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British Columbia Instream Flow Standards for Fish
Phase 1 – Initial Review and Consultation

  

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SUMMARY

This document presents and discusses progress to date toward development of the British Columbia Instream Flow Standards for Fish (“the Standards”). The Standards are presented here in preliminary draft form only. Further critical detailed review and refinement are necessary before the Standards can be finalized.

The Standards are intended to satisfy three critical needs: consistency in water license applications, a process for making water allocation decisions with respect to fish and fish habitat, and a suite of flow criteria that protect fish and fish habitat. The Standards represent a method for setting instream flows that will protect fish habitat in British Columbia streams in the absence of detailed biological and physical information. They offer an approach to satisfy the multiple objectives of streamlining the review of water license applications and developing flow-based measures for the protection of fish habitat.

The Standards address flow-related issues only. They do not address construction-related issues such as instream construction impacts, transmission and road corridors, entrainment of organisms at water intakes, etc. They are applicable to all streams in British Columbia, and for all uses, including temporary uses (e.g., hydropower) and consumptive uses (e.g., withdrawal for drinking water, agriculture, or industrial uses). However, a catalyst for creating the Standards is the large number of applications for water use associated with small hydropower development. The design and presentation of the Standards has therefore considered this need foremost. Discussion of the Standards and how to apply them therefore focuses on issues surrounding small hydropower.

The Standards have been developed with the input of provincial, federal, and consulting fish biologists and hydrologists. A series of three workshops were held in Vancouver in early 2002, where participants reviewed various needs and proposals for the Standards. It is expected that wider review and input will occur during subsequent phases of this project.

In addition to reviewing technical material related to flow standards, the technical review team developed several guiding principles on which the Standards must rely. These principles capture the motivation for standards, the approach and philosophy to setting standards, and the intended benefits of standards.

The guiding principles for the Standards fall into five general classes:

1. Work Within Existing Legal Framework,
2. Develop Standards from the Perspective of Protecting the Fish Resource,
3. Minimize Review Costs,
4. Maximize Consistency and Transparency, and
5. Implement a Scientifically Defensible Approach.

A detailed review of the existing legal framework is presented in Section 3. 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 is presented, along with their supporting policies and guidelines and the relevance of these to the Standards.

The Standards are under development, so their place in the regulatory framework has not yet been defined. Based on a review of the legislation, they appear to fit well within the *Fish Protection Act* and could be defined as a section within that act. The Instream Flow Standards 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.

The document briefly reviews what other resource managers are doing in similar geographic areas, with respect to government reviews of instream flows. The jurisdictions reviewed include Alaska, Alberta, Washington, Oregon, and Idaho. The experience of other jurisdictions unfortunately provides only vague guidance for British Columbia. BC is not unique in trying to balance conflicting demands in the face of imperfect information, but there is no single jurisdiction that seems to be doing markedly better at managing surface flows than other jurisdictions. All of the jurisdictions have implemented processes aimed at achieving a balance for new water uses, but there is a general feeling among fisheries managers that too much water has already been given away.

The biggest steps in preventing further over-allocation problems seem to be directed toward hydropower projects. Most U.S. jurisdictions have specific review processes for hydropower projects, which are additional to or at least complementary to the assessment requirements laid out by the Federal Energy Regulatory Commission (FERC). Managers from several jurisdictions noted that they had earlier gone through phases of reviewing large numbers of small hydropower applications, most of which were rejected. It would be instructive for British Columbia to pay close attention to this experience as its agencies prepare to review a large number of such applications. In this respect, British Columbia has a distinct advantage in that it can learn from experiences south of the border.

In comparison to hydropower issues, considerably less attention has been directed to managing the cumulative effect of granting water licenses for consumptive uses. This is ironic considering that many jurisdictions seem to be suffering over-allocation problems due to this effect.

The British Columbia Instream Flow Standards for Fish require the collection, analysis, and reporting of specific physical and biological information—requirements that must be fulfilled before review of a proposed water use can proceed. The data will be used to apply the Standards in order to screen applications for negative effects on fish and fish habitat.

Information that should be incorporated into a water license application includes, but is not necessarily limited to, a description of the proposed project, the natural hydrology and biology in the affected watershed, and a description of other land and water uses in the area. Data must be collected and summarized using suitable methods, and be certified by a professional in the appropriate field (e.g., R. P. Bio., P. Geo., P. Eng. etc.). The standards for collecting and reporting most data are presented in greater detail in the companion document, "Instream Flow Methodology Guidebook," which will be finalized during phase 2 of this project.

Section 6 presents methods and criteria for setting instream flow requirements for fish, and discusses how they can be used as a “coarse filter” for water license applications. It begins with a brief review of methods available, and is followed by a discussion of some of the most appropriate methods for British Columbia. Briefly, the design of the Standards is to use basic information on biology and hydrology 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 species and life stages of fish present, and thus vary among streams in the province. The discussion and evaluation of applicable methods is based in part on input received from technical experts during a series of instream flow workshops held specifically for this project. Broad agreement was reached for some aspects of the Standards, whereas other aspects require considerably more technical evaluation before they can be accepted as defensible.

The key ingredient of scientifically defensible instream flow standards is a detailed monitoring program. Monitoring is the cornerstone of effective resource management, providing the feedback mechanism that allows proper assessment of management decisions and programs. Monitoring is a vital element of the Standards because it will allow us to demonstrate the effectiveness of the Standards or identify how the Standards should be revised to increase effectiveness. Designing and implementing an effective monitoring program is not straightforward, especially since the program will need to evaluate potential flow-related changes in biological productivity over multiple spatial and temporal scales. Section 7 presents an overview of some of the more important aspects that must be considered when designing and implementing a monitoring program. The details of the monitoring program will be completed during phase 2 of this project, after the Standards have been finalized.

Acknowledgements

A very tight timeline made the initial phase of the design of British Columbia Instream Flow Standards for Fish particularly challenging. We express our sincere thanks to the technical committee members, who met to review material on short notice and did so in a spirit of constructive criticism. We are especially grateful to Kevin Conlin and Ted Down for spearheading the project.

1 INTRODUCTION

British Columbia has abundant water resources, which sustain productive aquatic ecosystems and many uses by humans (e.g., power generation, irrigation, drinking water, industrial uses, recreation, etc.). Determining how much water can be safely extracted from a river without negatively affecting fish and fish habitat is a daunting task, but one that is frequently asked of resource managers. This document presents and discusses the British Columbia Instream Flow Standards for Fish ("the Standards"). The Standards represent a method for setting instream flows that will protect fish and fish habitat in British Columbia streams in the absence of detailed biological and physical information.

Why are the Standards 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 licenses. Authority for granting and administering water licenses rests with the provincial government and its water resources agencies (currently Water Management Branch within the Ministry of Sustainable Resource Management).

At present, water license applications are reviewed by staff in Water Management and referred to other resource management agencies (federal and provincial) for comment. (Other licensees, applicants, or landowners, whose rights may be affected if the license 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.

A stated objective in British Columbia is to avoid referrals within the provincial government, with the intent of speeding up the review of applications and decisions for granting of water licenses. Guidance for protection of fish and fish habitat will become an even greater need for regulators as provincial policies are changed with respect to referrals. The Standards are intended to direct applicants to collect supporting data as needed, and to guide reviewers and applicants by providing a "coarse filter" that will flag specific fisheries concerns related to instream flows. Figure 1 lays out the general schematic of how the Standards are meant to work. An in depth discussion of the conceptual framework for the Standards is presented in Section 2, Guiding Principles.

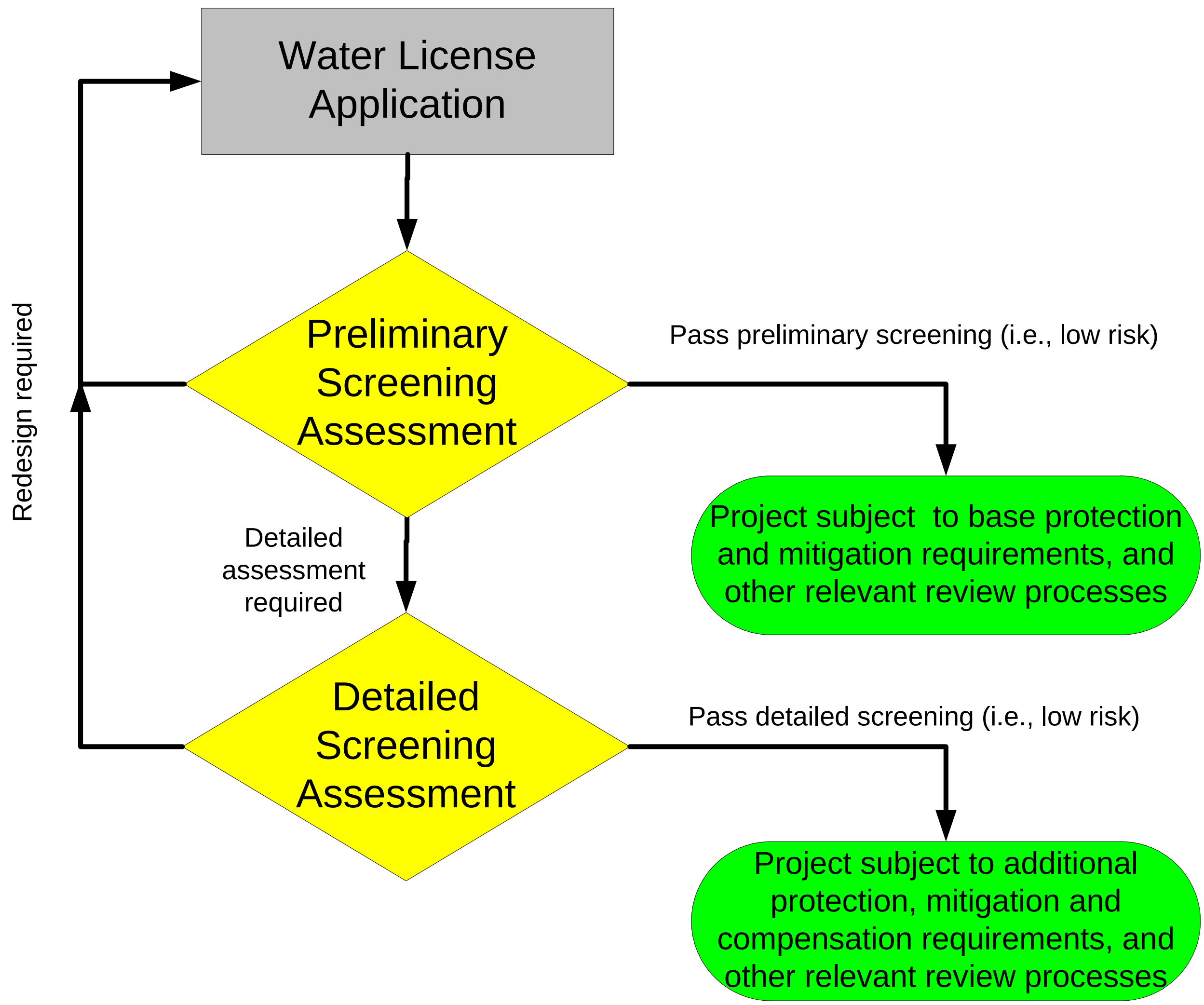

Figure 1. General decision schematic for the British Columbia Instream Flow Standards for Fish.

Despite efforts to manage flows for fish, there are many streams in British Columbia that, from a fisheries management perspective, are over-allocated (i.e., too much water is diverted or extracted). This status is observed throughout western North America for several reasons that are frequently encountered in resource management: water resources are held in common, the total effect of water licenses is a sum of many small decisions, and the solution for avoiding this situation is potentially complex. The Standards represent an approach to satisfy the multiple objectives of streamlining the review of water license applications and developing flow-based measures for the protection of fish and fish habitat.

Where will the Standards apply?

A catalyst for constructing the Standards is the large number of applications for water use associated with small hydropower development. The design and presentation of the Standards has therefore considered this need foremost. As a result, in this document discussion of the Standards and how to apply them focuses primarily on issues surrounding small hydropower. The Standards 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). The province is geoclimatically and biologically diverse, but the Standards are sufficiently flexible to determine or guide the determination of instream flows for fish throughout British Columbia. Subsequent phases of this project will explore in greater detail some of the specific issues surrounding non-power issues, and how to implement the Standards for consumptive uses.

Who will use the Standards?

The Standards 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 Standards will be water license applicants and regulatory agencies. The Standards are meant to guide water use decisions by indicating flow volumes and timing that minimize risk to fish habitat. In this way the Standards can be used both as a scoping tool by water license applicants and a formal review tool by regulators to assess the effects of a proposed water use.

How have the Standards been developed?

The Standards have been developed with the input of provincial, federal, and consulting fish biologists and hydrologists (Table 1). A series of three workshops were held in Vancouver in early 2002, where participants reviewed various needs and proposals for the Standards. In addition to reviewing technical material related to flow standards, participants developed several guiding principles on which the Standards must rely (see Section 2).

The Standards are presented here in preliminary draft form only. At this point they have been reviewed rather cursorily in a workshop setting and they require a critical detailed review and refinement during subsequent phases of this project. Ultimately, the Standards will make use of the best available technical and scientific information in order to be as rigorous and defensible as possible.

Table 1. List of reviewers and workshop participants during development of the British Columbia Instream Flow Standards for Fish.

Name	Affiliation
Larry Barr	MWLAP, Victoria
Mike Bradford	DFO, Vancouver
James Bruce	BC Hydro, Burnaby
Al Caverly	MWLAP, Kamloops
Kevin Conlin	MSRM, Victoria
Todd Hatfield	Solander Ecological Research, Victoria
Paul Higgins	BC Hydro, Burnaby
Adam Lewis	Ecofish Research, Richmond
Doug Lowe	MWLAP, Nanaimo
Steve Macfarlane	DFO, Vancouver
Steve McAdam	MWLAP, Victoria
Dan Ohlson	Compass Resource Management, Vancouver
John Patterson	DFO, Vancouver
Ron Ptolemy	MWLAP, Victoria
Dan Sneep	DFO, Vancouver
Heather Stahlberg	DFO, Kamloops

What are the Standards?

The Standards are intended to satisfy three critical needs: consistency in water license 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 Standards are presented in detail in Section 6, and in this report focus on addressing the latter two needs. 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 species and life stages of fish present, and thus vary among streams in the province.

Impacts from water use projects on fish and fish habitat can be conceptually divided into "operational" and "footprint" impacts. Operational impacts are those associated with the day-to-day running of a water intake, and are primarily flow-related. For example, the timing and volume of water extraction or diversion is an operational influence on fish and fish habitat. Footprint impacts are generally long-term effects from the construction of a water use project. Displacement of aquatic habitat at the site of a dam is an example of a footprint impact.

The Standards address operational or flow-related issues only. They do not address footprint issues nor any other potentially influential activities such as instream construction impacts, transmission and road corridors, entrainment of organisms at water intakes, etc. The Standards are intended to guide the review of operational impacts to fish and fish habitat.

2 GUIDING PRINCIPLES

Development of the British Columbia Instream Flow Standards for Fish ("the Standards") has relied on several guiding principles. These principles capture the motivation for standards, the approach and philosophy to setting standards, and the intended benefits of the Standards.

The guiding principles for the Standards fall into five general classes:

1. Work Within Existing Legal Framework,
2. Develop Standards from the Perspective of Protecting the Fish Resource,
3. Minimize Review Costs,
4. Maximize Consistency and Transparency, and
5. Implement a Scientifically Defensible Approach.

Work Within Existing Legal Framework

The Standards 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, British Columbia Environmental Assessment Act (BCEAA), Canadian Environmental Assessment Act (CEAA), Fisheries Act (Canada), Fish Protection Act (British Columbia), 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 3.) The Standards have been developed with existing legislation and policy in mind, to minimize potential conflict between the Standards and existing policies and laws. Where any such conflict arises, the existing legislative and policy framework supersedes the Standards.

Develop Standards from the Perspective of Protecting the Fish Resource

The Standards 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 license specifications. In some cases water use conflicts may arise where flow standards for fish indicate water levels that are suboptimal for other resources or interests. The Standards 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 license applicants and fisheries agencies may wish to explore options for compensatory works or activities to offset some of these trade-offs (see Section 3).

Minimize Review Costs

There are multiple costs associated with preparing and reviewing water license applications. These costs exist for project proponents, government reviewers, and society as a whole—costs associated with staff time, delays in project approvals, and the practicality of final decisions. We have developed the Standards 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 that the benefits of a clear application and review process would accrue to applicants and reviewers.

Maximize Consistency and Transparency

Water license applicants expect a review process to be transparent and applied consistently throughout the province, and by adopting the Standards resource agencies are attempting to provide such a process. The Standards have been designed to be as objective as possible. That is, decisions based on the Standards should not vary markedly among reviewers of water license 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 patterns, and stream characteristics vary considerably over the province. It is unreasonable to expect a single office-based review to capture all nuances of each location within the province. The Standards have therefore embraced a flexibility principle to allow individual reviewers to demand additional studies as needed. The flexibility principle is aimed at allowing agency reviewers to mould the Standards to the requirements of particular instances. The Standards should nevertheless form the foundation during each review.

Implement a Scientifically Defensible Approach

The Standards are built on the principle of using the best available scientific evidence to set stream flows in British Columbia that will protect the fisheries resource. Although the science of river biology is young and evolving quickly, there is a large body of literature relevant to British Columbia streams. In the following subsections we present a brief review of some of the most salient features of a scientifically defensible approach to setting the Standards: habitat-based and risk-averse criteria, requirements for effective monitoring, and application of appropriate mitigation and compensation. Those interested in a more comprehensive review of the ecological effects of changes to stream flow should consult recent review articles (e.g., Ligon et al. 1995; Steele and Smokorowski 2000).

Biological Response to Flow

At the heart of the Standards are ideas about biological responses to stream flow. The shape of the response curve is a critical determinant of recommendations regarding water use and protection of aquatic resources (Figure 2). The selection of a response curve that is most generalizable is driven in part by available scientific information, and in part by practicalities imposed by existing legislation and policy.

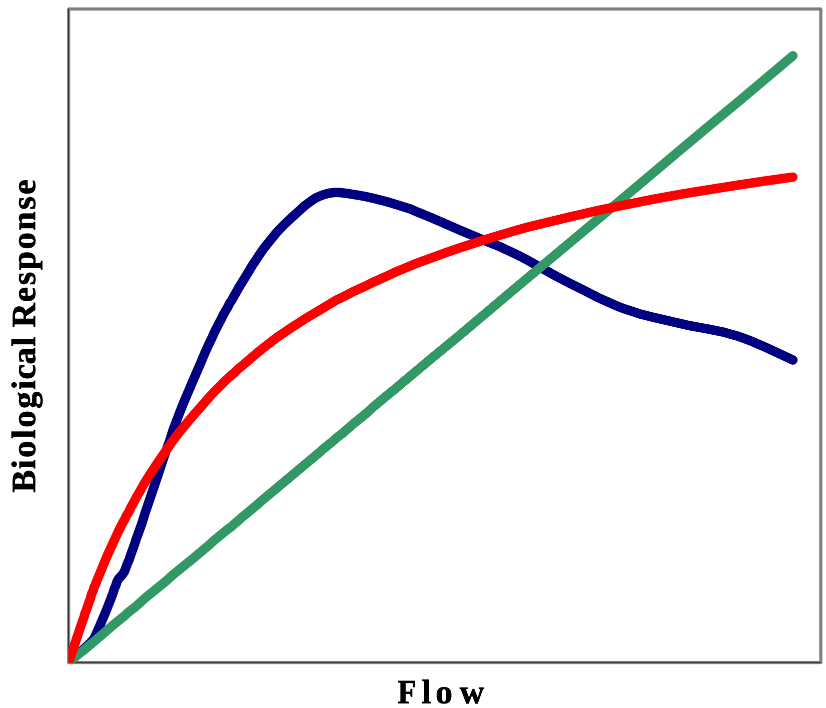

Figure 2. Hypothetical responses to flow. The shape of the response curve will dictate recommendations regarding water use and protection of aquatic resources.

Numerous methods have been devised to predict the effect of changes in flow on fish (see EA Engineering Science and Technology 1986; Jowett 1997), but the underlying premise of almost all methods is a correlation between habitat and fish abundance or biomass. Abundance and biomass are the parameters that managers are ultimately concerned with, but developing relationships of flow vs. abundance is exceptionally difficult. For assessment purposes resource managers have therefore often turned to simpler surrogate measures. The surrogate most often used is fish habitat because it is relatively easy to quantify in relation to flow. For this same reason, key components of environmental legislation are habitat-based.

If habitat is to be used as a surrogate, the critical issue is the biological response to changes in habitat. In many cases this relationship is quite complex—there is rarely a one-to-one correlation between abundance or productivity and various measures of habitat. On the other hand, experience and numerous studies indicate that large reductions in available habitat do result in fewer fish.

In developing the Standards we acknowledge that there are uncertainties and difficulties associated with habitat-based flow assessment methods (cf Jowett 1997), but for the purposes of setting standards they offer the most defensible results, at least initially. A habitat-based approach for the Standards is defensible for three main reasons: the relevant environmental legislation is habitat-based (see Section 3), there is considerable evidence to indicate a general correlation between fish productivity and habitat, and alternatives to habitat-based assessment are unworkable in a standard setting context.

The Standards therefore adopt a blended approach: they focus on setting standards that are risk averse for fish habitat, coupled with a commitment to effective monitoring of biological responses to changes in stream flow. The principle of monitoring is discussed in more detail below.

Importance of Non-Fish Bearing Streams

The Standards assume that nutrients and energy inputs from non-fish bearing streams provide benefits to downstream fish populations. As a result, the Standards do not allow full diversion, even for stream reaches that are non-fish bearing.

The assumption that upstream inputs affect local fish populations is consistent with 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 increasing 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. Our conclusion therefore is to recommend against full diversion. Nevertheless, we acknowledge that flows necessary to protect primary and secondary productivity (e.g., algae and invertebrates) may be less than that required to protect fish.

Risk management

The Standards embrace a risk-averse strategy for water use development. The Standards 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 available evidence indicates that there is not a simple one-to-one 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.

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).

The Standards propose two types of monitoring, a mandatory program and an elective program. The purpose of these monitoring programs is to create the feedback required to understand whether effective decisions are being made.

The mandatory program would be set up to ensure water license compliance and to provide regional data for assessing the efficacy of the Standards. Whether mandatory monitoring requires simple or detailed assessment will likely depend on the type of water use. The mandatory program may involve requirements for meters or gauges, a photographic record, or a periodic assessment (e.g., stock assessment). These data could be accessed by auditors hired to assess water license compliance, or used by resource agency staff to assess whether the Standards were protecting the resources they were designed to protect.

