monitoring that accrue to licensed water users and federal resource management agencies, particularly DFO. We recommend that provincial agencies vigorously explore cost sharing opportunities for designing and delivering an effective monitoring program.

This section briefly outlines a proposal for two types of monitoring, and describes a general business case framework that could be applied to support the design and evaluation of an effective monitoring program. The technical design of monitoring program options and the business case evaluation of those options could be undertaken with varying degrees of sophistication. As a starting point, we recommend undertaking a preliminary phase of design and evaluation, based on the guidance provided below, in conjunction with the formal peer review of these guidelines.

11.1 Compliance and Biotic Response Monitoring

We propose two types of monitoring as part of the guidelines, compliance monitoring and biotic response monitoring.

Compliance monitoring. Compliance monitoring is fairly straightforward and would simply monitor water use to ensure that a user is complying with the conditions of a water license. This should be done through installation and maintenance of continuous recording flow gauges for measuring instream flows and diversions. The main benefit of compliance monitoring is to ensure that water use is quantified and recorded, and to assess and encourage compliance. An additional benefit is that the data provided will add to flow data from the present network of gauges and thus aid in regional water planning including allocation of water to downstream users. Hubert et al. (1990) found that compliance by water users was poor, which is a strong argument to require compliance monitoring.

In some circumstances, compliance monitoring could be expanded beyond hydrological monitoring to include monitoring of water quality, channel morphology, or other physical state conditions. It could also be included for habitat compensation works.[7]

Biotic response monitoring. Biotic response monitoring is more difficult and would involve checking whether compliance with flow decisions results in the expected outcomes on the target ecological resources (i.e., fish populations, fish habitat, invertebrate production, etc.). Biotic response monitoring is often more costly than compliance monitoring, since biological responses are difficult to measure and variable in space and time. An effective monitoring program must be designed to address the complexity of relationships between biological responses and flow, and to account for external factors (i.e., non-flow related) and natural temporal variations. A common method for effectively addressing these monitoring challenges is to apply a Before-After, Control-Impact (BACI) design, in which “control” sites (i.e., streams without water withdrawal projects) are monitored simultaneously with “impact” sites for a predetermined period both before and after project implementation.

During the workshops and discussions held for this project there has been virtually unanimous support from resource managers for this type of monitoring. The overriding argument for implementing a biotic response monitoring program is recognition of the current uncertainty in predictions of biological response (e.g., fish populations) to changes in environmental conditions (e.g., instream flow regime) (Ludwig et al. 1993; Castleberry 1996).

11.2 Business case evaluation framework

The phase I report called for the development of a formal business case evaluation of monitoring. A business case evaluation would explore the incremental costs and benefits of alternative monitoring program design and implementation options. In doing so, the evaluation would help inform some important policy and program design questions, such as:

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[7] Typically, smaller scale habitat compensation is monitored for a finite period to ensure that it is physically stable and performing adequately. We assume that the agencies currently have an adequate monitoring program for habitat compensation and will continue to support it.

1. How will monitoring results be utilized in future water management decisions and regulatory processes?
2. What are the benefits of monitoring from a societal perspective? What level of benefits would justify program costs? How likely is it that this level of benefits will be achieved?
3. What are the costs? Are there creative ways to maximize benefits and minimize costs? What are the opportunities for partnerships and cost-sharing?
4. Are there risks to monitoring (administrative, legal or political)? If so, how might they be mitigated?

Prior to conducting a business case evaluation, the ministry should provide initial direction on the first question, confirming how monitoring results will be utilized in future water management decisions. Monitoring information will have value from a water management perspective only if it will be used to review and potentially revise the guideline flow thresholds themselves, specific water licenses, or mitigation/compensation requirements of the licensees. The implications of any future change in the thresholds should be assessed in advance with respect to agency resource requirements, existing water license holders, and future water license applicants.

The need for a formal business case evaluation is clear; if the proposed flow thresholds are too restrictive, then there is a lost opportunity for economic gain; if the proposed thresholds are too permissive, then there is a need for remedial action that may, among other things, involve revision of the thresholds.

