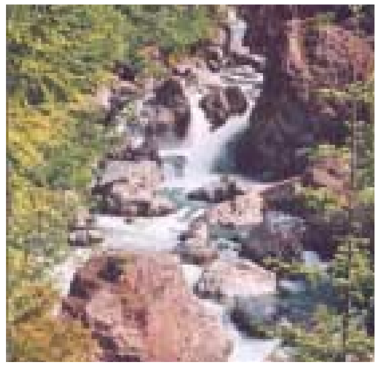
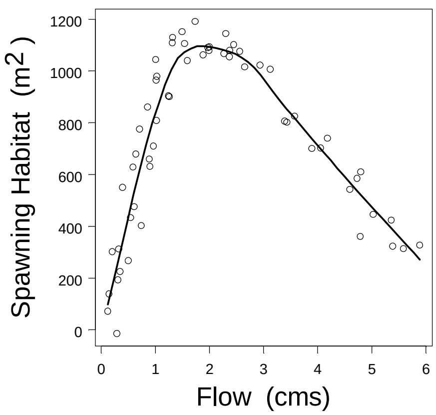
Instream flow thresholds for fish and fish habitat as guidelines for reviewing proposed water uses

SYNOPSIS




January 15, 2004

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1.0 INTRODUCTION

British Columbia has abundant water resources, which sustain productive aquatic ecosystems and many uses by humans (e.g., fishing, power generation, irrigation, drinking water, industrial uses, recreation, etc.). Determining how much water can be extracted from a river without negatively affecting fish and fish habitat is a daunting task, but one that is frequently asked of resource managers. The Ministry of Water, Land and Air Protection (MWLAP), Ministry of Sustainable Resource Management (MSRM), Land and Water BC Inc. (LWBC), and Fisheries and Oceans Canada (DFO) are developing the British Columbia Instream Flow Guidelines for Fish (referred to here as "the Guidelines") to aid in the process of setting instream flows in British Columbia streams. These Guidelines deal specifically with instream flow requirements to support aquatic ecosystem values. They do not address other environmental protection issues related to conserving fish, wildlife or plant communities (e.g., "footprint" impacts, construction impacts, or cumulative effects).

The Guidelines are made up of two main components, Flow Thresholds, and Assessment Methods. The Guidelines support a two-tiered review process for proposed water uses on BC streams (Figure 1). The first tier is a scoping level process that provides thresholds for alterations to natural stream flows that are expected to result in low risk to fish, fish habitat, and productive capacity. These thresholds are meant to act as a "coarse filter" during the review of proposed water uses on BC streams when there is little or no biological or physical data available. Projects that propose to exceed these flow thresholds must collect additional data, which will be reviewed and used during a more detailed project review (the second tier). The Assessment Methods are a set of endorsed techniques for assessing flow alterations on British Columbia streams. The Assessment Methods concentrate on techniques for collecting data used during more intensive project reviews.

This document presents a synopsis of the instream flow thresholds proposed as part of the Review Guidelines. A more detailed analysis (project description and history, literature reviews, data analysis, and performance assessment) is presented in Hatfield et al. (2003). The Assessment Methods are presented in a separate document (Lewis et al. 2003).