The elective monitoring program would be at the discretion of the water license holder and allow him or her to collect data in support of additional licensing volumes. The elective program would most likely lead to a fine scale adjustment to the license (e.g., small changes to volumes or shifts in timing of licensed volumes), although it is possible that larger adjustments could be made. The Standards would be used to set initial license specifications. Downward adjustment to these water levels would then need to be based on sound hydrologic and biological evidence. In this way a water license applicant would be entitled to preliminary water volumes, but may obtain additional water if data from a monitoring program indicate that additional water use is safe for the fish resource. Monitoring data would need to meet specific quality assurance criteria before they could be used to adjust water license specifications.

The exact nature of the elective and mandatory programs will be determined during Phase 2 of this project. Monitoring is discussed in more detail in Section 7.

Mitigation and Compensation

In the context of this document, mitigation refers to intentional activities undertaken to avoid negative impacts of construction and operation of an intake or diversion. Mitigation may also be used to reduce the likelihood of negative impacts. Compensation on the other hand, refers to intentional activities undertaken to offset inevitable impacts once they occur. Compensation offsets negative impacts by providing net 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 Standards is that mitigation is a superior option to compensation, and that compensation carries with it responsibilities to ensure its effectiveness. Under this principle water license applicants would be encouraged to design their projects to ensure that the Standards are met, and that the fish resource is protected. Where standards are not met, some form of habitat compensation may be required. In these instances the compensation would likely carry with it a responsibility to maintain the compensatory works and to monitor its effectiveness, to ensure that productivity targets were being met. This responsibility would be in place throughout the life of the project.

Whether habitat compensation is required, and the exact nature of the compensation, is for the most part, outside the scope of this document. However, we expect that where the Standards are not met, habitat compensation will very likely be required.

3 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 Standards for Fish ("the Standards"). 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 Standards for Fish are under development, thus their place in the regulatory framework has not yet been defined. Based on a review of the legislation, they appear to fit well within the *Fish Protection Act* and could be defined as a section within that act. The Instream Flow Standards 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 Standards allow the rapid assessment of potential effects, and encourage the planning of projects to meet levels of protection expected by fish habitat managers. The Standards are intended to reduce the time required for review, since they encourage projects to meet existing legislation.

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 the diversion and use of quantity of water over time, the 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 licenses 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 license, 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. Objections to water licenses may be filed by existing water license holders or applicants, as well as landowners potentially affected by the application. The comptroller or the regional water manager may hold a hearing to address any objections.

The comptroller or the regional water manager may grant an application or refuse it, amend the application, or ask for additional information. If granted, water licenses 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. Licenses may include conditions that specify environmental protection measures for fish, both as conditions that must be met before the license is finalized and as ongoing requirements. Security such as a performance bond may be required to obtain the license.

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 Standards, the regulation could be revised to include hydroelectric projects that meet the Standards.

As a result of a water license 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 license approval.

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

[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.

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

The *Fish Protection Act* directs the comptroller or regional water manager to consider the impact on fish and fish habitat, and includes conditions for fish and fish habitat (such as instream flow releases) in license 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 license 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* 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' (Anonymous 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 Standards 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 Standards may be

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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.

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 Instream Flow Standards have already been applied within ongoing water use plans and for projects on streams not subject to water management plans.

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. Where a water license is transferred or apportioned this reduction is limited to a maximum of 5% of the license. An important aspect of this is the potential to include conditions on the rate of diversion, time of diversion, storage, time of storage and use of water. Project proponents can reduce the risk of subsequent restrictions on their water license by following the Standards, which are designed to protect fish and habitat.

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 licenses or approvals in relation to the stream, regardless of precedence under the *Water Act*." Fortunately, use of the Instream Flow Standards would avoid the risk of temporary orders. During low flow conditions projects adopting the Standards 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 licenses, licenses that may be obtained by third parties for the protection of fish and habitat.

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 *B.C. 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.

Other British Columbia Regulatory Considerations

The Living Rivers Strategy is part of a land use strategy currently under development by the British Columbia government. The British Columbia Instream Flow Standards for Fish are part of the 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

Standards 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 shall be advised so that he may consider whether regulatory action is required." The spirit of this policy has been followed in crafting the Standards, in that Provincial fisheries personnel have helped define instream flow thresholds below which fish resources may be threatened.

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 2. 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.

Other Relevant DFO Documents

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 license 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.

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 Standards 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).

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 monitored to ensure that objectives are met.

In the context of the British Columbia Instream Flow Standards 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 Instream Flow Standards 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 Standards 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 Instream Flow Standards, 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.

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 license 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.

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 British Columbia Instream Flow Standards for Fish, which are calculated relative to the natural flow of a stream and so factor in existing uses, providing a standard that allows incremental allocation up to a fixed level. By requiring a naturalized flow as a reference point, the Standards 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 Standards 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 Standards, however, in the case of river basins where natural vegetation has been largely removed, any change in temperature may be detrimental, requiring an assessment.

Other Federal Acts

Other federal legislation relevant to the operation of hydroelectric facilities includes the *International Rivers Improvement Act*, and the *Navigable Waters Act*. The *Species at Risk Act* (SARA) may soon be tabled in the House of Commons and will have significant implications for streams with endangered species.

4 Review of Other Jurisdictions

This section briefly reviews "who is doing what, where" with respect to government reviews of instream flows. The objective for this section is not to present a comprehensive review, but to acknowledge what other resource managers are doing in similar geographic areas, and if possible, to learn from their experiences. The jurisdictions reviewed include Alaska, Alberta, Washington, Oregon, and Idaho. A review of experience in these jurisdictions has helped us design a defensible application review process for proposed projects in British Columbia.

Water rights are referred to using different terminologies in different jurisdictions. In the following discussion we refer to the legal right to use water as a "water license," using the British Columbia terminology.

The discussion makes reference to several instream flow assessment methods. These methods are described in greater detail in Section 6.

Synopsis

The experience of other jurisdictions unfortunately provides only vague guidance for British Columbia. BC is not unique in trying to balance conflicting demands in the face of imperfect information, but there is no single jurisdiction that seems to be doing markedly better at managing surface flows than other jurisdictions. In fact, with the exception of Alaska, all of the jurisdictions indicated that they suffer from a wide-spread problem of over-allocation of riverine water resources, and they are finding it exceptionally difficult to reacquire water rights for the protection of fish and fish habitat. All of the jurisdictions have implemented processes aimed at achieving a balance for new water uses, but there is a general feeling among fisheries managers that too much water has already been given away and there is no real chance of getting it back.

The biggest steps in preventing further over-allocation problems seem to be directed toward hydropower projects. Most U.S. jurisdictions have specific review processes for hydropower projects, which are additional to or at least complementary to the assessment requirements laid out by the Federal Energy Regulatory Commission (FERC). Managers from several jurisdictions noted that they had earlier gone through phases of reviewing large numbers of small hydropower applications, most of which were rejected. It would be instructive for British Columbia to pay close attention to this experience as its agencies prepare to review a large number of such applications. In this respect, British Columbia has a distinct advantage in that it can learn from experiences south of the border.

In comparison to hydropower issues, considerably less attention appears to have been directed to managing the cumulative effect of granting water licenses for small volumes. This is ironic considering that many jurisdictions seem to be suffering over-allocation problems due to this effect. Some jurisdictions (e.g., Oregon and Washington) have established or are establishing basin-wide objectives through internal agency and public processes that will attempt to address these issues.

British Columbia water resources have likely been under less intense development pressure than those in the US Pacific Northwest. In this respect, the BC experiences may be lagging those south of the border. If true, then our brief review of nearby jurisdictions foreshadows the likely effects of management inaction: over-allocation of water resources and concomitant negative effects on fish resources. The Standards represent an opportunity to avoid some of the severe water allocation problems observed in nearby jurisdictions, and through biological monitoring, to learn sufficiently about biological responses to changes in flow to make wise decisions in the future.

Alaska

The following description of Alaska's approach to determining instream flows was obtained through discussion with Christopher Estes, Statewide Aquatic Resources Coordination Unit Chief, Alaska Department of Fish and Game, Anchorage, Alaska.

The Alaska Department of Fish and Game (ADFG) reviews applications for water licenses on a one by one basis. ADFG has a general protocol for establishing instream flows through discussion and negotiation with applicants. The allocation tends to satisfy most applicants. Applications for water licenses associated with hydropower usually request more water than would be offered using this general protocol. In these situations applicants are required to undertake detailed hydrologic and biological studies to support their application. The level of detail required varies depending on the size of the project and the natural resources potentially affected. The approval process for a hydropower project may take several years.

ADFG has established standards for both hydrologic and biological studies. Hydrologic standards are necessarily flexible to accommodate the fact that more than 90% of streams are ungauged. An interagency hydrology committee sets protocols for modeling hydrologic data. ADFG recommends that proponents of hydropower projects immediately establish a gauge so that data are available during the review process, which may take several years. State legislation requires proponents to use the best available data. Similar standards and protocols exist for the collection and presentation of biological information. The protocols were not available for this review.

Alberta

The following description of Alberta's approach to determining instream flows was obtained through discussion with Allan Locke, Instream Flow Needs Specialist, Alberta Ministry of Sustainable Resource Development, Cochrane, Alberta.

The Ministry of Sustainable Resource Development (MSRD) reviews applications for water licenses on a one by one basis. Conflicts over water use arise primarily during applications for consumptive use such as irrigation or municipal uses like sewage treatment. MSRD lacks the legislative authority to compel applicants to undertake specific biological studies regarding instream flow needs, but does have the authority to reject applications based on needs for environmental protection.

In the absence of a detailed instream flow assessment the province has its own office-based standard-setting method, a modified-Tennant approach with a Fortran-based program for calculating minimum flows on a weekly time step. The approach used is the Tessman modification (Tessman 1980) of the Tennant method, and the computer program estimates the minimum allowable flow for a stream, based primarily on inputs of mean monthly flows and Tennant-like assessments of habitat quality in relation to flow. In addition to minimum flows, the approach also specifies other components of a flow regime such as flushing flows.

Locke acknowledged that the modified-Tennant approach has many drawbacks, including the fact that it has not been validated, and tends to address minimum flows rather than optima or ranges. Nevertheless, the approach is believed to provide a conservative estimate of minimum flows based on the natural hydrograph. For example, it will apparently shut down water use in 4 out of 10 years on most streams in the province.

If a proponent seeks to obtain licensed volumes in excess of that indicated as available by the modified-Tennant approach, they are encouraged to undertake a detailed instream flow assessment, but the province does not dictate how the study should be conducted and warns proponents that a detailed flow study will not necessarily provide a recommendation more favourable to the proponent. Where detailed studies have been conducted in the province, different methodologies have been used for different sites. MSRD may provide verbal input to study design if asked. Given the expense associated with a detailed flow study, and the uncertain outcome that might result, most applicants prefer to address their problems with other solutions, such as off channel storage.

In an effort to make their water allocation decisions more rigorous MSRD has embarked on a multi-year research program that will assess instream flow needs based on stream size, geographic location, and channel morphology. The objective is to first classify streams based on channel morphology and hydraulic characteristics, then to develop an understanding of instream flow needs for streams of each type. In this way one would be able to develop an acceptable flow regime by extrapolating from a known stream to an unknown stream. Assessment of instream flow needs would be based solely on easily obtained input variables, such as those obtained from a GIS system. The research program is currently validating results from phase one of the project to ensure that extrapolation procedures are working. Budget limitations have extended the estimated completion time for a finished product.

Washington

The following description of Washington's approach to determining instream flows was obtained through discussion with Hal Beecher, Fisheries Research Scientist, Washington Department of Fish and Wildlife, Olympia, Washington.

The Washington Department of Fish and Wildlife (WDFW) reviews applications for water licenses on a one by one basis, but the process is streamlined through the adoption of specific guidelines and policies. The review process begins by separating water requests into major and minor amounts, where major is defined as >1 cfs and >10% of seasonal 90% exceedence flow in any month. Minor water projects are assessed using the Tennant method, toe-width method (see Department of Ecology website at http://www.ecy.wa.gov/programs/wr/sw/inst.html), equations from Hatfield and Bruce (2000), or established instream flows, where applicable. Major water projects must conduct IFIM / PHABSIM studies and use WDFW guidelines for these studies. Although guidelines for how to conduct an instream flow assessment have been developed, WDFW has no formal written protocol for the review process once studies are completed.

Dr. Beecher noted that throughout the 1980s there were many applications for the development of small hydropower in the State of Washington, whereas presently there are only a few. Most applications were never approved. The main impediments to approval were the presence of anadromous fish in the diversion reach, or flow determinations that made a project economically unviable. As a policy decision, anadromous fish were given priority by Department of Fisheries (predecessor to WDFW). The requirement for effective screening of intakes (to prevent fish entrainment) often made small hydro projects unviable on anadromous streams. As an informal policy, Dr. Beecher tells those interested in power projects to look for bedrock controlled, high gradient systems, preferably without fish. Such systems lack many of the complicating factors (e.g., geomorphologic issues, riparian vegetation issues, etc.) that make flow allocations particularly difficult.

More recently, the main emphasis for instream flow issues is water allocation within larger systems. These issues are being addressed as part of a Watershed Planning process, which has been ongoing for about three to four years. This public process is motivated in part by Endangered Species Act-mandated recovery plans for listed stocks, and in part by the Washington legislature and state funding initiatives. The process has similarities to Water Use Planning in British Columbia.

Idaho

The following description of Idaho's approach to determining instream flows was obtained through discussion with Scott Grunder, Idaho Department of Fish and Game, Boise, Idaho.

Idaho Department of Fish and Game (IDFG) reviews applications for water licenses on a one by one basis, but has streamlined the review process through the adoption of specific guidelines and policies, particularly for larger projects. According to Mr. Grunder, Idaho has a problem with over-allocation of water on many rivers, particularly in the southern portion of the state. This has led to legal challenges regarding water use, some of which have been protracted and difficult. Due in part to such conflicts, some streams or sections of streams have been protected with dedicated legislation.

IDFG have implemented a policy and adopted specific guidelines to ensure that their review of water license applications for hydropower projects is consistent with the FERC review process. A FERC review must occur for all hydropower projects of 5 MW or more. Since fish and wildlife must be explicitly considered under a FERC licensing and relicensing process, it has been relatively easy for IDFG to ensure their involvement in the review process.

For large projects IDFG have the capacity to enforce use of a particular method for stream flow assessment. IFIM is the preferred method, but they continue to rely on the Tennant method, particularly during review of smaller applications. There is no established threshold to determine when an applicant is required to undertake specific biological studies (e.g., IFIM). IDFG will consider the use of other methods, but the onus is on the applicant to justify the use of a particular method.

The review process for smaller water licenses seems to be considerably more ad hoc than the review of large projects. The Idaho Department of Water Resources (IDWR) is responsible for issuing water licenses in the state, and there appears to be no formal referral process in place between IDWR and IDFG. Apparently the responsibility lies with regional IDFG staff to monitor local newspapers (applications for water licenses must be advertised before they can be granted) and watch for new applications. If IDFG staff consider there to be a significant fish or wildlife issue, then they file a protest with IDWR to ensure a review of the relevant biological concerns. A protest thus depends on the vigilance of IDFG staff and his or her subjective assessment of what constitutes a significant biological issue.

Like the State of Washington, during the 1980s Idaho received numerous applications for small hydropower development. Most applications were turned down, primarily based on fish and general flow issues. Interestingly, many of these same projects have resurfaced in the last year or two presumably driven by a surge in energy demand. Some potential projects have gone through several rounds of application and denial. Mr. Grunder expects that most re-applicants will be turned down for the same reasons they were originally denied. Critical issues that prevented approval were fish passage, entrainment, flow levels, water quality, and recreation values.

Oregon

The following description of Oregon's approach to determining instream flows was obtained through discussion with Rick Kruger, Instream Water Rights Coordinator, Habitat Division, Oregon Department of Fish and Wildlife, Portland, Oregon.

Oregon Department of Water Resources (ODWR) is responsible for issuing and regulating water licenses in the state. The extent to which Oregon Department of Fish and Wildlife (ODFW) reviews water license applications appears to be related in part to the license volume being applied for. ODFW appears to have more authority in the review of hydropower projects than in the review of applications for small water volumes. In part this is because there is a publicly-supported perception that commercial enterprises such as hydropower should be subject to greater scrutiny than other applicants such as farmers. It is also true that hydro projects trigger specific environmental reviews. Projects of 5 MW or more trigger a FERC review process, which mandates an in depth environmental review, with participation by local fish and wildlife agency staff. All hydro projects, including those less than 5 MW, are also subject to Oregon's own environmental review process, which is similar in scope and content to the FERC process. There has been an effort to streamline the review process and to make requirements for each process similar.

In Oregon, reserving stream flow for protection of fish was recognized as a beneficial use for the first time in 1955. At this point the agencies established the concept of *minimum perennial streamflow* (MPS), which was a threshold flow deemed a minimum necessary to protect fish and other aquatic resources. In general, this threshold was very low, and did not stop many streams from becoming over-allocated by today's measures. Over-allocation is particularly problematic for streams east of the Cascades, however, even on the coast many streams are considered over-allocated, especially through the drier summer months.

In 1987 the Instream Water Resources Act was passed, which made it considerably easier to obtain water rights for fish and wildlife, though for many streams this was simply too late to be of significant help. The Act allowed for water rights to be obtained for state fish and wildlife, parks and recreation, and water quality. Fisheries agencies were quick to respond and applied for rights to much of the remaining water in the state.

Moreso than many other jurisdictions, Oregon appears to have a good sense of how much water it has, how much it has licensed, and how much it is willing to license. State and federal agencies conducted many site-specific streamflow studies in the 1960s and 1970s throughout much of the state, setting up a broad database. Hydraulic and habitat data were collected using a process that came to be known as the "Oregon Method," and allowed development of habitat vs. flow relationships for many of the state's streams. Data were collected on 1500+ stream reaches throughout the 18 major basins in the state, in an effort to develop regional predictions for the state. Much of this information continues to be used.

In addition to the fish vs. flow information, the state has also done considerable work on collecting and modeling hydrologic data. In 1993 ODWR modeled and classified the hydrology of 1^{st} to 5^{th} order streams, over most of the state. These data allow calculations of natural hydrographs, as well as hydrographs corrected for licensed volumes. Using these regional data, ODWR calculates two summary statistics, before any new water license is reviewed, the 50% "naturalized" exceedence flow (i.e., median), and the 80% "naturalized" exceedence flow. If licensed volumes exceed the 80% threshold then ODWR will not accept new water license applications, and the stream is designated as fully appropriated. The 50% exceedence flow is stated as a target flow for fish, but since water rights are based on priority date, there is often no practical way to meet this target.

5 INFORMATION NEEDS

The British Columbia Instream Flow Standards for Fish require the collection, analysis, and reporting of specific physical and biological information—requirements that must be fulfilled before review of a proposed water use can proceed. The data will be used to apply the Standards in order to screen applications for negative effects on fish and fish habitat. It is important to note that additional information may be required for other purposes during the review of a water license application.

Information that should be incorporated into a water license application includes, but is not necessarily limited to, a description of the proposed project, the natural hydrology and biology in the affected watershed, and a description of other land and water uses in the area. Data must be collected and summarized using suitable methods, and be certified by a professional in the appropriate field (e.g., R. P. Bio., P. Geo., P. Eng. etc.). The standards for collecting and reporting most data are presented in greater detail in the companion document, "Instream Flow Methodology Guidebook," which will be finalized during phase 2 of this project.

Description of the Proposed Project

A reliable and sufficiently detailed description of a proposed project is required to complete a screening of a water license application. Impacts to fish and fish habitat from water use projects can be conveniently divided into "operational" and "footprint" impacts. Operational impacts are those associated with the day-to-day running of a water intake, and are primarily flow-related. For example, the timing and volume of water extraction or diversion is an operational influence on fish and fish habitat. Footprint impacts are generally long-term effects from the construction of a water use project. Physical displacement of aquatic habitat at the site of a dam is an example of a footprint impact.

An application should attempt to describe the main footprint and operational impacts. Such descriptions will likely vary with size of a project. On a large stream, a small intake for personal consumptive use may have virtually no discernable footprint impact (i.e., a small pipe laying in a stream), and only limited operational impact (e.g., risk of entrainment at the intake). On the other hand, a small hydropower project may have substantially larger footprint and operational impacts.

A project description should include the proposed water use (e.g., consumptive vs. non-consumptive), a hydrologic description (e.g., timing and volume of water used), the length of stream affected (e.g., the length of stream between point of diversion and point of discharge), a description of operations (e.g., general operating, maintenance, and emergency procedures), area of impact (i.e., for both footprint and operational impacts), and proposed mitigation measures (e.g., screening of intakes, timed flow releases, etc.).

Hydrology

This section summarizes the minimum acceptable hydrologic assessment requirements for the purpose of screening applications for negative effects on fish and fish habitat. In the context of water use it is appropriate that hydrologic information be collected, analyzed, and presented to a very high standard. Water Management has developed hydrologic standards for most parts of the province (see Obedkoff 1998, 1999, 2000, 2001**)**, and hydrology information submitted by applicants should meet or exceed these standards. Hydrologic assessment is a specialized field. We therefore expect all reviews to be signed off by a professional in the field of hydrologic assessment (e.g., P. Eng., P. Geo., etc.).

Preferred hydrologic data are empirical daily 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 at ungauged sites (see Obedkoff 1998, 1999, 2000, 2001). For example, synthetic records may be developed based on data from nearby weather stations and stream gauges. Where flow records must be synthesized we expect that a reasonable attempt at validation will be made, and potential biases and errors will be described.