A business case evaluation would involve four steps: development of monitoring program objectives, development of monitoring program scope and implementation options, option evaluation, and final recommendations. Preliminary guidance on these steps is provided below.

11.3 Development of Monitoring Program Objectives

A clear set of objectives is necessary in order to conduct a thorough business case evaluation. The starting point for the development of monitoring program objectives is recognition of the fundamental objectives of the Review Guidelines themselves, which are:

> **Protect fish, fish habitat and the productive capacity of aquatic ecosystems**.
> This objective recognizes the value placed on maintaining productive, functioning aquatic ecosystems across the province. This objective is the underlying driver of the coarse-filter approach.
>
> **Provide opportunities for economic development of water resources.**
> At the same time, there is a need to formally address the opportunity for beneficial human use of water for applications such as power generation, irrigation, drinking water, and recreation. Economic or financial implications can be assessed from at least three perspectives: government (i.e., water rental fees), water license holder (i.e., revenue generation), and society as a whole.

These fundamental objectives can be used to guide the design of monitoring program options in various ways. For example, alternative program designs, as reflected in the selection of which streams to monitor and what intensity of monitoring to undertake, could be driven by the importance of various streams from a fish perspective (e.g., streams with threatened species, or commercially/culturally important fish stocks) and/or from an economic perspective (e.g., streams where water or energy shortages exist, sites where significant financial value can be attained through incremental water use).

Monitoring of flow decisions is an important means for achieving these fundamental objectives. To maximize support for these fundamental objectives, specific monitoring program evaluation objectives are:

Improve water license compliance. Research has shown that water license compliance is generally low (Hubert et al. 1990). Increased levels of monitoring are therefore more likely to result in increased levels of compliance, which will be reflected in better fundamental objective performance.

Improve the science knowledge base. This objective aims at increasing scientific and management understanding of the relationship between instream flows and ecosystem functions. An improved knowledge base will support future management decision-making, and ensure that a science-based approach to resource is being achieved. It will improve the likelihood that a socially optimal balance between the fundamental objectives of ecological and economic objectives is achieved.

Minimize cost. The selection of a monitoring program design should be based on achieving the desired outcomes at the least cost. Costs can be analyzed from multiple perspectives. Government costs can be indicative of the level of government oversight that would be required under different program designs, which may be an important consideration.

Enhance partnerships and collaboration. Program designs that involve greater levels of collaboration over the long term will result in a common understanding of the relationships between fish, habitat and instream flow, and will increase support for future actions with respect to the Review Guidelines and flow thresholds.

Assessing the performance of alternative monitoring program designs against these objectives is core to the business case framework.

11.4 Development of a range of program design and implementation options

There are numerous options for the design of a monitoring program taking into account considerations such as scope of effort, timing, duration and geographic emphasis. The following illustrative examples provide an indication of the range of possible designs:

- Program Design 1: Continuous, full-scale monitoring (i.e., both compliance and biotic response) for all projects in all hydrologic regions.

- Program Design 2: Intermittent monitoring of certain variables (e.g., hydrologic compliance and fish habitat only) for a subset of projects (e.g., those that did not pass the coarse filter) over a defined time period (e.g., 3 years) in coastal regions only.
- Program Design 3: Random audits of hydrologic compliance only.

This wide range of possible effort suggests that thorough consideration should be given to both agency and water license holder/applicant resource requirements.

When deciding upon an appropriate monitoring scope, consideration could be given to prioritizing certain regions where water use conflicts are more pressing, or to circumstances where scientific uncertainty is greatest. Further, considering the proposed structure of the guidelines themselves, there could also be different monitoring requirements for projects based on whether a stream is fish-bearing or fishless, and whether the project approval passes the coarse screen or detailed assessment screen (see example in Table 10).

Table 10. Illustrative example of how the scope of monitoring effort could be based on fish-bearing status and license approval mechanism.