1.1 Why are the Flow Thresholds needed?

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

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

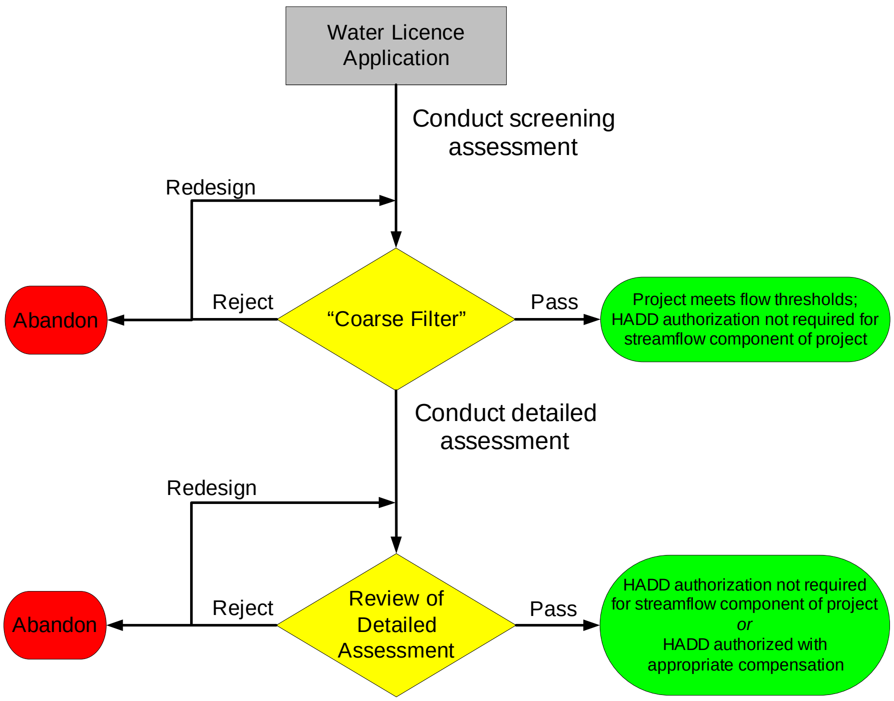

Figure 1. General decision schematic for a two-tiered review process. The "coarse filter" is first applied to a proposed water use. If the coarse filter indicates that fish-flow issues are not a concern the application would be approved subject to review of other fisheries concerns (e.g., intake screening, footprint issues, etc.). If the coarse filter indicated a potential fish-flow concern then the applicant has three options: abandon the project, redesign it to meet the flow thresholds (e.g., alter diversion rates or timing) or collect and present additional information to demonstrate that fish-flow concerns are adequately addressed within the proposed flow regime.

The Guidelines are intended to help in the process of setting instream flows in British Columbia streams. They present a set of seasonally-adjusted thresholds for alterations to natural stream flows. These alterations are expected to result in low risk to fish, fish habitat, and productive capacity. The thresholds are meant to act as a "coarse filter" during the review of proposed water uses – they are a general standard to be used on BC streams when there is little or no biologically relevant data available. The tremendous diversity of biogeoclimatic conditions in British Columbia is not conducive to establishing a single threshold setting method that will work equally well across the landscape. Good quality physical and biological data may indicate that it is safe to undertake water diversions in excess of the thresholds. In the absence of such information however, it cannot be assumed that exceeding the thresholds will be without risk. A conceptual diagram showing a hypothetical threshold relative to natural streamflows is presented in Figure 2. A general schematic of how the thresholds function as part of the review process is laid out in Figure 1. An in depth discussion of the conceptual framework for the thresholds is presented in Section 2.0.

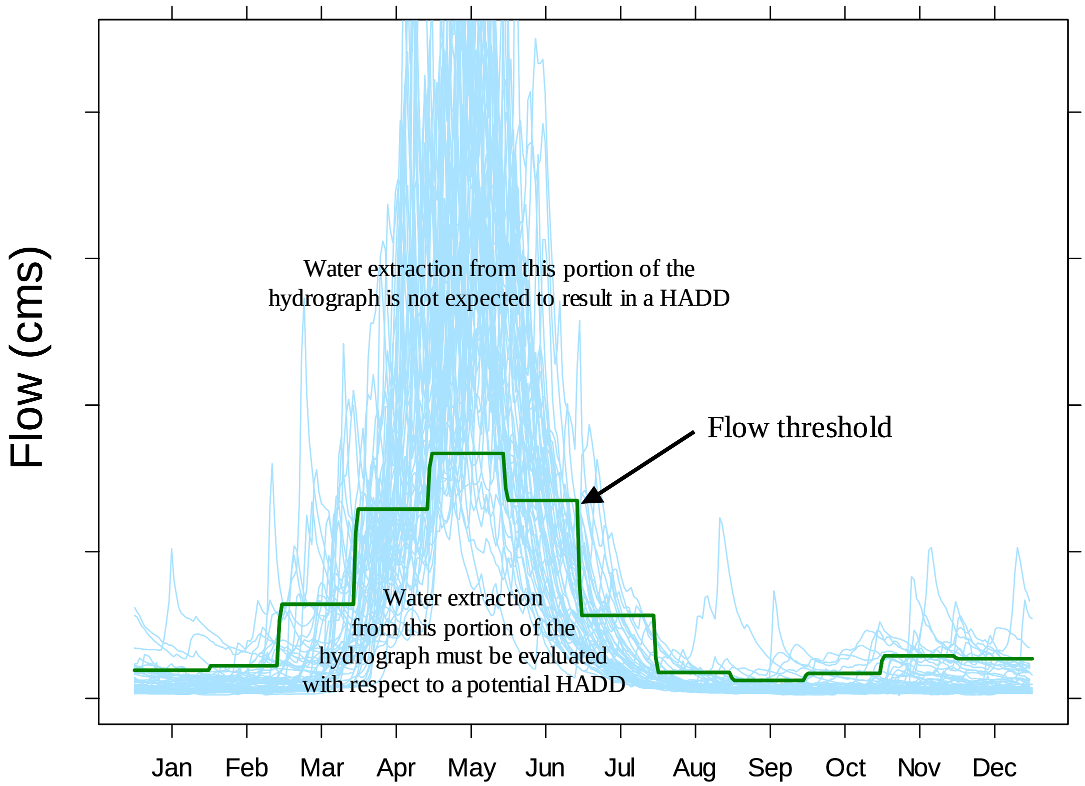

Figure 2. Concept of the flow threshold relative to observed natural streamflows and the streamflow level for Harmful Alteration, Disruption or Destruction (HADD) of fish habitat. In this example, the light blue lines trace mean daily flows with multiple years superimposed, for a hypothetical stream. The green line is the flow threshold proposed in the guidelines. Additional features of the guidelines, such as diversion capacity are discussed in the text. The flow threshold is conservative and represents the flow level to be retained in the stream. Below this threshold there is a reasonable likelihood of flow-related constraints on aquatic productivity and therefore the possibility that a HADD may result. The "true" HADD limit *may* be lower, but in the absence of more information it is not possible to tell whether exceeding the flow threshold will lead to a HADD.