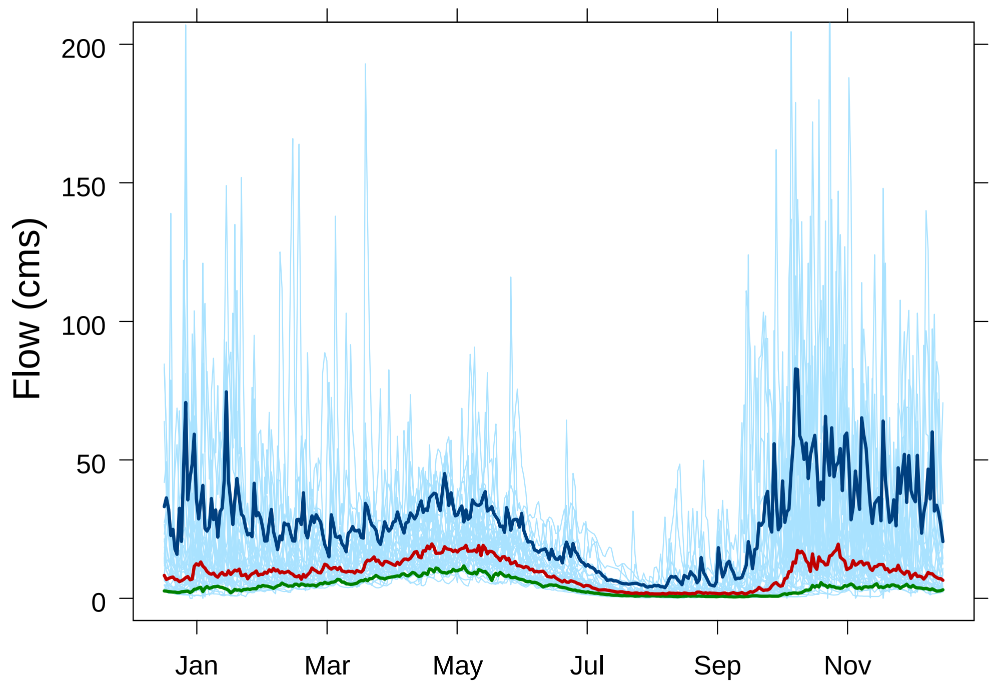
For the purposes of summarizing empirical hydrologic information, the entire period of record should be used if the data are reliable. Whether synthetic or empirical data are used, a minimum 20 year record should form the baseline. Records of this length will more accurately reflect natural variation in flows 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.

Hydrologic information should be presented in a manner that communicates a project's effects at all times of the year. Data should be summarized to facilitate understanding of natural flows in the affected watershed, how the project would affect the hydrograph, and how other water uses would interact with the proposed project. The purpose of the presentation is to understand potential limiting factors for fish, and to understand whether other water users may already be affecting fish and fish habitat through existing water uses. Flow data should be summarized in such a way that does not obscure important information. For example, expressing flow data as monthly means may provide good information about seasonal tendencies in a flow regime but it can obscure important patterns like short duration high and low flow events, or variation among years.

Presentation of hydrologic data should include:

1. naturalized, pre-project, and post-project mean annual discharge,
2. naturalized, pre-project, and post-project average 7-day low flow,
3. naturalized, pre-project, and post-project average 30-day low flow,
4. seasonal timing of low flow periods,
5. naturalized, pre-project, and post-project monthly minima, maxima, means and percentiles (10 th, 20 th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th),
6. estimates of variance in each summary statistic, where appropriate, and
7. discussion of potential biases; estimates of bias should be provided where possible.

To facilitate understanding, hydrologic information should be summarized in graphical and tabular format. An example of a graphic presentation is presented in Figure 3.



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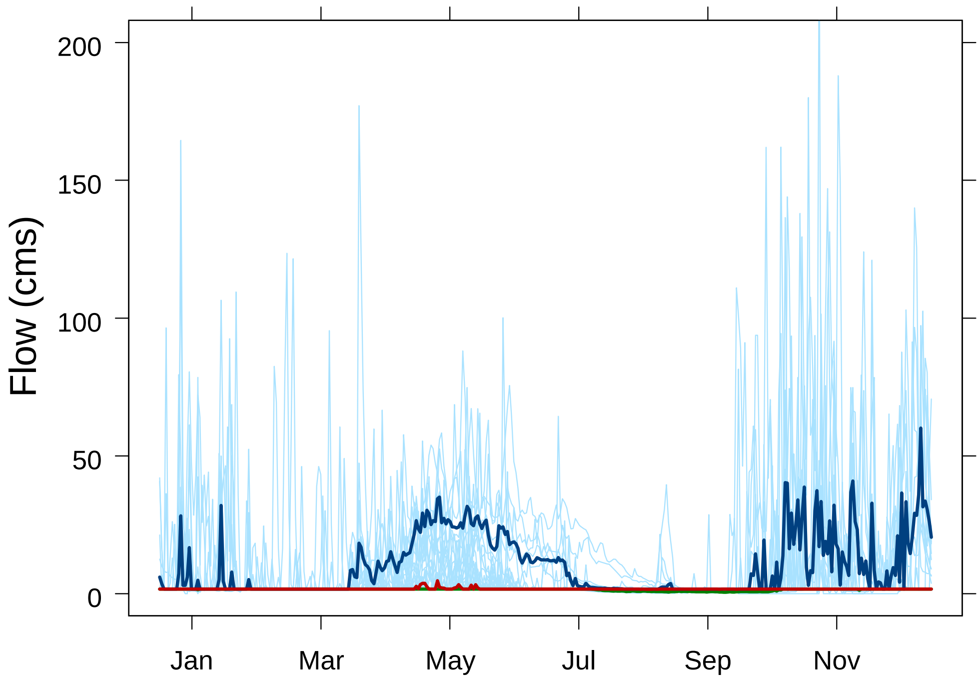

Figure 3. An example of stream flows under two scenarios for the Salmon River, Vancouver Island. The plots show 37 years of daily flows (light blue), 90th percentile (dark blue), median (red), and 10th percentile (green). A) Natural daily flows. B) Daily flows at the same site after proposed diversion of flows for power production.

The primary location of interest for hydrologic analysis is the stream segment immediately below the point of diversion. Impacts from a project will likely be attenuated as tributary inflows enter the stream below the water intake. However, some 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. Where this occurs the Standards may not be applicable.

Hydrologic analysis should flag potential concerns. As a rule of thumb, the Standards propose that hydrologic information should be presented to accurately reflect the effects of proposed water use in the "regulated reach." The regulated reach is the downstream section of river where tributary inflows exceed 80% of total flow (i.e., the point at which extracted or diverted flow is ≤ 20% of total natural inflow). The assumption underlying this criterion is that flow regimes acceptable in the regulated reach will be adequate for reaches further downstream where there is less influence of regulation. (This rule of thumb may be adjusted in the future as necessary.)

Biology

Recommendations for timing and magnitude of instream flows for any particular stream are determined in large part by the seasonal timing of habitat use by fish in that stream. This biological information includes species and life stages present, and timing of key biological activities such as spawning, incubation, migration, active rearing, overwintering, etc. Some of these activities are associated with particular life stages (for example, only adult fish spawn), whereas other activities are relevant to more than one life stage (for example, instream migration and rearing may occur at several life stages of different species). Each combination of life history and behaviour must therefore be specified. A species periodicity chart should be created to capture this information, listing the species and life stages present and the timing of key biological activities. Other flow-related ecological needs (e.g., geomorphic needs, riparian and floodplain maintenance, etc.) can also be entered in this table. An example is shown in Table 3.

For the purposes of screening applications using the Standards, the required biological information includes, but is not necessarily limited to:

1. distribution of fish (by species and life stage) throughout the watershed, including mainstem and tributaries, and upstream and downstream reaches,
2. seasonal and numerical abundance of fish (by species and life stage),
3. life history timing of each species (e.g., spawning, migration, rearing, etc.),
4. status of each species (e.g., are the species red-, blue-, or yellow-listed; or are any of the species designated of special management concern?),
5. description and distribution of habitats in the affected watershed(s), and
6. source and reliability of information.

Biological information must be reliable if a relevant schedule of instream flows is to be developed. If they exist, fisheries and ecological data from the same stream or watershed should be compiled. Information from adjacent or nearby basins should be used to define periods of habitat use, if more specific data are not available. General sources (e.g., Scott and Crossman 1973) may provide guidance, but are not sufficient for this purpose. Use of the provincial web-based tool “Fish Wizard” (see http://pisces.env.gov.bc.ca) may be helpful in this endeavour.

Biological assessment is a specialized field. Inventory and assessment standards have been developed and are presented in greater detail in the companion document, “Instream Flow Methodology Guidebook,” which will be finalized during phase 2 of this project. If empirical data are collected specifically for a project, and submitted as part of a water license application, they should meet or exceed those standards, and be signed off by a certified professional with appropriate experience (e.g., R.P. Bio.).

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Table 3. An example of a species periodicity chart, which would be compiled during the development of a recommended schedule of instream flows.

Species	Life history/behavior	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Chinook	Juvenile rearing				XX	XXXX	XXXX	XXX					
	Juvenile migration					XX	XXXX	XXXX	XXXX	XX			
	Adult migration								XX	XXXX	X		
	Adult spawning									XXX	XXX		
	Egg Incubation	XXXX	XXXX	XXXX	XX								
Rainbow	Juvenile rearing				XXXX	XXXX	XXXX	XXXX	XXXX	XXXX			
	Juvenile overwintering	XXXX	XXXX	XXXX							XXXX	XXXX	XXXX
	Juvenile migration					XX	XXXX	XXXX	XXXX	XX			
	Juvenile overwintering	XXXX	XXXX	XXXX							XXXX	XXXX	XXXX
	Adult rearing				XXXX	XXXX	XXXX	XXXX	XXXX	XXXX			
	Adult overwintering	XXXX	XXXX	XXXX							XXXX	XXXX	XXXX
	Adult migration				XXXX	XXXX							
	Adult spawning				XX	XXX							
	Egg Incubation					XXXX	XXXX	XXX					
Ecology													
	Short-term flows	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
	Wetland linkage flows				XXXX	XXXX	XXXX	X					
	Channel maintenance flows					X							

Land and Water Uses

The ways in which land and water has been and is used in a watershed can have a large effect on the degree to which a proposed project affects fish and fish habitat. For example, logging and agriculture affect runoff rates, and dykes affect flow patterns in a stream channel. Reasonable effort should be made to describe potential interactions between existing resource uses and the proposed project. Descriptions should include existing water licenses (both upstream and downstream), any known applications for water licenses, and land uses that may significantly affect hydrologic processes.

Other Relevant Studies

Water license applicants often initiate economic, physical, or biological studies, in an effort to understand potential effects of different operating scenarios on the viability of their project. These studies may also be useful for the purpose of screening applications for effects on fish and fish habitat. Although there is no need to include copies of these studies with the original application for a water license, applicants may wish to submit a reference list of relevant studies. Applicants should note however, that there are preferred methodologies for some assessments (see the companion document, "Instream Flow Methodology Guidebook," for preferred methods of instream flow assessment).

6 SETTING INSTREAM FLOW REQUIREMENTS FOR FISH

This section presents methods and criteria for setting instream flow requirements for fish, and discusses how they can be used as a "coarse filter" for water license applications. It begins with a brief review of methods available, and is followed by a discussion of some of the most appropriate methods for British Columbia. The discussion and evaluation of applicable methods is based in part on input received from technical experts during a series of instream flow workshops held specifically for this project. Broad agreement was reached for some aspects of the Standards, whereas other aspects require considerably more technical evaluation before they can be accepted as defensible.

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 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. 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 may be less clear in practise, 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 PHABSIM, two- and three-dimensional hydraulic modeling (e.g., 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, and PHABSIM prediction. The dominant standard-setting methods are reviewed briefly in the next section. Subsequent sections discuss how some of the standard-setting methods could be used by the British Columbia Instream Flow Standards for Fish. Readers interested in a more complete review of instream flow assessment methods should consult other documents (e.g., EA Engineering, Science and Technology 1986; Jowett 1997).

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. For any given flow Tennant (1976) found that habitat quality was very similar for each of his study streams. He therefore developed stream flow recommendations based on percentages of mean annual flow (Table 4).

Table 4. Instream flow regimens for fish, wildlife, recreation and related environmental resources, as described in Tennant (1976). Flows are expressed as percentages of mean annual discharge.

	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%

Critiques of the Tennant Method are numerous, but tend to focus on two aspects: the use of professional opinion 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 there has certainly 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. Despite criticisms, the method has stood the test of time and remains the second most widely used method in the continental United States (Reiser et al. 1989).

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 flows 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).

Wetted Perimeter Method.—This is part of a class of methods often 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.

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 standard and set the appropriate locations for placement of transects (e.g., in riffle habitats), thus making the method quick and efficient. However, there are also drawbacks. The determination of an "inflection point" is usually highly subjective (EA Engineering Science and Technology 1986), and therefore error prone. Additionally, the biological importance of the hydraulic threshold is assumed, and has generally not been validated (Jowett 1997).

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. 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 used to predict standing crop from habitat predictor variables. The method is not likely suitable 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.

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.

Ptolemy Method.—The Ptolemy Method is a “made in British Columbia” modification to the original Tennant Method, incorporating local biological and physical information to develop a schedule of streamflows that satisfy biological requirements of fish throughout the region. The method has evolved over the past 30 years and continues to be updated. Because it is widely used in British Columbia the method is reviewed here in detail.

The Ptolemy Method is both a process and a set of standards for use within that process. In this respect, it is similar to IFIM with PHABSIM: IFIM is a framework for decision-making, and PHABSIM is (originally, at least) a tool for use within IFIM (see Bovee et al. 1998). In this subsection, we review the set of flow standards currently used within Ptolemy's decision process. In a later section (Applying Standard-Setting Methods) we discuss the decision process itself in more detail.

A summary of Ptolemy's flow standards is presented in Table 5. The standards have been inferred from more than 30 years of professional experience, broad interaction with other professionals, and numerous studies of riverine fish distribution, abundance, and behaviour. The studies used by Ptolemy to develop the standards are listed in Table 6.

Table 5. Summary of Ptolemy's 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

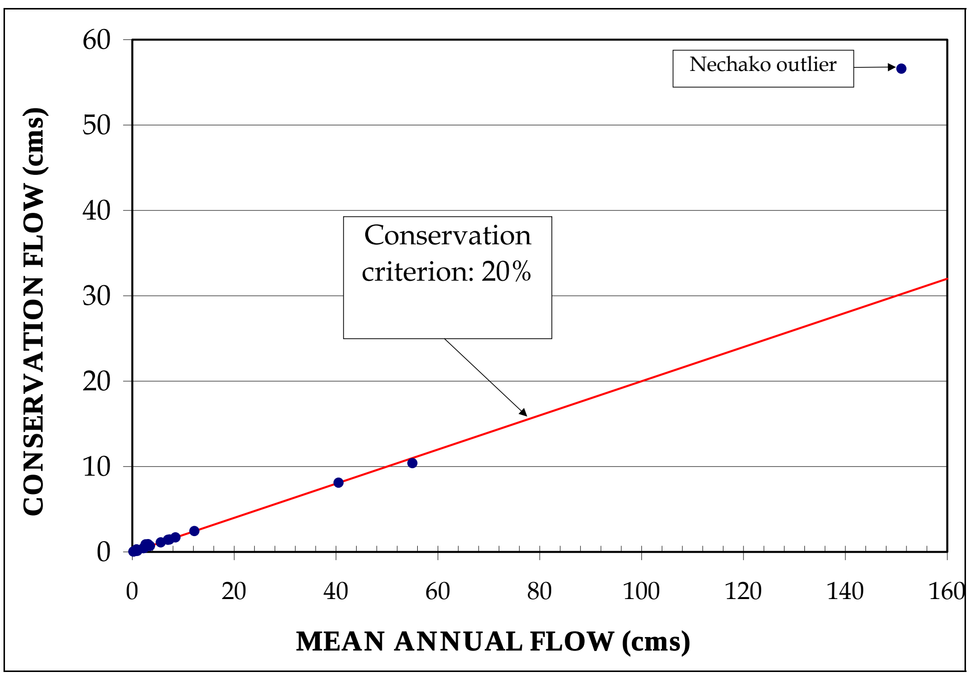
Table 6. List of studies used by Ptolemy to develop streamflow recommendations for spawning, rearing, and migration.

Author	Year	Study Description or Title	Methods
Peterson and Lyons	1968	A preliminary study of steelhead in the Big Qualicum River	Observations/tracking
Ptolemy	1977	Assessment of Rearing Flow Requirements and Storage for Colquitz River	Riffle Analysis
Ptolemy	1979	Assessment of Rearing Flow Requirements and Storage for Craigflower Creek	Riffle Analysis
Witt, Hunter and Harding	1980	A radio telemetry study of the migratory behaviour of winter run steelhead trout in Goldstream River, BC	Observations/tracking
Tredger	1980	Assessment of Powers Creek rainbow trout carrying capacity	Professional judgement/riffle analysis
deLeeuw and Stuart	1981	Small stream enhancement possibilities for sea-run cutthroat trout in the Lower Mainland and Sechelt Peninsula: Land and Water Use (Vol.2 of 4)	Riffle Analysis
Holtby and Hartman	1982	The population dynamics of coho salmon in a West Coast rain forest subjected to logging.	Riffle Analysis/Fish response
Gita Kapahi	1983	Regional analysis of fisheries flow requirements for East Coast Vancouver Island	Hamilton
Chamberlin	1983-85	Flow Limitation Assessment Project (FLAP) for East Coast Vancouver Island	Wetted Perimeter
Wightman and Ptolemy	1989	Evaluation of available trout habitat in the upper Cowichan River in response to flows	Modified IFIM/Others
Tredger	1989	Okanagan Lake tributary assessment: Progress in 1988	Modified IFIM/Others
Tredger	1989	Fish production capacity of Mission Creek at 4 modelled discharge levels	Modified IFIM/Others
Griffith	1990	Nanaimo River instream flow requirements for recreational fisheries	Wetted Perimeter/Tennant
Ptolemy	1992	Assessment of Rearing Flow Requirements and Storage for Sandhill Creek	Riffle Analysis
Griffith	1993	Ash River Aquatic Biophysical Assessment 1992-93	Wetted Perimeter
Rood and Hamilton	1994	Hydrology and water use for salmon streams in the Fraser Delta Management Area, British Columbia	Tennant

Four general methods were used in the studies that make up Ptolemy's database: modified IFIM, wetted perimeter ("riffle analysis"), modified Tennant, and miscellaneous empirical data (e.g., observed fish density or abundance at known flows).

Streamflow requirements of fish were inferred from these sources and synthesized using a combination of professional judgement and statistical techniques.

For rearing and spawning, a sufficient number of studies were available to allow graphical and statistical analysis. The analysis consisted of plotting the streamflow recommended in each study against the naturalized mean annual discharge of each stream (Figures 1 and 2) and developing regression equations for the relationships. Although the methods used to derive the recommended streamflow varied among studies, some strong relationships were nevertheless observed over the range of study streams. The results indicate that the recommended instream flow requirements for rearing and spawning increase with natural flow (Figures 4 and 5). The rearing criterion appears relatively constant at ~ 20%, with the exception of the highest value, the Nechako River, which is treated as an outlier. Flow requirements for spawning are well-approximated by a non-linear function ($1.56 * MAD^{0.63}$). A linear function of approximately 55% of mean annual discharge may be used for simplicity, but is inefficient because it leads to the potential loss of water use and of fish habitat. To offset this inefficiency, practitioners are expected to exercise professional judgement.



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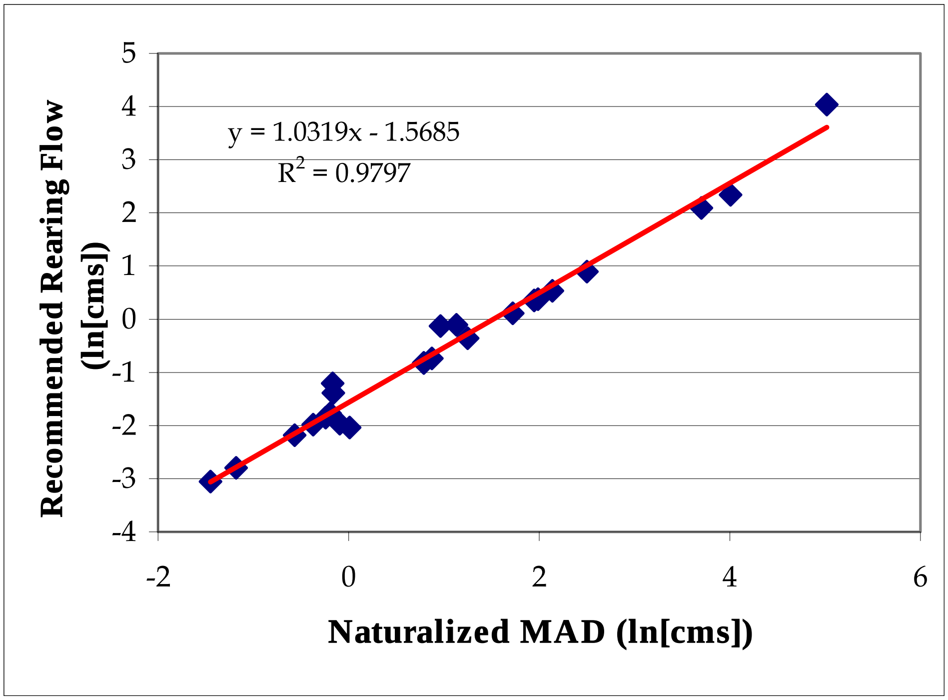

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Figure 4. Flow recommendations for fish rearing obtained from each of the studies in Ptolemy's database plotted against mean annual flow of the study stream. A) Untransformed data and the exclusion of the Nechako River data point indicate a 20% criterion; B) $\log_e$ transformation and inclusion of the Nechako datum indicate slightly higher flows as a proportion of mean annual discharge.

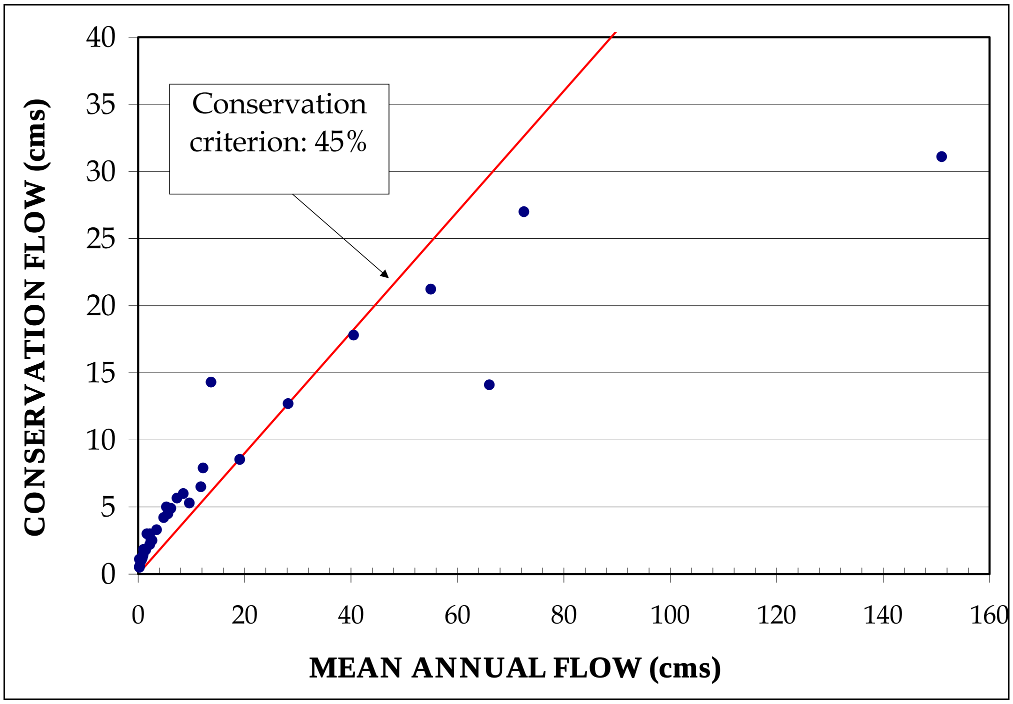


Figure 5. Flow recommendations for fish spawning obtained from each of the studies in Ptolemy's database plotted against mean annual flow of the study stream.