	Fishless Streams	**Fish-Bearing Streams**
Project Implemented with Coarse Filter Approval	• compliance	• compliance • biotic – fish habitat
Project Implemented with Detailed Assessment Approval	• compliance • biotic - invertebrates	• compliance • biotic – fish habitat • biotic – fish populations

From an implementation and program delivery perspective, numerous options also exist. Questions to consider include:

- What roles could be fulfilled by the various parties including, government (all levels), individual proponents, business associations, or non-governmental institutions?
- Who would develop the necessary guidance documents to ensure high quality monitoring design?
- How would quality control/assurance, data warehousing, synthesis and analysis be managed?
- What funding options are available? (The question of who pays is largely a distributional issue that might best be dealt with in the evaluation step (see Section 11.5 below). Options range from making both compliance and biotic response monitoring a proponent responsibility, to having a central fund made up of contributions from both proponents and government.)

Clearly, there is a wide array of options for designing and implementing a monitoring program. We recommend, as an initial step, developing a set of program design and implementation options that reflect the full range of potential approaches. For example at one extreme, a minimal approach to monitoring might involve solely compliance monitoring (perhaps on an audit basis) and the gathering of information to test the key hypotheses that direct the Guidelines (e.g., maintenance of flow connectivity in the diversion section). At the other extreme, a comprehensive experimental approach to monitoring incorporating BACI design, central data warehousing and analysis capability, and joint funding from all sectors could be designed. Options in between these extremes would also be designed.

These initial options would then be formally evaluated against the program objectives to expose the incremental costs and benefits of alternative program design options (see 11.5 below). Following this initial round of evaluation, the process could be repeated on a refined selection of program design options, until a preferred monitoring program design is achieved.

11.5 Option evaluation tools and techniques

There are a variety of evaluation tools and techniques that should be applied to implement a business case evaluation for flow decision monitoring. However the scope of actual evaluation requirements remains unclear until such time as the monitoring program options are designed, and specific decision criteria or performance measures are established for each evaluation objective. Nonetheless, a brief overview of some of the evaluation tools and techniques likely to be applied is provided below.

Critical value analysis. Critical value analysis can be a useful technique in both the design and screening of alternative monitoring program designs. Critical value analysis is most often applied to establish what threshold level of benefits (monetary or non-monetary) are required to justify a proposed level of costs. It provides the means of considering such questions as:

- For a given monitoring program design with a total cost of X$, what incremental change in the flow thresholds (i.e., decreased instream flow requirement) would be necessary to result in enough increased revenues to re-coup the costs?
- What increase in % compliance (due to monitoring) would be necessary to make mandatory hydrological monitoring of all projects worthwhile?
- What combinations of “improved knowledge”, “increased compliance” and “improved partnerships” would collectively justify a monitoring program expenditure of Y$?

As a design tool, critical value analysis could be used to establish the appropriate scope of individual monitoring program design elements (e.g., the minimum level of compliance monitoring required under all circumstances). As a screening tool, critical value analysis could be used to eliminate unworkable program designs early in the evaluation process.

Multiple account evaluation. A Multiple Account Evaluation (MAE) should be adopted as the overall framework for the business case evaluation, once initial design and screening has taken place. An MAE is specifically designed to evaluate options in the context of the multiple objectives inherent in resource management decisions. The approach has been used extensively in British Columbia for electricity resource planning, land use planning, and more recently water use planning (Crown Corporations Secretariat 1993; Integrated Resource Planning Committee 1993; Province of British Columbia 1998).

Within an MAE, the performance of each program design option with respect to each monitoring program objective would be documented and evaluated. Key trade-offs across and within alternative program design options would be explored to guide the iterative development of an option that achieves the best balance across all program objectives (Figure 15).

An MAE provides the structure, context and starting point for many other evaluation techniques such as benefit-cost analysis and scenario analysis.