In addition to flows for spawning and rearing, Ptolemy suggests flow requirements for other aspects of fish behaviour and general stream ecology. These recommendations include flows for incubation, migration, overwintering, "short-term maintenance flow," channel maintenance, and wetland linkage. The standards for these ecological needs are based on fewer data and therefore required a more subjective assessment.

For example, the short term maintenance flow is based on work by Tennant (1976), and summaries of similar data from British Columbia. From a variety of cross-sectional measurements, the relationship between wetted width and %MAD indicates an abrupt change (sometimes called the inflection point) at approximately 10% MAD (Figure 3). Tennant and others have used this value as indicating a threshold below which there is a rapid loss of habitat with decreases in flow. The relationship is assumed to be indicative of biological response. In practise, this relationship is often much less clear (EA Engineering Science and Technology 1986), and the biological response is usually unknown.

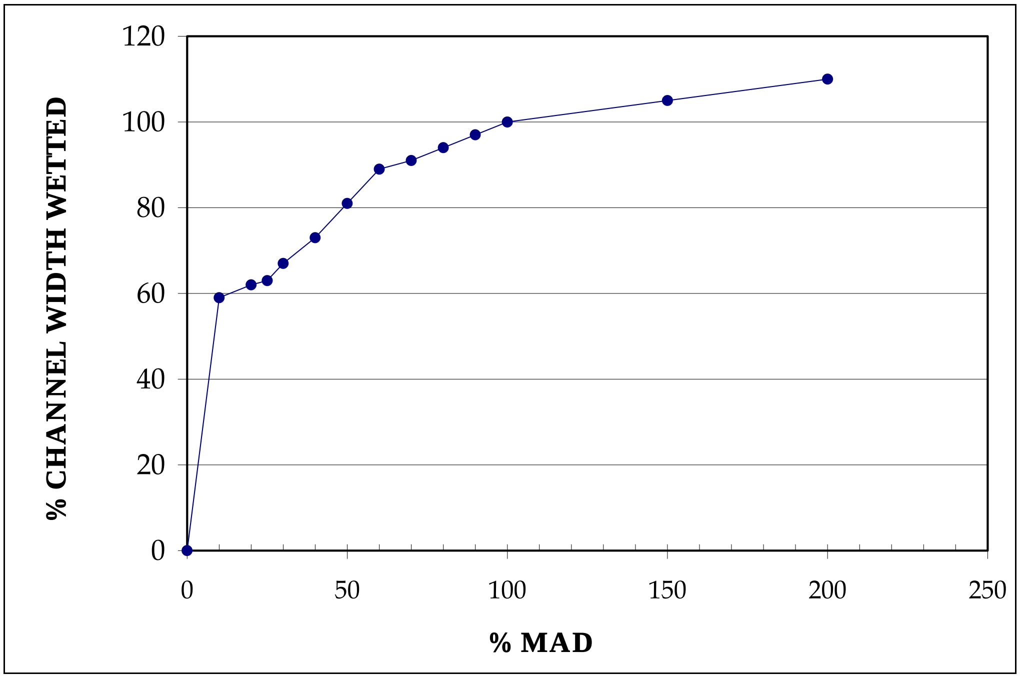


Figure 6. Percentage of wetted channel in relation to the percentage of mean annual discharge (%MAD). Data taken from Tennant (1976).

Critiques of Ptolemy's flow criteria are essentially the same as for other standard-setting techniques: the extensive use of professional opinion and the lack of biological validation. The criteria also suffer from being only vaguely described and a lack of peer review. In this respect, the criteria are not necessarily wrong. Instead, they should be seen as hypotheses in need of empirical testing.

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 prediction equations have been incorporated into a computer-based program with a graphical user interface (see Figure 7). In addition to habitat vs. flow relationships, the computer program (referred to hereafter as "the meta-analysis") calculates "risk" relationships that describe the probability that a particular flow will provide a particular amount of habitat. A screen shot of the meta-analysis is shown below for steelhead juveniles, using inputs for the Salmon River, Vancouver Island. The graph on the left describes the predicted relationship between habitat and flow, with estimates of uncertainty (shades of yellow) surrounding the median (blue line). The graph on the right describes the risk associated with each flow. According to these calculations, the flow of least risk for steelhead juveniles is 5.5 cms. From this flow of least risk, the estimates of risk rise sharply at flows less than 5.5 cms, but rise less sharply at flows greater than 5.5 cms. For the graph in figure 4, risk is defined as the probability that a particular flow will not provide 50% or more of maximum potential habitat.

The required inputs for the meta-analysis are mean annual discharge (in cms or cfs), latitude (in decimal degrees), and longitude (in decimal degrees). One then selects the species and life stage of interest and presses "calculate." Risk functions for each relevant species and life stage can then be exported and overlaid to compare outputs (Figure 8). Managers must decide whether to target one species or life stage, apply equal weighting to all species and life stages, or select the most relevant species or life stages for different times of the year. The risk functions can be used to develop recommendations for instream flows.

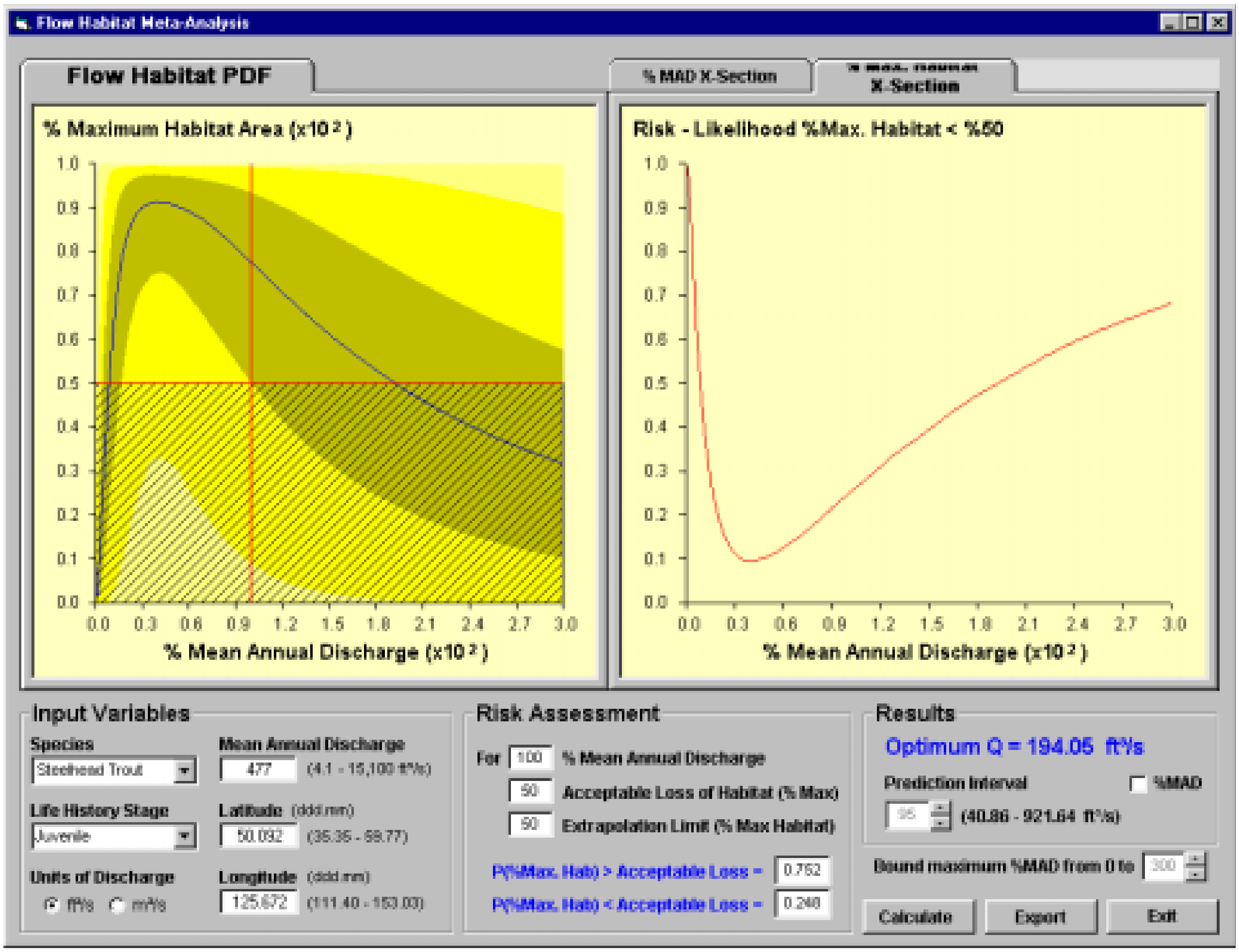
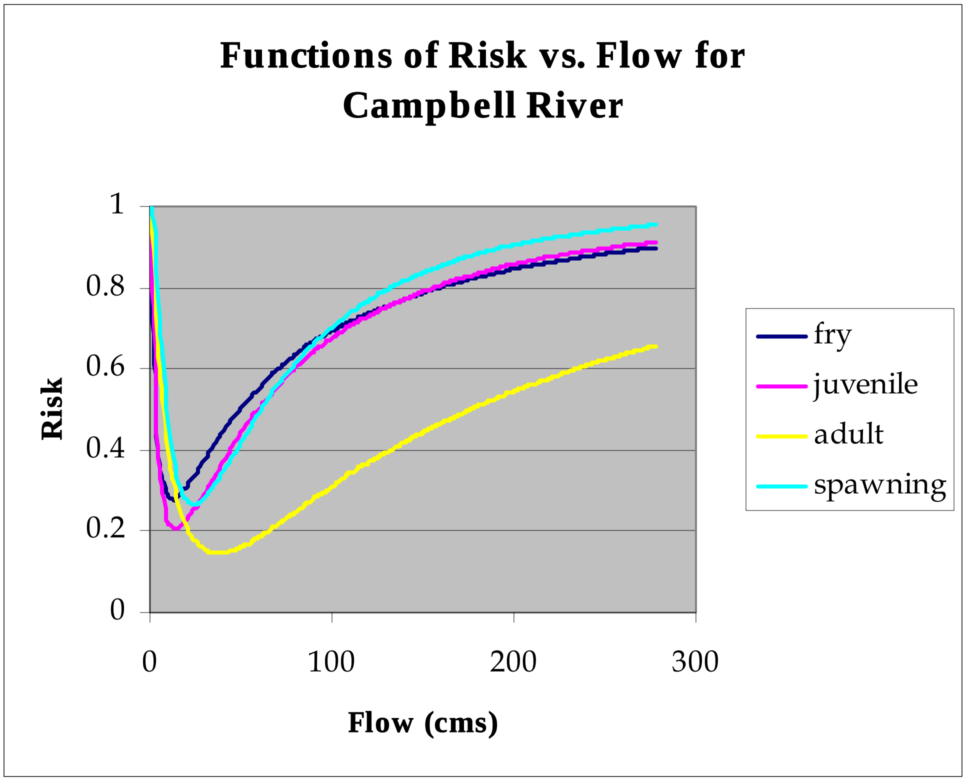
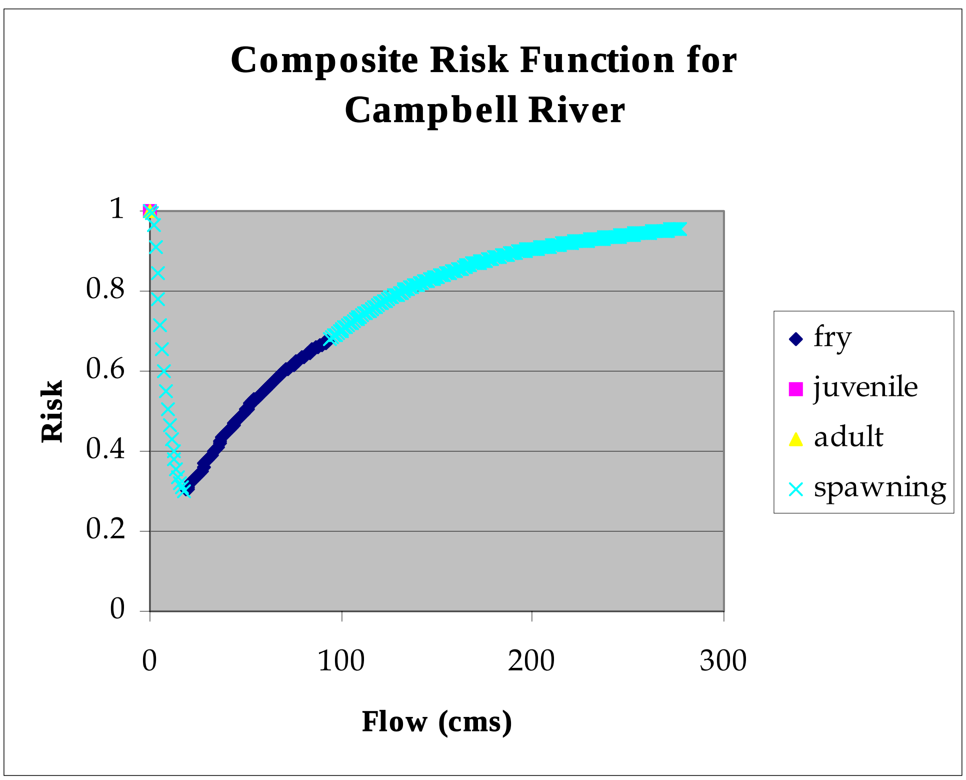


Figure 7. Screen shot of the meta-analysis tool using stream flow and geographic coordinate values from the Salmon River, Vancouver Island.



Functions of Risk vs. Flow for Campbell River
Risk
1
0.8
0.6
0.4
0.2
0
0
100
200
300
Flow (cms)
fry
juvenile
adult
spawning

A



Composite Risk Function for Campbell River
Risk
1
0.8
0.6
0.4
0.2
0
0
100
200
300
Flow (cms)
fry
juvenile
adult
spawning

B

Figure 8. A) Risk vs. flow functions for four life stages of salmonids, using stream flow and geographic coordinates for the Campbell River, Vancouver Island. B) Risk functions can be combined to produce a single composite curve. The composite curve may vary depending on which life stages are present at any particular time.

Before calculating risk functions, users must also specify the species and life stages of interest, and set the appropriate level of risk. Risk is defined as the probability that a flow will not provide between X% and 100% of potential fish habitat. The risk levels (i.e., X%) can be set from 50 to 99%. Higher risk thresholds lead to flatter risk functions (Figure 9). The meta-analysis can calculate risk functions for only a small subset of species found in many British Columbia streams. Users must therefore select representative species from the short list available (chinook, rainbow, steelhead, and "all salmonids"). The "all salmonids" equations are believed to be the most robust of those available.

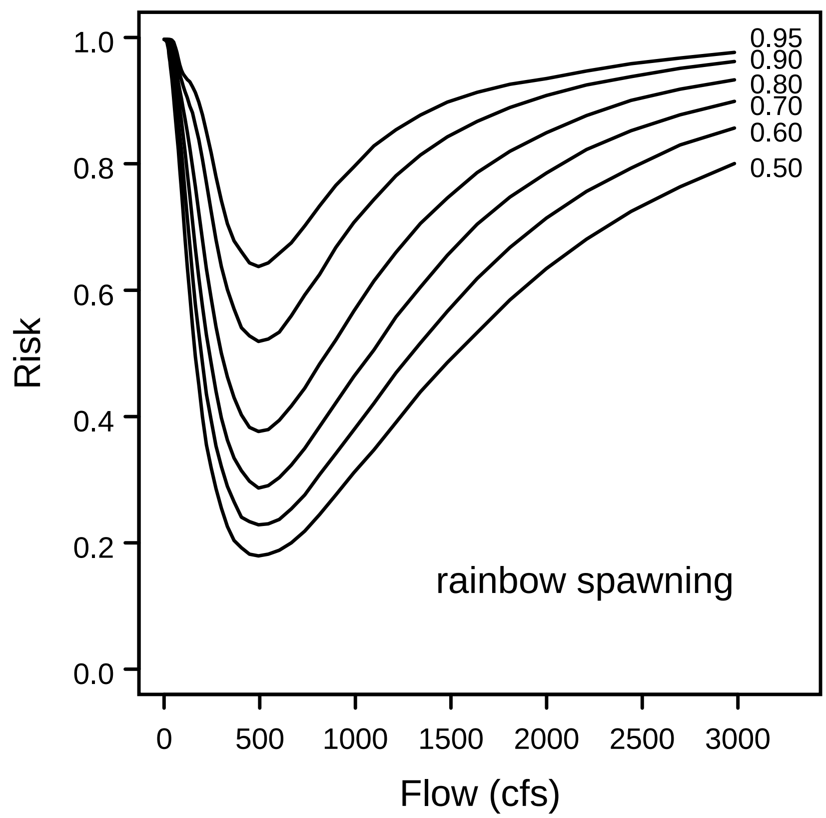


Figure 9. Curves showing risk in relation to flow for rainbow trout spawning habitat based on 10,000 Monte Carlo runs using inputs from the Coquitlam River, British Columbia (mad = 946.79, latitude = 49.317, longitude = 122.766). Each curve represents risk in relation to flow under a different habitat-risk threshold, from 50% to 95%. The curve developed using a habitat-risk threshold of 50% indicates the risk of a particular flow not providing at least 50% of maximum habitat. For all thresholds the flow of least risk is the predicted optimum flow, but

the curves indicate that risk may be relatively high for all flows depending on the selected habitat-risk threshold.

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 that would not remove the fact that different users may develop substantially different recommendations using the same set of risk functions, if given the freedom to do so.

Applying Standard-Setting Methods

All of the above methods require a process for determining an annual schedule of instream flow requirements if the schedule is to be moulded to the biological and physical needs of a specific stream. The process as laid out in the Ptolemy Method is an excellent one for implementing any set of standards. It uses site-specific biological and hydrologic information to set the ecological context for the standards, and ultimately to develop a recommended schedule of instream flow requirements. During workshops held during the development of the Standards, this process received broad acceptance by technical experts as a rationale and preferred method. The assembly and use of information for applying this process are described below.

Fish Life History and Ecology.—Recommendations for timing and magnitude of instream flows for any particular stream are determined in large part by the seasonal timing of habitat use by fish in that stream. This biological information includes species and life stages present, and timing of key biological activities such as spawning, incubation, migration, active rearing, overwintering, etc. Some of these activities are associated with particular life stages (for example, only adult fish spawn), whereas other activities are relevant to more than one life stage (for example, instream migration and rearing may occur at several life stages of different species). Each combination of life history and behaviour must therefore be specified. A species periodicity chart is created to capture this information, listing the species and life stages present and the timing of key biological activities. An example is shown in Table 3.

The biological information must be reliable if a relevant schedule of instream flows is to be developed. If they exist, data from the same stream or watershed should be compiled. Information from adjacent or nearby basins should be used to define the period of habitat use, if more specific data are not available. General sources (e.g., Scott and Crossman 1973) may provide guidance, but are not sufficient for this purpose.

Natural Flow Data.—Accurate estimates of natural flow are also critical for development of a recommended schedule of instream flow requirements. Hydrologic calculations and summaries should be completed as noted in Section 5.

Differences in annual hydrographs have implications for fish and habitat, and should be considered when developing a recommended schedule of instream flows. Figure 10 illustrates the annual hydrographs of two rivers: the Ash River located on Vancouver Island, and the Bridge River near Lillooet. The shape of the hydrographs differ in magnitude and timing of the peak and low flows—the Bridge River shows an extended late spring and summer freshet, whereas Ash River flows peak in the fall and spring. The relative volume of flow also shows large differences between the two rivers during critical periods of the year. The critical stream flow month (month of lowest stream flow during the growing season) is 17% of MAD in the Ash River, but 119% of MAD in the Bridge River.

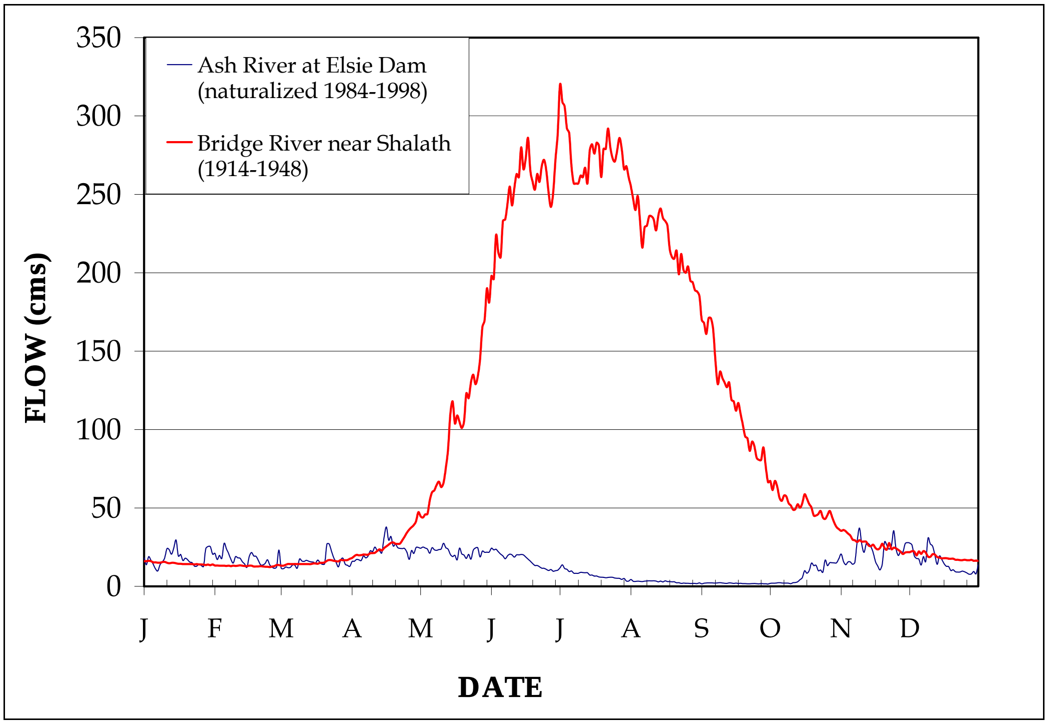


Figure 10. Streamflow patterns vary considerably among streams in the province, as indicated by median daily flows for the Ash and Bridge Rivers. Flow in the Ash River is primarily driven by rainfall, whereas flows in the Bridge River are primarily related to snowmelt.

Developing a Schedule of Instream Flow Requirements.—Using the Ptolemy Method's process, a schedule of instream flow requirements is developed by referring to the species periodicity chart, the natural flow data, and developing an understanding of other 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 a flow standard for each ecological requirement (e.g., Tennant's standards, the Ptolemy Method's standards, flows of minimum risk as calculated by the meta-analysis, etc.). An example summary table is shown in Table 7, and a graphical presentation of an annual schedule of instream flow requirements is shown conceptually for the Ash River in Figure 11.

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, but the rationale for this is predicated more on practicality than biology. Water licenses are almost never "clawed back," so allocation of water acts as a ratchet. Selecting the highest flows within any period recognizes this reality, and is risk averse in that it ensures that too much water is not permanently allocated for human use.

Biologically there may be other solutions that should be considered. For example, if one life stage or species is more preferred (say because it is limiting or endangered) then a series of weights could be added to the table to help understand trade-offs among conflicting needs. It is appropriate for these finer-scaled decisions to be part of a detailed assessment, rather than part of the Standards.

The natural annual hydrologic cycle should also 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.

Table 7. Flow requirements by species and life stage plus other ecological needs. Values are to week-long time blocks, and the annual instream flow requirements (the last row) are determined by defaulting to the highest value in each column.

MAD (cms)	5.8																									
Species	**Life history/behavior**	**Criteria**	JAN				FEB				MAR				APR				MAY				JUN			
Chinook	Juvenile rearing	20%															1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	Juvenile migration	45%																			2.6	2.6	2.6	2.6	2.6	2.6
	Adult migration	100%																								
	Adult spawning	45%																								
	Egg Incubation	20%	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2										
Rainbow	Juvenile rearing	20%													1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	Juvenile overwintering	20%	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2												
	Juvenile migration	20%																			1.2	1.2	1.2	1.2	1.2	1.2
	Juvenile overwintering	20%	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2												
	Adult rearing	40%													2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	Adult overwintering	20%	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2												
	Adult migration	50%													2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9				
	Adult spawning	45%															2.6	2.6	2.6	2.6	2.6					
	Egg Incubation	20%																	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Ecology	Short-term flows	10%	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	Wetland linkage flows	100%													5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
	Channel maintenance flows	400%																		23						
CONSERVATION FLOW			1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	5.8	5.8	5.8	5.8	5.8	23	5.8	5.8	5.8	5.8	5.8	5.8

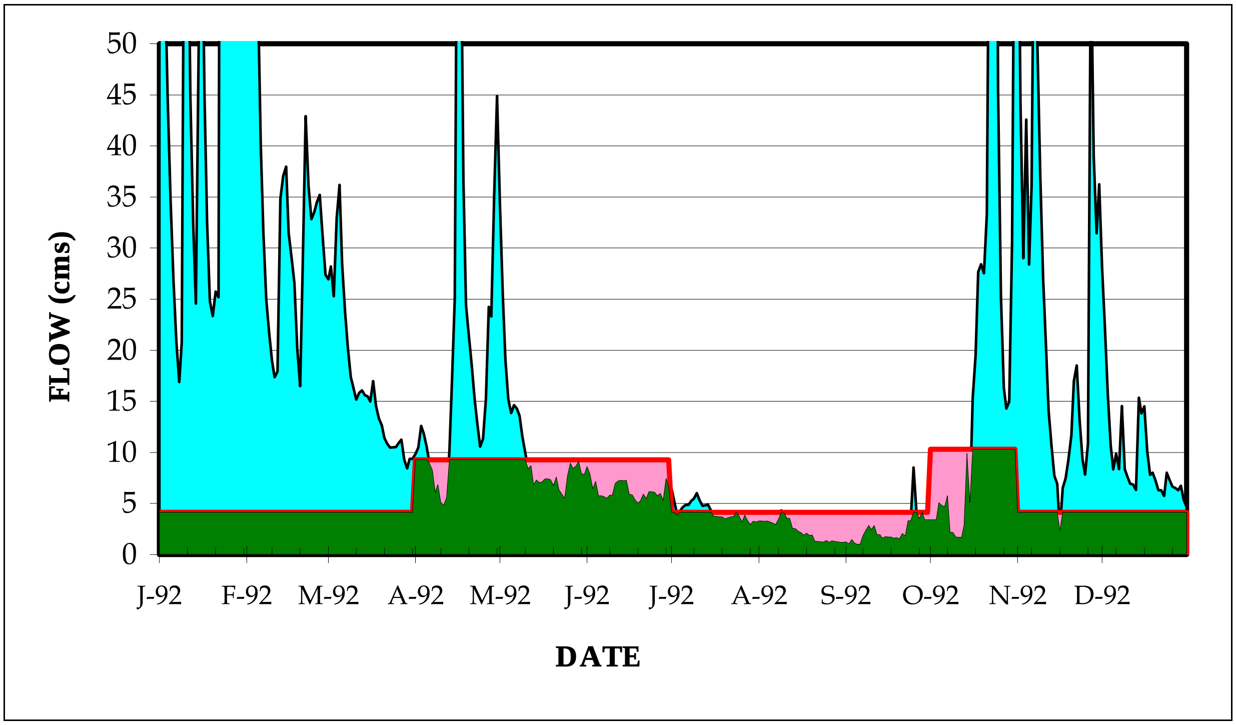


Figure 11. An example of a schedule of instream flow requirements superimposed on a natural hydrograph. Both naturalized mean daily flows (black line) and instream flow requirements (red line) are indicated. The light blue area denotes surplus flows (those available for withdrawal), whereas volumes up to and including the red line are required to meet ecological needs of fish. The green area denotes flow available to meet these needs; the pink area shows where natural stream flows are insufficient to meet these needs. This example is based on estimated daily flow in the middle Ash River during 1992, a dry year.

Deciding on Flow Criteria

Of the methods available, Ptolemy's criteria and those based on PHABSIM meta-analysis calculations appear to be best suited for application to British Columbia streams. (Conceptually, there is no reason why other standard-setting methods cannot be used, but these two are based more on local conditions than are the other methods.) Both sets of criteria are easy to calculate using readily available information. However, both have strengths and weaknesses.

Like the original Tennant Method, Ptolemy's criteria are primarily fixed flows (expressed as proportions of naturalized MAD) selected to satisfy particular ecological needs. One of the main strengths of these criteria is the ease with which they can be calculated. Implementation error is therefore likely to be lower relative to more complex criteria. Another key strength is that the criteria cover ecological needs spanning the entire year, so there are no "holes" left in a schedule of instream flow requirements. Weaknesses of the criteria include development using a relatively small database, incorporation of a fairly large component of subjective judgement, a concentration on salmonid species, and a lack of peer review and biological validation.

The PHABSIM meta-analysis allows the calculation of habitat-flow risk functions for rearing and spawning salmonids (Figure 8). The main strengths of meta-analysis based criteria are twofold. They are built on a very large database collected and analysed in an explicit manner, which has been peer reviewed. And the risk functions allow trade-offs to be made more explicitly than with many other methods. Weaknesses include a lack of biological validation of the risk functions, incomplete coverage throughout the year (e.g., they offer no guidance for flows outside the rearing and spawning periods), and they require some expertise (e.g., to combine risk functions). Implementation error may be relatively high in comparison to less complex criteria.

The meta-analysis was designed as a decision tool rather than a standard-setting tool, and it provides some important insight into the standard-setting exercise. One of the key messages of the meta-analysis is that there is no universal flow value that protects all fish habitat in all streams. This is a very different statement than the flow criteria put forward by Tennant (1976) or Ptolemy. The meta-analysis equations predict how fish habitat (as described by velocity and depth measures) varies with streamflow, but there is error in this prediction, which is described by variance around the prediction line. In other words, the equation represents an average. If one were to select this line as a standard, it implies that on average it would perform well, but that on some streams the standard would be too rigid and on others too lax. The risk curves calculated by the tool indicate the potential consequences (on average) to habitat of moving away from that average line. In this way, it forces one to recognize that an instream flow standard is a probabilistic statement regarding the protection of fish habitat. In this respect it also forces one to recognize that setting a standard is a policy decision with respect to whether such a level of protection is acceptable. Standards based on other methods give no estimates of the error around their predictions.

A weakness common to both criteria is a lack of validation (i.e., biological response to recommended flows is unknown). Both PHABSIM and the Tennant Method have been used many times to recommend instream flow requirements. The results of these implementations have been “evaluated” through ongoing management activities on the same streams, so in one sense the methods have been assessed. But this cannot be considered a sufficient or valid test. This limitation means that it would be difficult to present either of the two criteria as anything more than hypotheses. Since the PHABSIM meta-analysis and the Ptolemy criteria indicate different functional relationships of fish vs. flow (Figure 12), the two methods could even be considered competing hypotheses (Hilborn and Mangel 1997). The difference in functional relationships between fixed percentages and hydraulic methods has been pointed out by other authors (Beecher 1990; Jowett 1997; Hatfield and Bruce 2000) and should be carefully assessed during phase 2 of this project to ensure that undue risks are not being taken for some stream sizes.

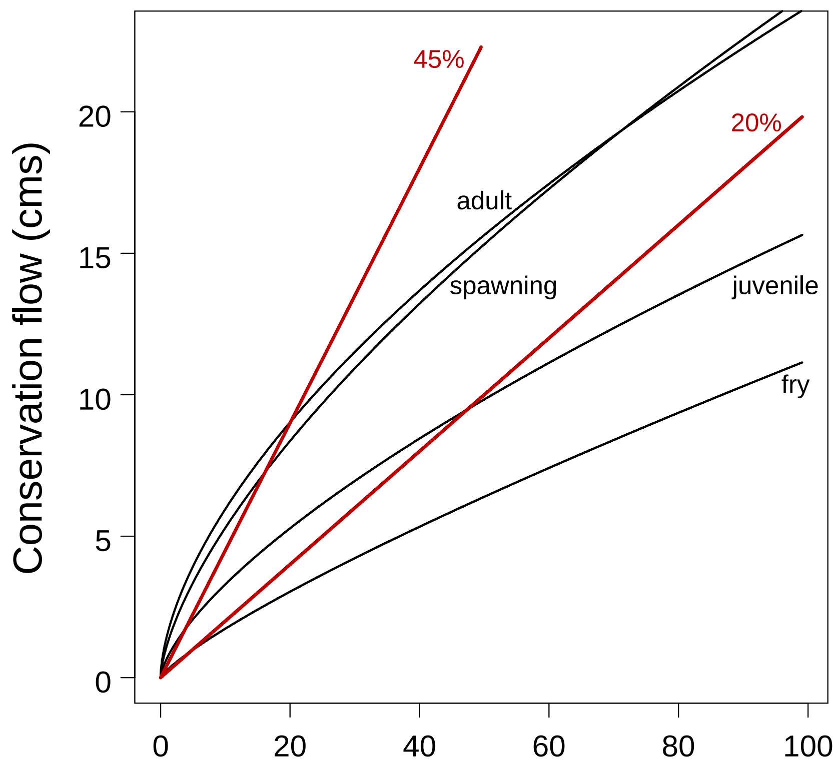
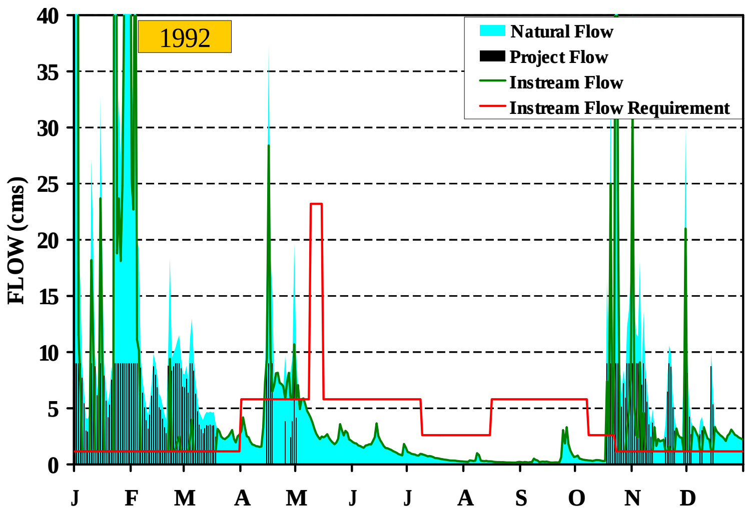


Figure 12. Relationships of rearing and spawning instream flow requirements versus mean annual discharge, based on the Ptolemy Method (in red) and PHABSIM meta-analysis (in black). The two methods produce functional relationships that are very different, and as a result the two methods would lead to divergent flow recommendations.

The selection of flow criteria obviously has implications for protection of fish and fish habitat, as well as the economic viability of water use projects. It may be less obvious that there are also potential interactions between operations and instream flows that are directly related to the instream flow requirements, and which influence fish and fish habitat beyond just minimum flows. For example, a hydropower facility requires a specific minimum volume of water before it can run its turbines, and this minimum sets a threshold above the instream flow requirement. In other words, hydroelectric plants cannot make full use of all water available above the instream flow requirement (unless it builds and takes advantage of storage). Natural flows will often need to be well in excess of the instream flow requirement before a facility can begin generating. A simple example has been simulated for Figure 13, and highlights two consequences of the instream flow requirement. There are few flat line instream flows because of daily variation in flows, and the project does not operate very often, even in wet years. These types of implications need further technical assessment, and should be clearly communicated to policy makers before acceptance of finalized instream flow standards.



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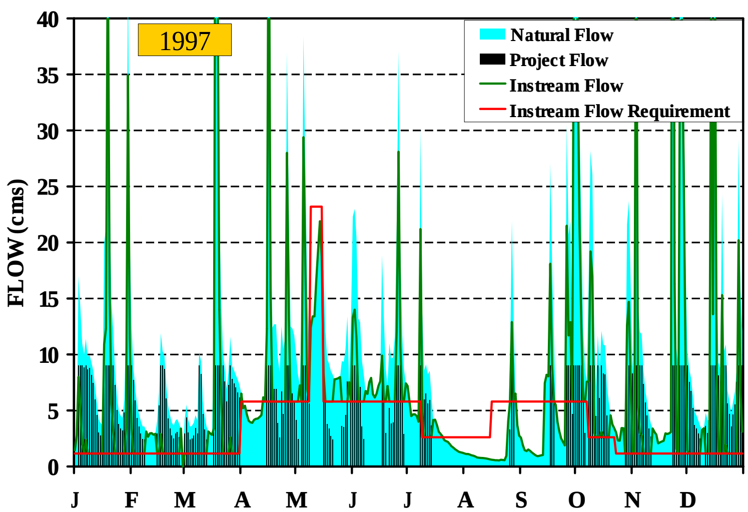

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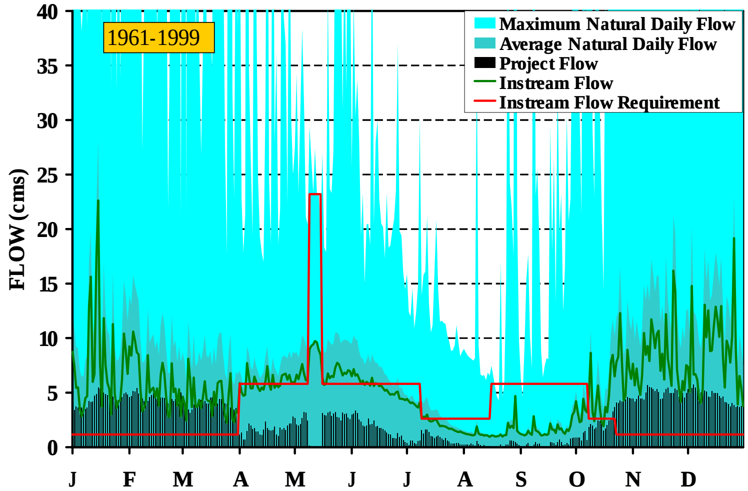

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Figure 13. Simulated operations for a hypothetical run-of-river hydropower project for the Tsable River, Vancouver Island. The project has been operated to meet the instream flow requirements as calculated using the Ptolemy Method, for (A) 1992, a dry year, (B) 1997, a wet year, and (C) averaged from 1961 to 1999. Based on a MAD of 8.0 cms the instream flow requirements have been calculated and plotted as the solid red line. The blue shaded area shows the natural flows and the green solid line shows the instream flows released to meet the instream flow requirements. The black columns are flows diverted for the project.

Application and Approval Process

Current process.—At present, water licenses are applied for by completing and submitting an application form (available at http://srmwww.gov.bc.ca/wat/wrs) to the British Columbia Ministry of Sustainable Resource Management, along with a project drawing and the appropriate application fee. Generally, water license applications associated with small hydropower projects are supported by biological and hydrologic assessments, however, the application form does not require this information, and many applications are submitted without it. Staff of the Water Management Branch currently process the applications by reviewing them for completeness and accuracy, requesting additional information as required, and referring the application to other resource management agencies and other licensees, applicants or landowners whose rights may be affected if the application is granted.

Regional staff may inspect sites of proposed water withdrawals. A report is completed for each application either recommending that the license be granted or that the application be refused.

Applying the Coarse Filter.—The Standards are intended to act as a coarse filter to screen water license applications for flow-related impacts. As such, they should flag applications that require additional information, and let through any applications that satisfy certain flow-related criteria. By flagging applications the intent is to direct attention to those flow-related aspects of a project most in need of attention. A project proponent would then be expected to undertake the necessary assessment of those concerns and to address them as appropriate. By letting applications through the coarse filter the intent is to allow reviewers to direct attention to other aspects of the project application.

The screening process would work as follows. An application would be submitted, along with information requirements as noted in Section 5, and instream flow requirements calculated as per Section 6 (of course, this can only be done when flow criteria are finalized). The application would undergo a preliminary screening assessment (Figure 1) to see whether it met the Standards. If the project passes this screening, it may still undergo additional review. For example, it will be subject to basic protection requirements (e.g., preparation of an environmental protection plan including management of hazardous materials and construction timing restrictions) and basic mitigation requirements (e.g., intake screening, emergency shutdown protocols, and TGP management) and these needs will be reviewed separately, as required.

If the project does not pass the preliminary screening assessment, it would undergo a detailed screening assessment, wherein one or more detailed studies may be required. The detailed study will be directed toward issues that cause the discrepancy between the Standards and the proposed project. For example, the proposed project may request large diversions during a time of year when high instream flows are required to meet spawning needs for certain species. This creates a clear discrepancy between the proposed flows and the Standard, and points to the ecological factors that are paramount in that particular time block. The detailed study would therefore focus on that specific aspect, rather than trying to assess myriad unrelated issues. The detailed study will help determine the specific risks associated with not meeting the Standard, and lead to a decision whether to allow the project to proceed as planned.

Alternatively, the project may be re-designed so that it is able to pass the preliminary screening assessment. Re-design is also an option for projects that fail to pass the detailed screening assessment. If a project successfully passes a detailed screening, it will be subject to base protection and mitigation requirements and also additional mitigation or compensation as determined by the detailed studies.

It should be clearly understood by applicants and reviewers that this coarse filter does not prejudice additional review. For example, Fisheries and Oceans Canada has its own obligations for review and will undertake these independently of the coarse filter. It is nevertheless expected that this coarse filter will greatly aid subsequent reviews, by ensuring that specific information requirements are met and attention focussed on specific aspects of the proposed project.

Next Steps

A great deal of work in a variety of jurisdictions has gone into developing streamflow criteria for fish, and these have been used for stream flow allocation prescriptions over the last two or three decades. It is troubling that we know so little about the biological response to these prescriptions, yet it is certain that this knowledge is not going to accrue prior to the final design and implementation of the British Columbia Instream Flow Standards for Fish. It will therefore be necessary to very carefully analyze all flow criteria proposed for the Standards to ensure that they are as defensible as possible, and to understand the implications of different criteria. It will also be necessary to develop a strong business case for monitoring instream flow prescriptions (see Section 7).

During the final workshop for this phase of the project there was fairly broad agreement that simple criteria such as Ptolemy's or Tennant's were the most appropriate as "coarse filter" standards. However, during the workshops and in subsequent discussions it was clear that support for the criteria was not unanimous. For example, a conflict was apparent between the recommendations of most PHABSIM studies as predicted though the meta-analysis tool and the simple criteria, suggesting that the fixed criteria may not provide adequate protection to streams of less than 5 cms MAD.

Although the simple criteria may indeed be adequate as a coarse filter , we cannot be certain of this given the current state of the science. After release of the Standards, we anticipate that they will be critically reviewed by a number of parties, including industry and non-governmental organizations. Given this, we emphasize the need to support the standards with a more rigorous analysis of the background information than that provided to us. Additional information may be available to support the criteria (new information was provided to us in the final week of this project). The detailed review and integration of this information represents original research that will be necessary if the simple criteria are to be well supported.

The British Columbia Instream Flow Standards for Fish are intended to address three main needs: consistency in applications, a process to devise a schedule of instream flow requirements, and criteria to use within that process. Phase one of this project has compiled information that largely addresses the first two of these needs. Several issues need addressing during phase two of the project before a recommendation can be developed for finalized criteria to be used within the Standards. Some of these issues are policy related, and some of them are technical. The three key issues that must be addressed include:

- technical assessment of the rationale for all proposed flow criteria (using hydraulic, geomorphic, and biological principles and data),
- technical assessment of the implications (hydraulic, geomorphic, and biological) of all proposed flow criteria, and
- input from provincial and federal policy makers regarding intent and implications of the Standards.

7 MONITORING

Monitoring is the cornerstone of effective resource management, providing the feedback mechanism that allows proper assessment of management decisions and programs. Monitoring is a vital element of the Standards because it will allow us to demonstrate the effectiveness of the Standards or identify how the Standards should be revised to increase effectiveness. The decision to monitor is only the first of many decisions that must be made during the design of a monitoring program. Designing and implementing an effective monitoring program is not straightforward, especially since the program will need to evaluate potential flow-related changes in biological productivity over multiple spatial and temporal scales. This section presents an overview of some of the more important aspects that must be considered when designing and implementing a monitoring program. The details of the monitoring program will be completed during phase 2 of this project, after the Standards have been finalized. There are a number of policy level questions raised throughout this section that require answers prior to designing the monitoring program.