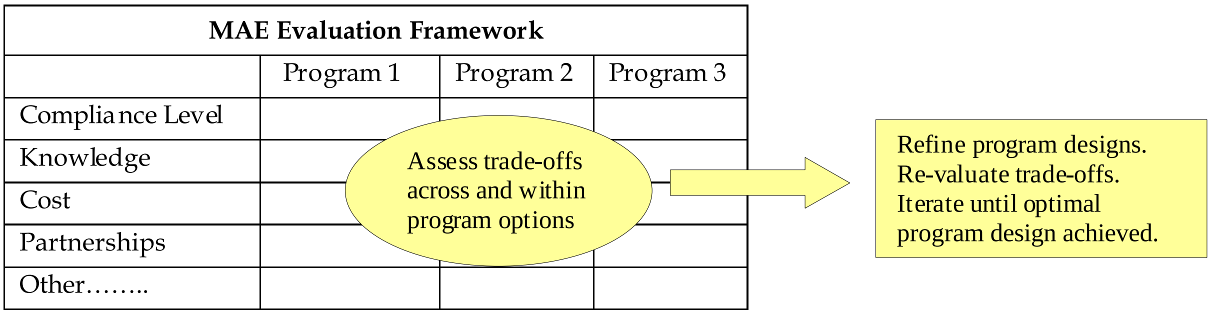

Figure 15. Process of applying a Multiple Account Evaluation framework.

Sensitivity analysis. The design of monitoring program options will require the need to make management assumptions related to expected costs (e.g., installation and maintenance of streamflow gauges; contract field auditing services; management and future reporting requirements) and expected benefits (e.g., % of sites for which flow– habitat relationships can be confirmed; % improvement in compliance). Assumptions could also be made regarding the expected future refinement of the flow thresholds (e.g., adjustment to a minimum flow release equal to the 30th/70th percentile monthly flow in the low flow month for fishless streams). These assumptions will have varying degrees of uncertainty that must be evaluated. Sensitivity analysis would be used to examine the effect of changing a given assumption on the performance of each option. As an important part of the overall business case evaluation, all key uncertainties will be identified and tested using sensitivity analysis.

11.6 Formal recommendations

The outcome of the business case evaluation would be a set of formal recommendations that outline:

- Key program design elements (scope, timing, duration, locations and priorities)
- Management, implementation and reporting structure
- Funding strategy
- Performance measures and targets
- Risk management strategy

12.0 SUMMARY OF RECOMMENDATIONS

1. All recommendations and flow thresholds proposed in this document should be subjected to a formal peer review process conducted by agencies and third party reviewers.
2. We recommend the use of an historic flow method, based on natural mean daily flows, to set flow thresholds for screening proposed water uses in BC streams. This approach ensures the relevance of the thresholds to flows that are naturally available in the stream of interest.
3. Encourage preferential development of fishless streams through the use of different flow thresholds based in part on fish-bearing status of streams.
4. Ensure installation of continuous recording flow gauges for all hydropower projects, and where water demands are high.
5. Promote "holistic" diversion criteria that focus on preserving key features of the natural hydrograph, since it is these features that are responsible for maintaining fish habitat in alluvial streams.
6. We recommend against full diversion of any stream, including fishless streams.
7. Where water uses exceed proposed flow thresholds reviewers should carefully consider the effects of stream size when assessing effects of water withdrawals on fish and fish habitat.
8. Projects that use the proposed guidelines should be assessed to ensure basic objectives (e.g., connectivity in the diversion section) are met.
9. Monitoring has received unanimous support during development of these guidelines. We recommend two types of monitoring as part of the guidelines, compliance monitoring and biotic response monitoring.
10. Details of the monitoring program should be worked out pending completion of policy clarifications. As a starting point, we recommend undertaking initial technical design and business case evaluation.
11. Where synthesized flow data are used, the diversion rules should be annually adjusted during a period of at least five years, based on continuous discharge data collected from a gauge installed on the target stream.
12. The guidelines, if adopted, should be accompanied by a dedicated software application to automate aspects of the flow setting process. Alternatively, the province can calculate the thresholds for specific sites throughout the province and make the results available on a web site.
13. Agency policy implications and hurdles should be clarified to ensure that biological response monitoring is conducted for projects with intensive water uses.

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Appendix A. Hydrometric summaries for selected sites in British Columbia

Appendix B. Methods used to develop and evaluate the recommended flow thresholds

Appendix C. Pre- and post-project flows based on flow thresholds for fish-bearing streams

Appendix D. Evaluation of simulated post-project flows for fish-bearing streams

Appendix E. Pre- and post-project flows based on flow thresholds for fishless streams

Appendix F. Evaluation of simulated post-project flows for fishless streams