What is monitoring?—Environmental monitoring in the context of instream flow standards for fish is the observation, measurement, and evaluation of streamflows and fish to test the efficacy of management actions. Effective monitoring will allow the Province to measure success. Traditionally, in British Columbia and elsewhere, decisions have too often merely been implemented and assumed to be successful. For example, the Salmon Enhancement Program was considered successful in its early stages because the decision to enhance salmon was acted upon, mostly by building hatcheries and spawning channels. However, data necessary to evaluate its benefits and risks were not collected until late in the program, when it became apparent that the key objective of the action had not been achieved (a doubling of salmon stocks). Viewed as a process, the traditional resource management model has been simplistic and self-fulfilling: “we made a decision to do what was best, and we did it, therefore we did what was best.” In contrast, effective resource management requires a decision to act, an action, and a post-action evaluation of the action that can be used to revise the decision, if needed. The traditional process is shown in Figure 15 as a simple feedback loop; effective management is shown in the adjacent, more complex, loop.

A monitoring program develops and calculates “indicators,” to fulfill the needs for proper feedback. Indicators are used to describe system conditions and trends. They are a way of distilling a complicated “big picture” into manageable pieces, and monitor whether conditions are getting better, worse, or staying the same. Indicators such as unemployment rates, average house prices, and the gross domestic product are used by decision-makers every day to inform and guide economic and social policy. Environmental indicators can be similarly used to monitor environmental conditions and determine whether regulations and policies are leading toward desired goals.

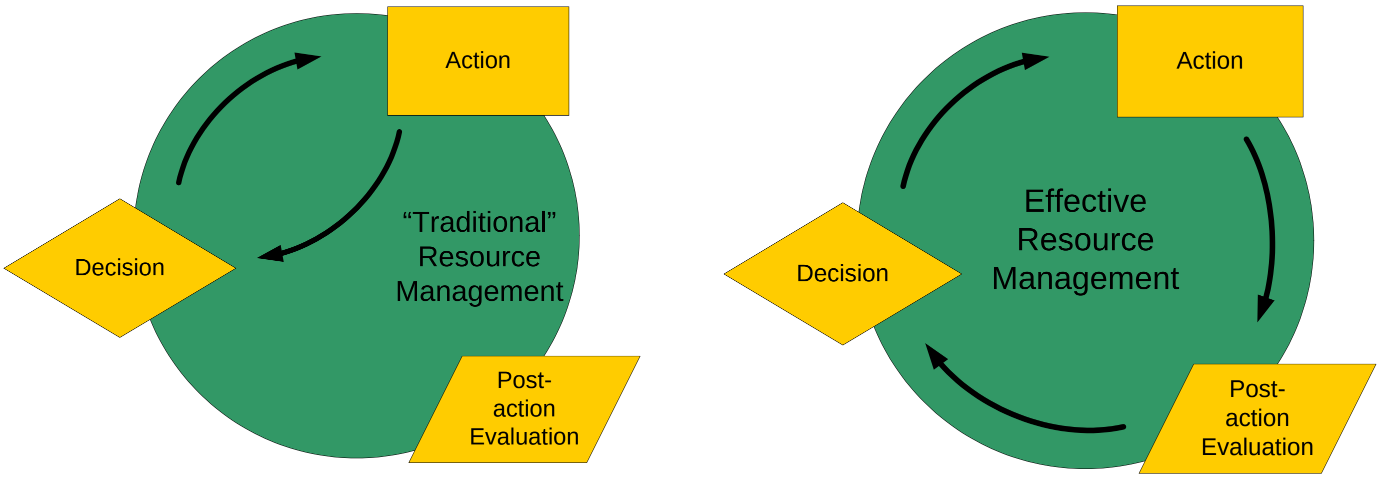


Figure 14. Traditionally, resource managers put a great deal of effort into making initial decisions, and considerably less effort into evaluating decisions after they are made. Effective resource management requires a strong feedback mechanism (i.e., monitoring) that allows proper evaluation of management decisions. Good environmental indicators can strengthen resource management by providing this much needed evaluative feedback.

To be most useful, indicators must be reliable, responsive, understandable, and scientifically defensible. Just as pulp mills must monitor effluent to identify treatment process efficiency, and monitor biota in the receiving environment to demonstrate bioaccumulation or lack thereof, managers of facilities that affect instream flows should monitor both streamflow and the response of biota to flows. For instream flows, appropriate indicators will describe:

Conditions: What is the current state of flows and biota in a stream, or group of streams?

Trends: How has streamflow or the biota changed over recent years? Are conditions deteriorating or improving?

Causes: What are some of the pressures on the biota? How have these pressures changed over time?

Comparisons: How do conditions compare with accepted standards or with circumstances in other places?

Discussions of monitoring are intertwined with the ideas of adaptive management (Walters 1986; Lee 1993). At the heart of the discussion is an acceptance that all decisions (particularly resource management decisions) are essentially experiments with uncertain outcomes. To most effectively learn from our mistakes and successes decisions should be made and evaluated within an explicit experimental framework. Higgins (1999) reviews some of the options for this framework with respect to instream flow decisions, and describes a continuum of choices from non-experimental to active approaches (Figure 16).

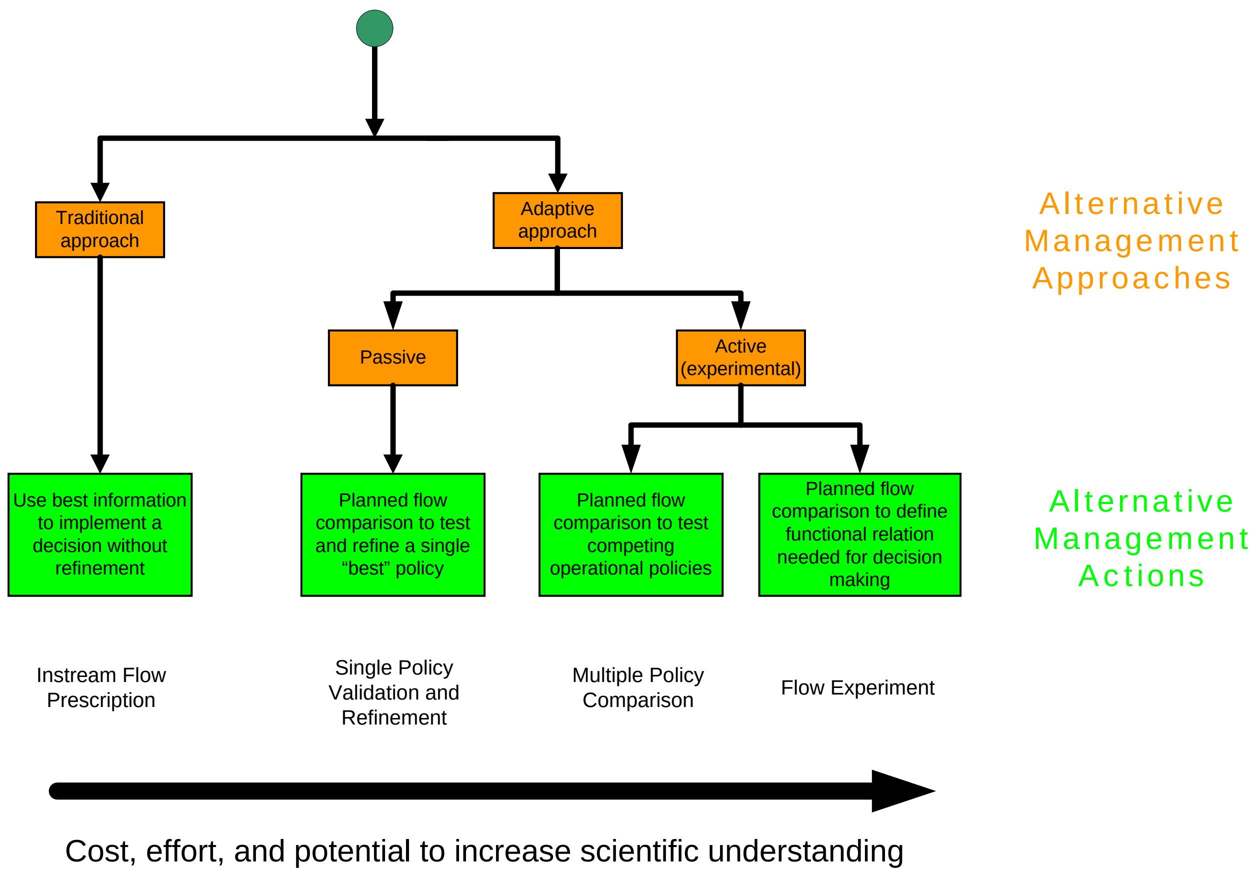


Figure 15. Decision pathway and explanation of approaches to implementing instream flow decisions (from Higgins 1999). In practise these distinctions may be less precise. For example, the traditional approach sometimes includes ad hoc investigation and refinement, but such monitoring is rarely structured as a hypothesis test.

Why monitor?— Traditionally, instream flow decisions have been non-adaptive. Impact assessment studies and opinions are collected and a decision is implemented that reflects the "best" available information. Seldom are these decisions systematically evaluated after they are made. This is dangerous given our poor ability to predict the response of ecological systems to environmental changes. It is the wide uncertainty in predictive ability that provides the strongest argument for monitoring (Ludwig et al. 1993; Castleberry 1996).

Although the need for monitoring is widely recognized, monitoring is often accomplished in an ad hoc and qualitative manner. In general, this is because it is difficult to make a convincing "business case" for monitoring, particularly since effective monitoring programs require a considerable commitment of resources (both labour and money) and often provide tangible returns (e.g., by confirming or altering decisions) only in the long term. Yet resource managers intuitively understand that "we can't know where we're going, unless we know where we've been," and that an occasional inventory study is inadequate for providing a much needed evaluation of past and present policies and their implementation.

The decision of whether to embark on a monitoring program entails at least a rudimentary accounting of associated benefits and costs. Without this accounting, it will be difficult to justify monitoring and to select an appropriate level of effort for the program. Potential benefits fall out of the three different purposes of monitoring—compliance, validation, and scientific understanding. The potential benefits increase as one moves from the first to the last of these categories, but so too do the costs (Figure 2).

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. For example, intakes may be gauged to ensure that water is used in the appropriate quantities and at the appropriate times. The main benefit of compliance monitoring is that water use is quantified and recorded, which can aid in the allocation of remaining amounts. Hubert et al. (1990) found that compliance by water users was poor, which is a strong argument for requiring this type of monitoring. This form of monitoring can also provide regional data for use in assessing the efficacy of the Standards by linking changes in flow to larger scale patterns in the biota.

Benefits of Monitoring.—The potential benefits of validation to improving the effectiveness of management decisions are much greater than those of compliance monitoring. Decision validation monitoring can evaluate individual water use prescriptions and, when applied across several systems, the efficacy of the Standards. For example, individual water use projects (e.g., a small hydropower project) can be monitored using a simple before-after (BA) comparison. The comparison would allow a description of the biological response to a change in flow (i.e., improvement, deterioration, no change). Such comparisons would evaluate the Standards on a site-by-site basis. Given that every stream is different and our knowledge of the ecological role of flow is limited, we anticipate that the Standards may not perform well on each stream. However, over all streams we expect the Standards to do well, and combining monitoring study results over streams, we can evaluate the Standards on a regional basis.

BA comparisons would improve scientific understanding by detecting responses to flow changes, but by themselves would not likely resolve the mechanisms for the biological response. That is, if fish resources decline after implementation of the Standards, the monitoring program might detect this (depending on statistical power of the experiment), but it would not by itself help understand why, unless very detailed monitoring programs were implemented that studied links between the indicator and abiotic and biotic factors other than just flow. Detailed monitoring can define the functional relationships between fish resources and flow characteristics (e.g., a better description of the benefits and costs in relation to possible water use options). Improved scientific understanding can be gained with more direct experimental approaches to management (see Figure 16), which allow the evaluation of more than one policy option (e.g., tests of competing hypotheses). In combination with detailed monitoring, adaptive management can identify superior management approaches and therefore better Standards more quickly than simple BA comparisons.

The most important benefit of monitoring for habitat managers is that real declines in the fish resource can be detected as quickly as possible, allowing managers to correct errors quickly. On the other hand, if the monitoring program is rigorous and detects no effect of water use decisions on the resource, then a defensible management response may be to allocate additional water. In either case, managers can formulate a data-driven management plan that protects the fish resource while allowing water use development to proceed. In short, everyone in society benefits because decisions regarding resource use and conservation are driven by quality-assured information analyzed in a defined framework rather than by untested information assembled into post-hoc rationalizations in undefined frameworks.

These benefits of monitoring are only real if there is a commitment to revise the Standards based on new information, if data suggest revisions are warranted. That is, if the monitoring program indicates the Standards are too lax, then they should become more restrictive; or if the fish resource shows no deterioration then the Standards may be too restrictive and should be loosened. Of course, if monitoring indicates that the Standards are adequate, then pressure to change them should be resisted. It may seem obvious, but there really is no point investing in a monitoring program if the Standards are immoveable, and results cannot lead to changes in them.

A final benefit of monitoring is more intangible. One of the key Guiding Principles for developing the Standards is to "implement a scientifically defensible approach." Monitoring is an obligation if we are truly committed to this principle. A key conclusion of this report and others (e.g., Castleberry et al. 1996) is that development of an instream flow standard is possible, but that uncertainties regarding the biological response to changes in flow are so profound that prediction is a highly suspect endeavour. An instream flow standard can therefore more accurately be called a working hypothesis, and should be tested in a proper scientific framework. In other words, virtually every instream flow expert recognizes the need to develop a standard (whatever it may be) in order to halt a long and gradual decline in the quality of riverine habitats. But it would be improper to call the standard scientifically defensible unless it is embedded in a framework that includes effective monitoring.

Costs of Monitoring.—Costs need to be defined, just as benefits are. Direct monetary costs are likely the easiest to quantify, but there may also be political and legal costs (or risks) associated with monitoring. Both the political and legal risks stem from the same source: an admission of scientific uncertainty can be (mis-) interpreted as an admission of ineptitude. Reliable evaluation of the Standards may take several to many years, which is usually well beyond most political timeframes. There will therefore be a constant pressure to deny or erode funding for monitoring. The legal risks are similar. Admission of scientific uncertainty may inspire challenges to water allocation decisions. Indeed, some have interpreted bold management stances regarding the efficacy of instream flow standards as motivated in part by this factor (Hamilton 1996). A sound rationale and business case for monitoring will offset some of these risks.

A related issue is, who pays for monitoring? The answers to this question are especially important for how a monitoring program is structured and implemented. For example, a proponent for a hydropower project will resist committing resources to monitoring if there is no direct benefit. The resistance will be especially strong if a monitoring program exposes him or her to a "clawback" of water allocation. A more appropriate model may therefore be to prescribe a flow regime that is conservative from a fisheries perspective, but allow additional water allocation if data support this decision. This structure satisfies the principle of being risk averse, recognizes the economic reality of capital-intensive projects, and provides an incentive for monitoring.

On the other hand are small consumptive uses (e.g., irrigation and drinking water). It may be unreasonable to ask this type of water user to commit financial and technical resources to conduct anything more than compliance monitoring. Yet, the cumulative effect of these diversions is often large, as has been seen throughout western North America (see Section 4). For such uses the Standards offer clear benefits, but it will likely fall on the resource agencies to undertake monitoring on these systems to ensure that goals and objectives are being met.

What to monitor?—With the exception of compliance monitoring, the general question one is trying to address with a monitoring program is, what is the biological response to changes in flow? The biological response we are most interested in is changes in abundance and biomass of fishes.

Population abundance is difficult to measure and notoriously variable in space and time. It is therefore tempting to search for surrogate measures, or indicators of biological productivity. Indeed, this is the implicit logic of so many of the habitat-based instream flow assessment methods. While there may be some logic in using habitat-based measures or other indicators during an initial assessment (e.g., as has been done during Water Use Planning), there are good reasons to avoid an over-reliance on indicators during the monitoring phase.

Flow changes can affect fish in both simple and complex ways. For example, an increase in flow will wet more channel, and may produce more food for fish, and thereby increase overall fish production (Figure 17a). However, because the causal pathway from flow to fish is usually embedded in a complex web of interactions (Figure 17b), a strong, consistent, link from flow to fish is rarely so straightforward. In general, the more physical relationships and trophic levels there are between the management variable (flow) and the target variable (fish), the weaker and less consistent the link, and the more tenuous the conceptual model linking the two. For this reason the choice of what to monitor can be crucial to the effectiveness of monitoring and to furthering our understanding of the ecological system.

Indicators alone may not reveal the effect of management actions on fish. For example, monitoring periphyton abundance may not show what is happening with fish abundance and biomass. Measuring multiple indicators may not help either: one of the main arguments in favour of adaptive management (e.g., Ludwig et al. 1993) is that a more complete understanding of ecological interactions is elusive, and unlikely to occur any time soon. Rather than trying to understand and predict the myriad biotic and abiotic interactions, it makes more sense to manipulate flow and look for changes directly in fish.

Despite the complexity of fish-flow relationships, indicators can offer complementary information that can be used in a weight-of-evidence approach. For example, a monitoring program may indicate a response in fish, but the response is difficult to detect because of high variance and insufficient monitoring duration. When evidence is combined with monitoring data on food availability, fish health, and habitat indicators, the evidence taken together may show a significant biological response to flow changes. This additional evidence is worthwhile for trying to distinguish the causal mechanisms for changes in fish abundance and biomass, but may also lead to early detection of broader biological responses.

Changes in fish abundance in any particular watershed occur as a result of many local, regional, and global influences. Even where causal relationships can be described the magnitude of effect attributable to any one factor usually has large statistical error, which makes quantification difficult. Regional and global influences include, but are not limited to, declines in marine survival (Walters and Ward 1998; Smith and Ward 2000), climate change (Pyper and Peterman 1999; Welch et al. 1998), sublethal effects of pollution (Sherwood et al. 2000), declines in marine derived nutrients (Cedarholm et al. 1999, 2000), harvest pressure (Bradford and Irvine 2000) , and changes in land use (Bradford and Irvine 2000). Other influences may be positive, such as habitat restoration initiatives (Slaney and Martin 1997), or of uncertain benefit, such as hatcheries, and artificial spawning channels. With such a long list of potential influences it may be preferable to monitor species that are more likely to consistently respond to changes in flow. Monitoring programs should consider selecting resident species over anadromous ones for the purposes of monitoring. Resident species are subjected to local influences for more of their life than are anadromous species. They may therefore offer greater sensitivity for detecting flow treatment effects that are small.

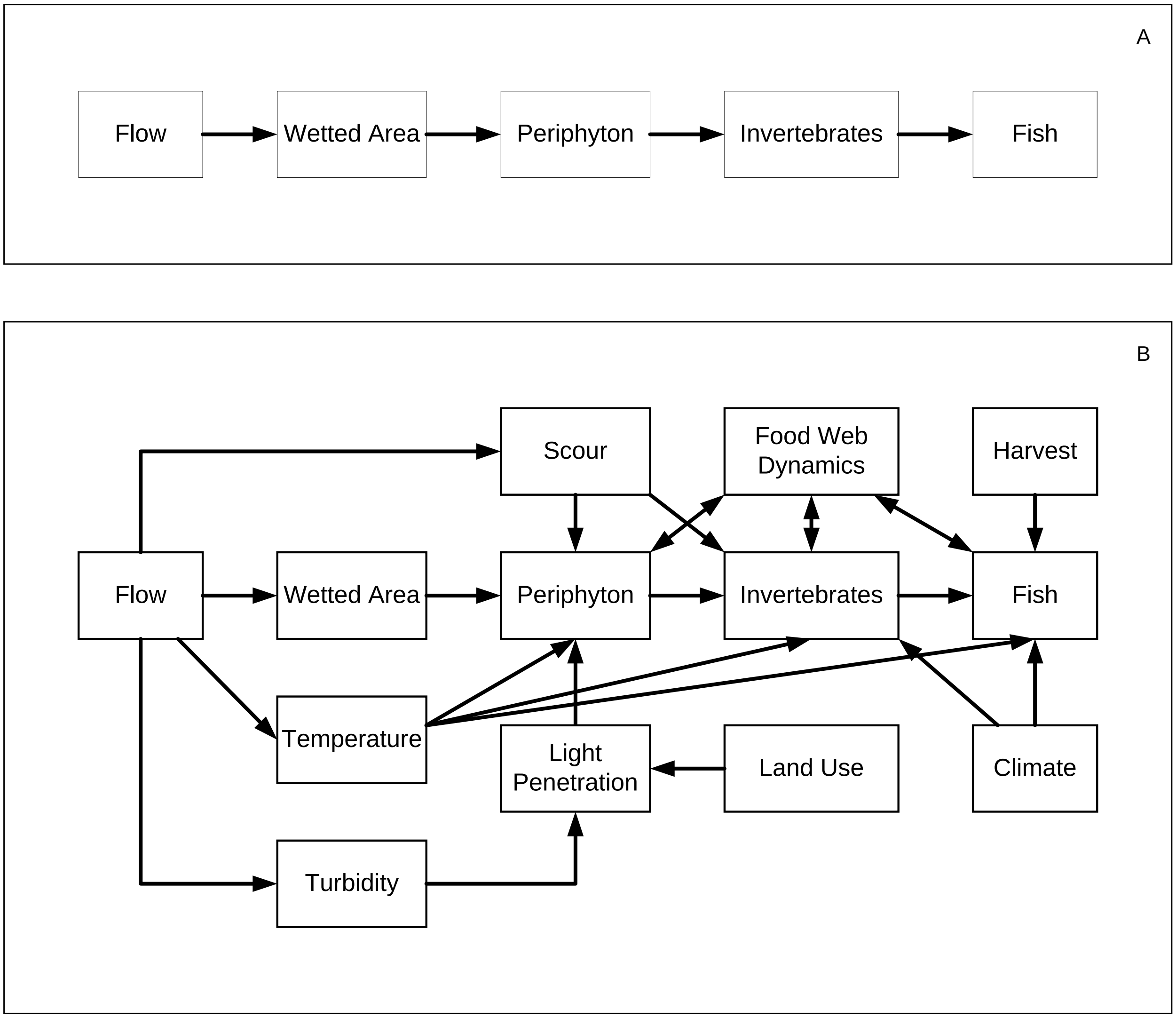


Figure 16. (A) It is almost always possible to think of a simple mechanistic pathway between a controlling variable and a response variable. (B) However, in ecological systems the causal link is seldom so straightforward because the pathway is embedded in a complex web of abiotic and biotic interactions. For this reason it is usually best to monitor the variable of interest directly rather than a surrogate indicator variable.

When to monitor?—There are three related questions with respect to when to monitor: when to start monitoring, when to stop monitoring, and what time of year should be the biological reference point? At a gross level, monitoring should begin years before the project is built, and end years later, and only when a certain level of certainty is achieved. Monitoring programs must grapple with natural temporal variation in fish abundance, or any indicator of fish abundance. A critical question, even for well-designed programs that monitor fish directly, is how do we know that factors other than flow are not responsible for observed changes in fish abundance (or lack thereof)? There are numerous examples that indicate that this is a major concern (e.g., Walters et al. 1989).

The standard method for controlling for such influences is the simultaneous monitoring of "control" sites, i.e. streams without water withdrawal projects. This experimental design is referred to as a Before-After, Control-Impact (BACI) design. Similar "responses" at both control and impact sites implicate factors other than flow change. Notwithstanding the difficulties of finding appropriate control sites, and a potential loss in statistical power if control and impact sites are dissimilar, the need to control for regional influences may be less relevant to evaluation of the Standards than to evaluation of single projects. Assuming the Standards are approved, they are likely to be applied only gradually because water use projects themselves will come on line only gradually. If this assumption is reasonable, then flow treatments will be distributed in time and space, and provide "controls" for one another (i.e., regional trends can be detected from the group as a whole). The extent to which this is possible should be explored using statistical modeling techniques (e.g., Monte Carlo simulation and power analysis).

More troublesome will be problems associated with a general lack of pre-treatment data. For the most part monitoring is likely to occur only after water licenses are granted, and we will be lucky to obtain one or two years of data prior to a project being built. The quality and amount of data collected after a project may have little influence on the sensitivity of a monitoring program if there are too few data to use as a baseline comparison. The only way to improve this constraint is to obtain baseline data from control streams (i.e., use a BACI design), to compel water users to collect data well in advance of building a project, or have regulators directly undertake some aspects of the monitoring program. Either option would entail a funding and policy decision on the part of the agencies and should be carefully considered. The extent of pre-project data required to meet a certain sensitivity threshold would need to be explored using computer simulations.

The decision of what time of year to concentrate on for data collection is primarily a logistics and sampling efficacy issue. Fortunately these two factors are often not in conflict. For example, times of low flow tend to be those with the easiest working conditions and the best sampling efficacy. Summer low periods also coincide with periods in which fish have hatched are out of the gravel, juveniles and adults are well distributed in the stream channel, and fish are actively feeding and growing. This period therefore usually allows one to best estimate recruitment as well as abundance and biomass. Of course, the summer low flow period is not necessarily the best period to sample all species of fish, so the best time of year for monitoring may be species-dependent.

Where to monitor?—The decision of where to monitor is in part a policy decision and in part an experimental design decision. The policy decision has to do with which type of water use should be monitored, whether all projects should be monitored, and whether monitoring should be spread throughout the province or concentrated in specific regions. For example, agencies may wish to support a policy requiring that all hydropower projects be monitored. Likewise, a policy might be developed that concentrates monitoring effort in one or a few regions in an attempt to reach a critical sample size for among-project comparisons. In part, these decisions should be guided by the experimental needs of the monitoring program, and these needs (e.g., how many sites to monitor) need to be explored using computer simulations. Given our current knowledge base, crippled by the absence of monitoring of past projects, and the stepwise pattern of project initiation anticipated over the next ten years, the monitoring of all new projects is warranted, over the next decade, at least.

How to monitor?—Decisions on how to monitor are essentially decisions regarding experimental design and analysis, and should be made in concert with many of the decisions discussed above. Before a monitoring program is implemented one should seek to develop a good sense as to its likely sensitivity in relation to various aspects of the monitoring program. For example, how large a biological response can be detected if the monitoring program is run for 5 years on 5 streams using a specified sampling technique, 10 years on 10 streams, and so on. The best way to explore the statistical power of different sampling options and scenarios is through the use of Monte Carlo simulation techniques. Using values from previous studies to describe the likely variance associated with different components of the program it is possible to simulate the range of possible outcomes and the probability of detecting different biological responses. That very detailed level of planning is expected to occur during phase 2 of this project.

8 RECOMMENDATIONS

Phase one of the development of the British Columbia Instream Flow Standards for Fish has highlighted several high-priority tasks that should be addressed during the next phase. An overview of these tasks is presented here.

1. Complete technical assessment of instream flow criteria.
    - review individual studies to support and evaluate criteria
    - develop weight-of-evidence approach to support and evaluate criteria
    - conduct literature reviews as necessary
    - conduct expert elicitation of photographic records to support and evaluate criteria
    - review of stage-discharge relationships (wetted perimeter data) to provide support for short-term flow criteria
    - review of discrepancies between criteria that have been developed using different methods
    - recommend finalized criteria for use in the Standards

2. Complete policy analysis of intent and implications of the Standards
    - develop agreement between provincial and federal agencies with respect to the intent and implications of the Standards
    - develop understanding of implementation barriers and limitations of the Standards (e.g., To what extent can the Standards impose monitoring of hydropower projects?)

3. Develop a strong business case for monitoring.
    - Past experience indicates that monitoring will only be funded if there is an economic benefit. A business case should be developed, which clearly articulates the benefits and costs of a monitoring program.

4. Complete technical details for monitoring program.
    - The planning and design of a monitoring program is a technically complex exercise that requires experience in experimental design.
    - The methods for conducting the monitoring program should be clearly explained as part of the proposed Methodology Guidebook.

5. Peer review of finalized Standards.
    - To be effective the Standards should be peer reviewed by a technical expert that has not been involved in their development. An independent review will make the Standards more rigorous, and defensible in the face of potential criticisms from industry and non-governmental organizations.

6. Solicit input from regional staff, industry, etc.
    - The Standards will need to be implemented by MWLAP and MSRM staff in regional offices throughout the province, and will also need to be understood be regional staff of DFO. Prior to finalizing the Standards, these practitioners should be consulted for their input. Consideration should also be given to allowing other groups (e.g., industry and non-governmental organizations) to review and provide input to the Standards.

7. Develop methods for base information and detailed studies.
    - The Standards require that water license applications include baseline hydrologic and biological information that is collected, calculated, and presented in a consistent manner, and signed off by a certified professional. The methods for collecting, calculating, and presenting this information should be clearly explained in the proposed Methodology Guidebook.
    - The Standards will likely flag a substantial portion of projects as requiring additional study. The methods for these additional studies should be clearly explained in the proposed Methodology Guidebook.

8. Develop a strategy for applying the Standards to consumptive uses.
    - The catalyst for the Standards has been a backlog of applications associated with small hydropower, although it has been recognized that the Standards will also be useful for gauging the effects of consumptive uses (e.g., irrigation, drinking water, industrial uses, etc.).
    - Phase two of the project should consider how regulatory agencies can utilize the Standards to assess the cumulative effects of consumptive uses. This process may require a different implementation approach than that proposed for small hydropower.

9. Beta test the standards by post hoc assessment of existing small hydropower projects.
    - To understand the implications of the Standards, they should be used in a mock review of existing small hydropower projects.

9 REFERENCES

Anon. 1998. Water Use Planning Guidelines. Province of British Columbia, Victoria.

Beecher, H. A. 1990. Standards for instream flows. Rivers 1:97-109.

Binns, N.A. and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society. 108: 215-228.

Bovee, K. D., B. L. Lamb, J. M. Bartholow, C. B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. Biological Resources Division Information and Technology Report United States Geological Survey, Fort Collins, Colorado, USA.

Bradford, M. J. and J. R. Irvine. 2000. Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon. Canadian Journal of Fisheries and Aquatic Sciences 57: 13-16.

Bruce, J., and T. Hatfield. 2002. Predicting salmonid habitat-flow relationships for streams from western North America. II. Prediction of whole curves. unpublished manuscript.

Castleberry, D. T., J. J. J. Cech, D. C. Erman, D. Hankin, M. Healey, G. M. Kondolf, M. Mangel, M. Mohr, P. B. Moyle, J. Nielsen, T. P. Speed, and J. G. Williams. 1996. Uncertainty and instream flow standards. Fisheries 21(8):20-21.

Cedarholm, C. J., D. H. Johnson, R. E. Bilby, L. G. Dominguez, A. M. Garrett, W. H. Graeber, E. L. Greda, M. D. Kunze, B. G. Marcot, J. F. Palmisano, R. W. Plotnikoff, W. G. Pearcy, C. A. Simenstad, and P. C. Trotter. 2000. Pacific salmon and wildlife – ecological contexts, relationships, and implications for management. Special edition technical report, Washington Department of Fish and Wildlife, Olympia.

Cedarholm, C. J., M. D. Kunze, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24(10): 6 – 15.

EA Engineering Science and Technology. 1986. Instream flow methodologies. Electric Power Research Institute, Palo Alto, California, USA.

Estes, C.C. 1995. Annual Summary of Alaska Department of Fish and Game Instream Flow Reservation Applications. Alaska Department of Fish and Game, Fishery Data Series No. 95-39, Anchorage, Alaska. 63 pp.

Fisheries and Oceans Canada. 1986. Policy for the management of fish habitat. Fish Habitat Management Branch, Department of Fisheries and Oceans, Ottawa, Canada.

Fisheries and Oceans Canada. 1995. Fish habitat and conservation protection guidelines for attaining no net loss. Fisheries and Oceans Canada, Ottawa, Canada.

Fisheries and Oceans Canada. 1998. Decision framework for the determination and authorization of harmful alteration, disruption or destruction of fish habitat. Minister of Public Works and Government Services Canada.

Fisheries and Oceans Canada. 1998. Habitat Conservation and Protection Guidelines. Minister of Public Works and Government Services Canada.

Hamilton, R. 1996. Review of methodologies for the determination of instream flows for fish. prepared for Department of Fisheries and Oceans, and British Columbia Ministry of Environment, Lands and Parks.

Hatfield, T., and J. Bruce. 2000. Predicting salmonid habitat-flow relationships for streams from western North America. North American Journal of Fisheries Management 20:1005-1015.

Higgins, P.S. 1999. Using Adaptive Management approaches for instream flow assessment of water use planning in British Columbia. Report prepared for water use planning fisheries advisory team, Discussion paper, September 1999.

Hilborn, R., and M. Mangel. 1997. The ecological detective. Confronting models with data. Monographs in population biology. Volume 28. Princeton University Press, Princeton.

Hubert, W. A., C. Raley, and S. H. Anderson. 1990. Compliance with instream flow agreements in Colorado, Montana, and Wyoming. Fisheries 15(2):8-10.

Jowett, I. G. 1997. Instream flow methods: a comparison of approaches. Regulated Rivers: Research and Management 13:115-127.

Lee, K. N. 1993. Compass and gyroscope. Integrating science and politics for the environment. Island Press, Washington, D.C.

Ligon, F. K., W. E. Dietrich, and W. J. Trush. 1995. Downstream ecological effects of dams. A geomorphic perspective. BioScience 45:183-192.

Locke, A. 1999. The Tessman calculation in Alberta. Alberta Environmental Protection document.

Ludwig, D., R. Hilborn, and C. J. Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science 260:17,36.

Mathur, D., W. H. Bason, E. J. Purdy Jr. and C. A. Silver. 1985. A critique of the Instream Flow Incremental Methodology. Canadian Journal of Fisheries and Aquatic Sciences. 42: 825-831.

Obedkoff, W. 1998. Streamflow in the Southern Interior Region. British Columbia Ministry of Environment, Lands and Parks. Victoria, British Columbia.

Obedkoff, W. 1999. Streamflow in the Cariboo Region. British Columbia Ministry of Environment, Lands and Parks. Victoria, British Columbia.

Obedkoff, W. 2000. Interior community watershed streamflow inventory. British Columbia Ministry of Environment, Lands and Parks. Victoria, British Columbia.

Obedkoff, W. 2001. Streamflow in the Skeena Region. British Columbia Ministry of Environment, Lands and Parks. Victoria, British Columbia.

Pyper, B. J. and R. M. Peterman. 1999. Relationship among adult body length, abundance, and ocean temperature for British Columbia and Alaska sockeye salmon (Oncorhynchus nerka), 1967-1997. Canadian Journal of Fisheries and Aquatic Sciences 56: 1716-1720.

Reiser, D. W., T. A. Wesche, and C. Estes. 1989. Status of instream flow legislation and practices in North America. Fisheries 14(2):22-29.

Rushton, C. D. 2000. Instream flows in Washington State past, present, and future. Department of Ecology, Olympia, Washington.

Sawada, J., J. Korman, and C. Walters. 2002. Large rivers assessment methods review. Workshop document. prepared for British Columbia Ministry of Water, Land, and Air Protection.

Scott, D. and C. S. Shirvell. 1987. A critique of the instream flow incremental methodology and observations on flow determination in New Zealand. Pages 27-43 In: J. F. Craig and J. R. Kemper (editors), Regulated Streams Advances in Ecology. Plenum Press, New York, New York, USA.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bulletin of the Fisheries Research Board of Canada 184.

Sherwood, G. D., J. B. Rasmussen, D. J. Rowan, J. Brodeur, and A. Hontela. 2000. Bioenergetic costs of heavy metal exposure in yellow perch (*Perca flavescens*): in situ estimates with a radiotracer (^{137}Cs) technique. Canadian Journal of Fisheries and Aquatic Sciences 57: 441-450.

Slaney, P. A. and A. D. Martin. 1997. The Watershed Restoration Program of British Columbia: Accelerating natural recovery processes. Water Quality Research Journal of Canada 32: 325-346.

Smith, B. D. and B. R. Ward. 2000. Trends in wild adult steelhead (*Oncorhynchus mykiss*) abundance for coastal regions of British Columbia support the variable marine survival hypothesis. Canadian Journal of Fisheries and Aquatic Sciences 57: 271 – 284.

Steele, R. J., and K. E. Smokorowski. 2000. Review of literature related to the downstream ecological effects of hydroelectric power generation. Canadian Technical Report of Fisheries and Aquatic Sciences 2334.

Summit Environmental Consultants. 1998. Technical guidebook to a process for instream flow assessment in British Columbia. prepared for British Columbia Ministry of Environment, Lands, and Parks, and Fisheries and Oceans Canada.

Swift, C.H. III. 1976. Estimation of Stream Discharges Preferred by Steelhead Trout for Spawning and Rearing in Western Washington. USGS Open-file Report 75-155. Prepared in cooperation with the State of Washington Department of Game. 50 pp.; illus.

Swift, C.H. III. 1979. Preferred Stream Discharges for Salmon Spawning and Rearing in Washington. USGS Open-file Report 77-422. Prepared in cooperation with the State of Washington Department of Fisheries. 51 pp.; Illus.

Tennant, D. L. 1976. Instream flow regimens for fish, wildlife, recreation and related environmental resources. Pages 359-373 *in* J. F. Orsborn and C. H. Allman, editors. Proceedings of the symposium and specialty conference on instream flow needs. Volume 11. American Fisheries Society, Bethesda.

Tessman, S.A. 1980. Environmental Assessment. Technical Appendix E in: Reconnaissance elements - western Dakotas regions of South Dakota study. Water Resources Research Institute, South Dakota State University.

Walters, C. and B. Ward. 1998. Is solar radiation responsible for declines in marine survival rates of anadromous salmonids that rear in small streams? Canadian Journal of Fisheries and Aquatic Sciences 55: 2533-2538.

Walters, C. J. 1986. Adaptive management of renewable resources. Macmillan Publishing Company, New York.

Walters, C.J., J.S. Collie, and T. Webb. 1989. Experimental designs for estimating transient responses to habitat alteration: Is it practical to control for environmental interactions?, p. 13-20. *In* C.D. Levings, L.B. Holtby, and M.A. Henderson [ed.] Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Canadian Special Publication of Fisheries and Aquatic Sciences 105.

Welch, D. W., Y. Ishida, and K. Nagasawa. 1998. Thermal limits and ocean migrations of sockeye salmon (*Oncorhynchus nerka*): long-term consequences of global warming. Canadian Journal of Fisheries and Aquatic Sciences 55: 937-948.

Williams, J. G. 1996. Lost in space: minimum confidence intervals for idealized PHABSIM studies. Transactions of the American Fisheries Society. 125: 458-465.

Appendix A

Examples of Ptolemy's Criteria
applied to British Columbia streams

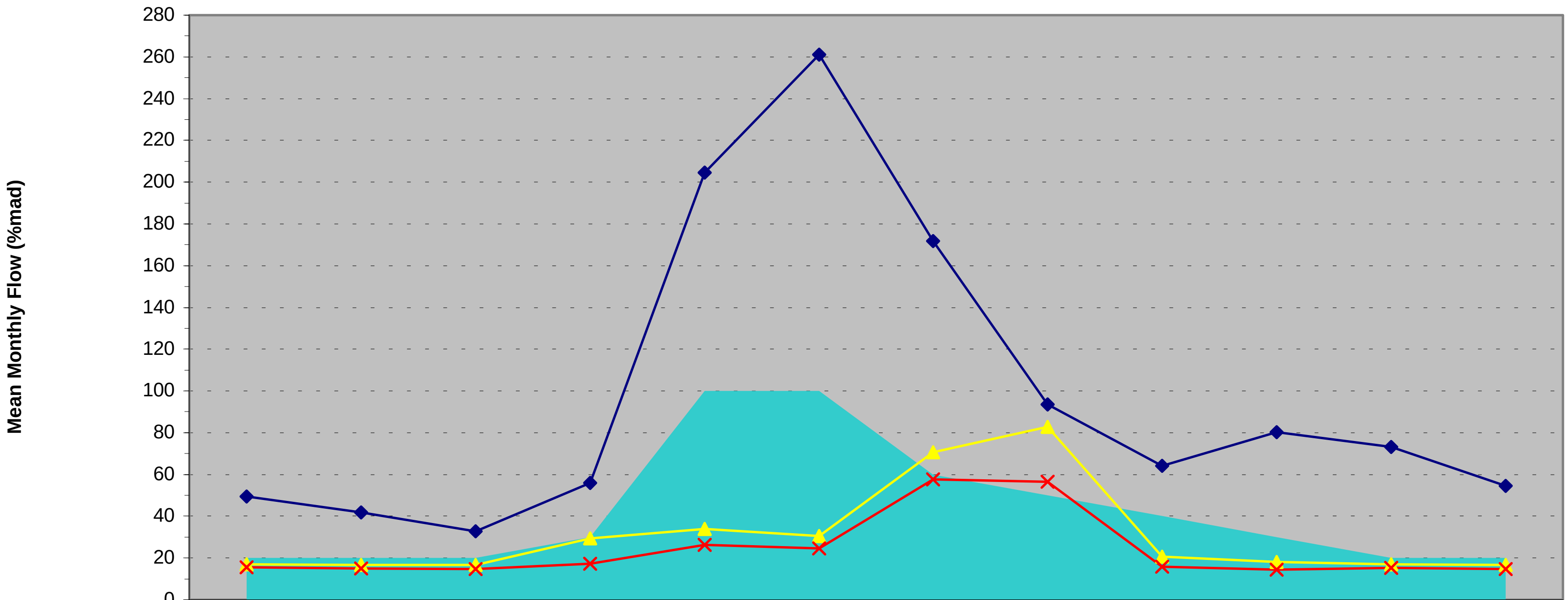
NECHAKO RIVER

Fish periodicity chart for Nechako River below Cheslatta Falls, British Columbia

Nechako River Naturalized Mean Annual Discharge (mad in cms) = 198 cms at WSC Station 08JA017 DA = 15,600 km2; WY = 1.2692 cms per 100 sq.km.

Species/Issues	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Flow Standard (%mad)	Notes
Resident Rainbow Trout														
Adult passage				xx	**xxxx**	**xxxx**							100; sustained for days-weeks for tributary access in synch with high flows in tribs	
Spawning					**xxxx**	**xxxx**							100; sustained for days-weeks	Must be in synch with high flows in tributaries
Incubation						xxxx	xxxx	xxxx					20 in tributaries	
Rearing (juveniles only)					xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			20	
Rearing (adults only)					xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			55; 184 days where temps>7 degrees C	
Over-wintering	xxxx	xxxx	xxxx	xxxx							xxxx	xxxx	20	
														Short-term maintenance flow of 10%mad or 19.8 cms for 7-days
Ecological Needs														
Wetland/trib linkage					**xxxx**	**xxxx**	**xx**						100	
Flushing						**xxxx**							>200 for several days on alternative years	Geo.Mean (1915-1952) = 440 cms or 222%mad
Short-term (days to a few weeks) maintainance	xxxx	xxxx	xxxx	xxxx							xxxx	xxxx	10	
Hydrology														
Naturalized Mean Monthly Flow (%mad)	49	42	33	56	205	261	172	93	64	80	73	55	Based on Inflow data from 1960-1995; DA = 14,132 km2	
Conservation Flow (%mad): PRELIMINARY	**20**	**20**	**20**	**30**	**100**	**100**	**60**	**50**	**40**	**30**	**20**	**20**	Highest per event in month	
Present Flows (%mad)	**17**	**17**	**17**	**29**	**34**	**30**	**71**	**83**	**21**	**18**	**17**	**17**		
Present Flows (cms)	**34**	**33**	**33**	**58**	**67**	**60**	**140**	**164**	**41**	**36**	**33**	**33**	Regulated mad = 62 cms; equivalent to 31% Inflow	
Extreme Min Monthly Flow (cms)	30.7	30	28.9	34.3	52.0	48.7	114	112	32	29	30	29		
Extreme Min Monthly Flow (%mad)	16	15	15	17	26	25	58	57	16	15	15	15		
Naturalized Mean Monthly Flow (cms)	98	83	65	111	405	517	340	185	127	159	145	108		
Conservation flow (cms)	40	40	40	59	198	198	119	99	79	59	40	40	Mean Annual = 92 cms or 46%Natural Inflow	
Alcan Flows for Fish (cms)	10.6	10.6	10.6	28	30	30	?	?	24	10.6	10.6	10.6	?includes variable "cooling" flow releases	
White Sturgeon														
Adult passage				**xx**	**xxxx**	**xxxx**	**xxxx**						100	
Adult migration (feeding/over-wintering)				xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			30	
Spawning						**xx**	**xxxx**						100	
Incubation							**xxxx**	**xxxx**	**xxxx**				20	
Rearing					xxxx	**xxxx**	**xxxx**	**xxxx**	xxxx	xxxx			20-100; Access to sidechannels is an issue	
Juvenile migration				xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx		20	
Over-wintering	xxxx	xxxx	xxxx	xxxx							xxxx	xxxx	20	
Chinook Salmon														
Adult passage							xxxx	**xxxx**						
Spawning									**xxxx**				22	
Incubation	xxxx	xxxx	xxxx						xxxx	xxxx	xxxx	xxxx	20	
Rearing				xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			20	
Wetland/side-channel refuge					**xxxx**	**xxxx**	**xxxx**						100	
Smolt outmigration					xxxx	xxxx							50	
Over-wintering	xxxx	xxxx	xxxx	xxxx							xxxx	xxxx	20	
Sockeye Salmon														
Adult passage							xxxx	xxxx						
Spawning in Stewart River														
Smolt outmigration				xxxx	xxxx	xxxx								
Bull Tout (char)														
Adult passage									**xxxx**	**xxxx**			40-80	
Spawning (in tribs)										xxxx	xxxx		N/A	
Incubation	xxxx	xxxx	xxxx								xxxx	xxxx	N/A	
Rearing (adult and juvenile)				xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx		55	

Annual hydrograph for Nechako River below Cheslatta Falls (WSC Station 08JA017), British Columbia. Naturalized mean annual discharge = 198 cms or 7,000 cfs. Present extreme lows and mean over-layed.



	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Consvr Q	20	20	20	30	100	100	60	50	40	30	20	20
Extr Low	16	15	15	17	26	25	58	57	16	15	15	15
Present Q	17	17	17	29	34	30	71	83	21	18	17	17
Nat Q	49	42	33	56	205	261	172	93	64	80	73	55

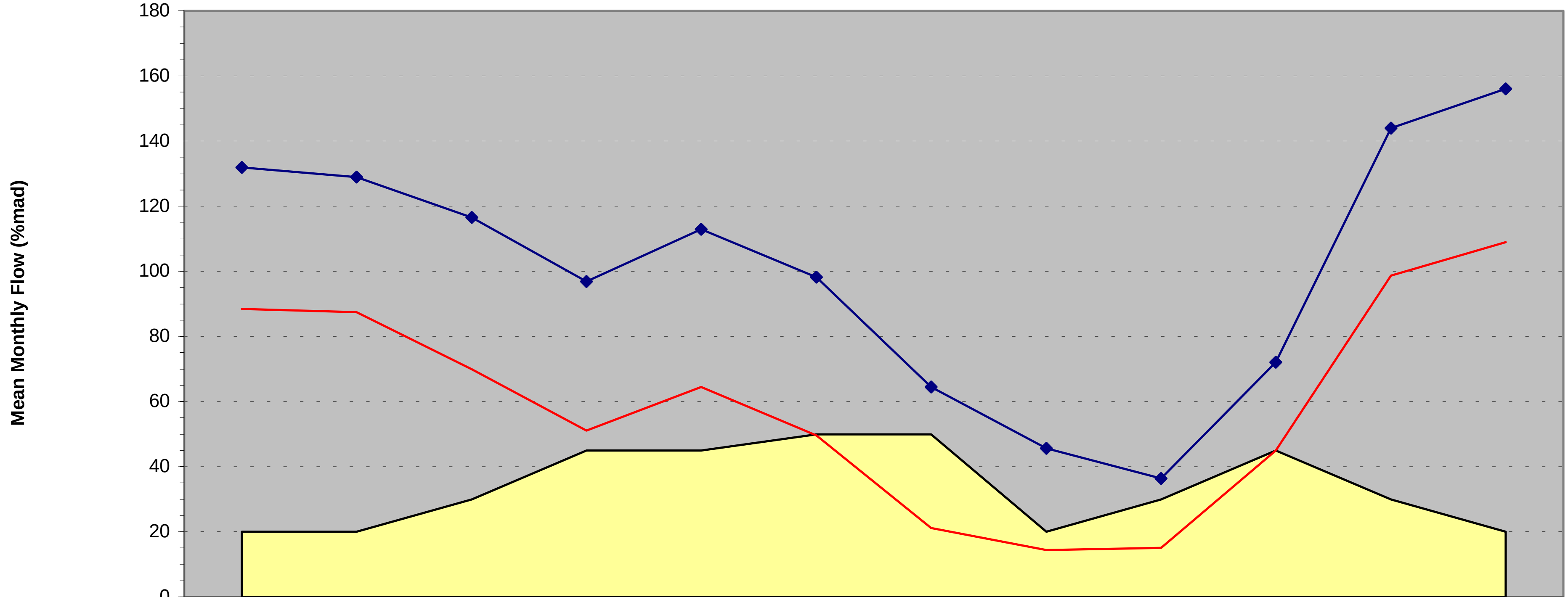
ASH RIVER

Draft Fish periodicity chart for Ash River below Moran Creek, Vancouver Island, British Columbia

Ash River Naturalized Mean Annual Discharge (mad in cms) = 27.8 cms at WSC Station 08MB023 (Port Alberni)

Species	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Flow Standard (%mad)
Steelhead													
Smolt passage				xxxx	xxxx	xx							45 for days
Winter Adult passage		xxxx	xxxx	xxxx									45 for days
Summer Adult passage							xxxx	xxxx	xxxx	xxxx			50-100 for several days
Spawning	xxxx	xxxx	xxxx	xxxx									45 for weeks
Incubation	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx							20
Rearing				xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			20; 188 days where temps>7 degrees C
Over-wintering	xxxx	xxxx	xxxx	xx							xxxx	xxxx	20
Ecological Needs													
Flushing	xxxx	xxxx	xxxx								xxxx	xxxx	>>400 for several days on alternative yea
Wetland/trib linkage	xxxx	xxxx	xxxx								xxxx	xxxx	100
Angling Season	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	30-100
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Nat Mean Monthly Flow (9	132	129	117	97	113	98	65	46	36	72	144	156	
Conservation Flow (	**20**	**20**	**30**	**45**	**45**	**50**	**50**	**20**	**30**	**45**	**30**	**20**	**Highest per event in month**
Present Flows (%ma	**88.5**	**87.4**	**70.0**	**51.0**	**64.4**	**49.6**	**21.2**	**14.4**	**15.1**	**45.0**	**98.6**	**109.0**	
Chinook Salmon (SEDS)													
Smolt passage				xx	xxxx	xxxx	xxxx						
Adult passage								xx	xxxx	xxxx			
Spawning									xxxx	xxxx			
Incubation	xxxx	xxxx	xxxx	xx					xxxx	xxxx	xxxx	xxxx	
Rearing				xx	xxxx	xxxx	xxxx						
Coho Salmon (primary use of smaller tributaries such as Wolf, Lanterman)													
Adult passage								x	xxxx	xxxx	xxxx	xxxx	
Spawning										xx	xxxx	xxxx	
Incubation	xxxx	xxxx	xx							xx	xxxx	xxxx	
Rearing				xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			
Smolt migration				xx	xxxx	xxx							
Over-wintering	xxxx	xxxx	xxxx	xx						xx	xxxx	xxxx	
Adult passage (general)		**45%mad or 12.5 cms for Days**											
Summer Steelhead passage		**50-100%mad or up to 27.8 cms for Days**											
Spawning		**45%mad or 12.5 cms for Days-Weeks**											
Incubation		**20%mad or 5.5 cms for months**											
Rearing		**20%mad or 5.5 cms for months**											
Over-wintering		**20%mad or 5.5 cms for months**											
Smolt Migration		**45%mad or 12.5 cms for Weeks**											
Short-term Maintenance		**10%mad or 2.8 cms for Days to a Week**											
Note: Drivers are highlighted in Yellow													
A driver is an activity that demands a greater flow than other fish/stream events													

Annual hydrograph for the Ash River below Moran Creek (WSC Station 08HB023), British Columbia. Naturalized mean annual discharge = 27.8 cms or 982 cfs. Regulated since 1958.



	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Consvr Q	20	20	30	45	45	50	50	20	30	45	30	20
Present Q	88.5	87.4	70.0	51.0	64.4	49.6	21.2	14.4	15.1	45.0	98.6	109.0
Nat Q	132	129	117	97	113	98	65	46	36	72	144	156

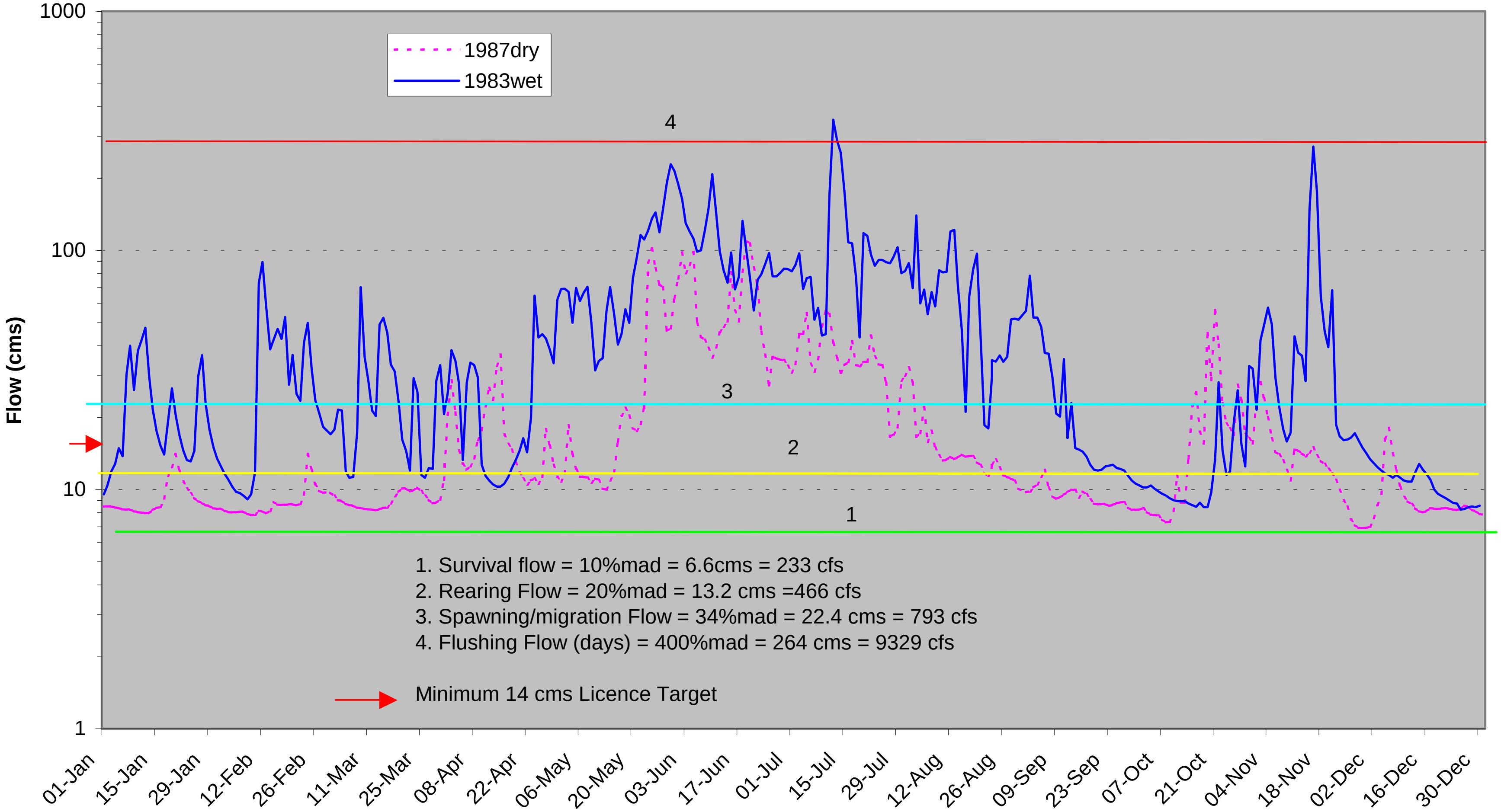
CHEAKAMUS RIVER

Fish periodicity chart for Cheakamus River, Brackendale, British Columbia

Cheakamus River Naturalized Mean Annual Discharge (mad in cms) = 66 cms at WSC Station 08GA043

Species/Event	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Nominal Flow Standard (%mad)
Ecological													
Flushing											xxxx	xxxx	>400 for several days on alternative years
Icing	xxxx	xxxx										xxxx	refer to daily flow/ice records such as 1990
Wetland/trib/sidechannel linkage					xxxx	xxxx	xx						100
Steelhead													
Smolt passage				xx	xxxx	xx							34; Keogh , Little Campbell and Quinsam timing
Adult passage	x	xxxx	xxxx	xxxx	xxxx								34
Spawning				xxxx	xxxx	xxx							34; start at 5 C
Incubation				xx	xxxx	xxxx	xxx						20
Rearing				x	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			20; days where temps>7 degrees C
Over-wintering	xxxx	xxxx	xxxx	xxx							xxxx	xxxx	20
Angling Season	xxxx	xxxx	xxxx	xxxx	xxxx	x						xxxx	30-100
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Naturalized Mean Monthly Flow (%mad)	45	46	36	68	152	205	193	132	102	100	81	63	
Conservation Flow (%mad): PRELIMINARY	**20**	**27**	**34**	**34**	**67**	**100**	**67**	**34**	**34**	**34**	**34**	**20**	**Highest per event in month**
Mean regulated flows (%mad) prior to 45%Rule	**28**	**28**	**24**	**25**	**54**	**124**	**100**	**48**	**29**	**38**	**40**	**33**	
45%Rule	20	21	16	31	68	92	87	59	46	45	37	28	
Regulated Extreme Min Monthly Flow prior to 45%Rule	11	13	14	16	19	48	23	22	14	15	20	13	
Conservation Flow (cms)	13	18	22	22	44	66	44	22	22	22	22	13	
Steelhead Harvest (#sampled) 1977-78	1	2	24	12	4	1							March 1978 mean flow = 17.6 cms
Steelhead Harvest (#sampled) 1978-79	0	9	22	12	18	0							March 1979 mean flow = 18.9 cms; Apr = 13.1; May = 24.6
Conservation Flow (cfs)	466	630	793	793	1562	2332	1562	793	793	793	793	466	
Chinook Salmon													
Migrant-Smolt passage			xxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			
Adult passage						xx	xxxx	xxxx	xxxx	xx			
Spawning							xxxx	xxxx	xxxx	xx			
Incubation									xxxx	xxxx	xxxx		90 days if mean temp = 5 C
Rearing		xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			
Over-wintering	xxxx	xx									xxxx	xxxx	
Chum Salmon													
Adult passage									xx	xxxx	xxxx	xxxx	
Spawning	x									xxxx	xxxx	xxxx	
Incubation	xxxx	xxxx									xxxx	xxxx	117 days at 4.0 C; dewatered redss on Dec.6/92 at flows of 11.1 cms or 17%mad
Fry immigration			xxxx	xxxx	xx								
Pink Salmon													
Adult passage								xxxx	xxxx	xxxx			
Spawning								xx	xxxx	xxxx			
Incubation	xxxx	xx							xx	xxxx	xxxx	xxxx	
Fry immigration		xx	xxxx	xx									
Coho Salmon													
Adult passage	xxxx							x	xxxx	xxxx	xxxx	xxxx	
Spawning	xxxx	x								xxxx	xxxx	xxxx	mainly in side-channels and tributaries
Incubation	xxxx	xxxx	xxxx	xxx							xx	xxxx	
Rearing					xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			
Smolt migration				xx	xxxx	xxxx	x						
Over-wintering	xxxx	xxxx	xxxx	xxxx							xxxx	xxxx	
Resident Rainbow Trout													
Adult passage into tributaries				xxxx	xxxx	xxxx							
Spawning					xxxx	xxxx							
Incubation						xxxx	xxxx	xxxx					
Rearing					xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx		
Over-wintering	xxxx	xxxx	xxxx	xxxx							xxxx	xxxx	
Angling conditions							xxxx	xxxx	xxxx	xxxx			

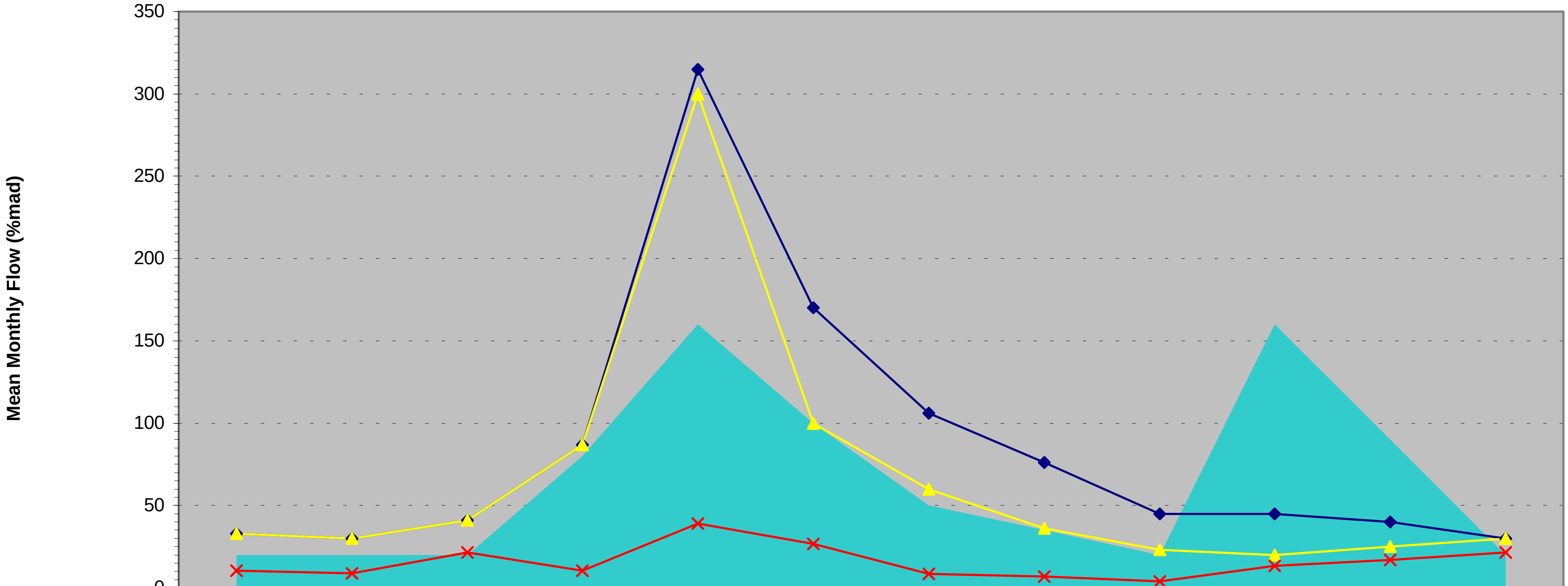
Daily flows recorded in a "wet" and "dry" year near Brackendale (WSC Station08GA043) in the Cheakamus River. Naturalized mean annual discharge = 66 cms. Four key flow levels illustrated on log10 scale.



SINMAX CREEK

Fish periodicity chart for Sinmax Creek, Adams River watershed, British Columbia														
Sinmax Creek Naturalized Mean Annual Discharge (mad in L/s) = 780 at WSC Station 0LD004 (d/s Johnson Creek); DA = 130 km2; catchment area at mouth is 169 km2 and mad = 1022 L/s.														
Species	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Flow Standard (%mad)**	**Notes**
Rainbow Trout														
Migrant passage				xx	xxxx	xx							50	
Adult passage				**xx**	**xxxx**	**xx**							160	
Spawning					xxxx								160	
Incubation						xxxx	xx						20	
Rearing (juveniles only)					xxxx	xxxx	xxxx	xxxx	xxxx	xx			20; 167 days where temps>7 degrees C	CPSF(regulated) = 148 L/s or 19%mad (14 years records)
Rearing (adults)					xxxx	xxxx	xxxx	xxxx	xxxx	xx			50 (Binns model);adult stream-resident rainbow numbers assumed to be low	
Over-wintering	xxxx	xxxx	xxxx	xxxx						xx	xxxx	xxxx	20	GeoMean Min daily flow = 66 L/s or 8.5%mad
Ecological Needs														
Wetland/trib linkage				xx	xxxx	xxxx	xx						100	
Flushing					xxxx	xxxx							200-400 for several days on alternative years	
Hydrology														
Naturalized Mean Monthly Flow (%mad)	33	30	41	87	315	170	106	76	45	45	40	30		
Conservation Flow (%mad): PRELIMINARY	**20**	**20**	**20**	**80**	**160**	**100**	**50**	**35**	**20**	**160**	**90**	**20**	Highest per event in month	
Present Flows (%mad)	**33**	**30**	**41**	**87**	**300**	**100**	**60**	**36**	**23**	**20**	**25**	**30**	No continuous monitoring; CPSF <1 cms	
Present Flows (L/s)	**257**	**234**	**320**	**679**	**2340**	**780**	**468**	**281**	**179**	**156**	**195**	**234**		
Extreme Min Monthly Flow (L/s)	80	68	167	80	305	208	66	54	30	103	131	167	Extreme low recorded (1915-90); 1987 summer very dry	
Extreme Min Monthly Flow (%mad)	10	9	21	10	39	27	8	7	4	13	17	21		
Naturalized Mean Monthly Flow (L/s)	257	234	320	679	2457	1326	827	593	351	351	312	234	Sum release in dam3 = 118,541	
Water Use (L/s)	0	0	0	0	117	546	359	312	172	195	117	0		
													mean monthly release over the year	
Conservation Flow (cfs)	6	6	6	22	44	28	14	10	6	44	25	6		
Coho Salmon														
Adult passage										**xx**	xxxx			
Spawning											**xx**xx			
Incubation	xxxx	xxxx	xxxx								xxx	xxxx		
Rearing					xxxx	xxxx	xxxx	xxxx	xxxx	xx				
Smolt migration					xxxx	xxxx								
Over-wintering	xxxx	xxxx	xxxx	xx						xx	xxx	xxxx		
Sockeye Salmon (Jacks)														
Adult passage										xx**xx**				
Spawning										xx	xx			
Incubation	xxxx	xxxx	xxxx								xxxx	xxxx		
Fry Migration to Adams Lake				xxxx										
Kokanee Salmon														
Adult passage										xxxx				
Spawning										xxxx	xxxx		Flow standard for kokanee about 40%mad???	
Incubation	xxxx	xxxx	xxxx								xxxx	xxxx		
Fry Migration to Adams Lake				xxxx										
Bull Trout														
Migrant passage				xxxx	xxxx									
Adult passage										xxxx	xxxx			
Spawning											xxxx	xx		
Incubation	xxxx	xxxx									xxxx	xxxx		
Rearing			xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx			
Over-wintering	xxxx	xxxx										xxxx		

Annual hydrograph for Sinmax Creek below Johnson Creek (WSC Station 08LD004), British Columbia. Naturalized mean annual discharge = 780 L/s or 28 cfs.



	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Consvr Q	20	20	20	80	160	100	50	35	20	160	90	20
Extr Low	10	9	21	10	39	27	8	7	4	13	17	21
Present Q	33	30	41	87	300	100	60	36	23	20	25	30
Nat Q	33	30	41	87	315	170	106	76	45	45	40	30