1.2 Where will the Flow Thresholds apply?

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

1.3 Who will use the Flow Thresholds?

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

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

1.4 How have the Flow Thresholds been developed?

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

2.0 OBJECTIVES AND GUIDING PRINCIPLES

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

This objective was met by developing the thresholds under several guiding principles:

1. **Work within existing legal framework.** The guidelines propose no new legislation, regulations, or policies – they are meant to work entirely within the existing legislative and policy framework of the federal and provincial governments and their resource management agencies.

2. **Develop guidelines from the perspective of sustaining the fish resource.** The flow thresholds assess only the needs of fish. Other natural resources (e.g., wildlife) or interests (e.g., public safety) may need to be considered during the development of water licence specifications, but are not specifically addressed with these guidelines.

3. **Minimize review costs.** The guidelines have been developed 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). The benefits of a clear application and review process should accrue to applicants and reviewers.

4. **Maximize consistency and transparency.** Water licence applicants expect a review process to be transparent and applied consistently throughout the province, and by

constructing and adopting the guidelines resource agencies are attempting to provide such a process. The flow thresholds have been designed to be as objective as possible.

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

These principles capture the motivation for the thresholds, the approach and philosophy to setting the thresholds, and their intended benefits.

3.0 RECOMMENDED INSTREAM FLOW THRESHOLDS FOR BRITISH COLUMBIA

3.1 Background

A wide variety of standard-setting techniques were assessed for their acceptability to agencies, and their applicability to BC. The screening of techniques led ultimately to the recommendation to adapt an historic flow method for use as a "coarse filter" for reviewing water licence applications. The proposed thresholds for fishless and fish-bearing streams are described in this section and worked examples are presented in Appendix A and B. Performance of the guidelines was assessed in detail using both quantitative and qualitative measures; detailed results are presented in a companion technical document (Hatfield et al. 2003).

The proposed guidelines are founded on several key assumptions about riverine ecology and hydropower diversion works. These assumptions are discussed in greater detail in Hatfield et al. (2003), but are summarized here.

1. In the absence of biological and physical information it is difficult to predict changes to natural flow patterns that benefit fish. If fish are present in a stream it is because they are able to withstand the flow regime there, or are specifically adapted to it. The most logical strategy therefore is to preserve the key features of its natural hydrograph, which affect fish both directly (e.g., hydraulically suitable habitat) and indirectly (e.g., geomorphology, riparian habitat). This logic is widely supported by the scientific literature.
2. Low flow periods are a common bottleneck to fish production in streams. For example, low flows during summer may limit available rearing habitat, and low flows during winter may limit availability of overwintering habitat and ice-free refuges. These periods should therefore be targeted for the greatest relative level of protection against water abstraction.
3. Flows additional to those during the low flow period may be directly beneficial to fish, but the benefit does not accrue in a linear relationship. For this reason, naturally low flow periods should receive greater protection against water abstraction than naturally high flow periods.

4. High flow events are important for determining stream morphology and sediment dynamics in streams. For this reason, aspects of high flow events should be maintained in a regulated stream.
5. The guidelines rely on flows in excess of the diversion works ("residual flows") to provide geomorphological and ecological benefits. The guidelines are therefore explicit in specifying a maximum diversion rate—maximum diversion capacity is set equivalent to 80th percentile flow over the period of record. This flow is usually substantially greater than MAD.

3.2 Data requirements for calculating the flow thresholds

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

Fish-bearing status. Determining the fish-bearing status of all streams in the project area is perhaps the most basic of biological information needs. In the absence of reliable data these streams will be considered fish-bearing. Appropriate methods for determining fish presence and absence are detailed in the Assessment Methods guidebook. It should be noted that these methods may differ from those used for other industries. For example, since the impact of hydro development is more permanent than that from some other activities, the determination of fish absence must be based on data collected over a suitable period of time and will not rely on proxy measures such as stream gradient or other physical features.

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

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

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

3.3 Recommended flow threshold for fishless streams

The recommended flow threshold for fishless streams is a minimum instream flow release equivalent to the median monthly flow during the low flow month. This value represents the minimum instream flow requirement through the diversion section at all times of the year. The low flow month is defined as the calendar month with the lowest median flow, based on natural mean daily flows.

The flow threshold must be based on data that meet requirements as described in Section 3.2. For example, non-fish bearing status must be demonstrated using techniques as described in the Assessment Methods guidebook, calculations must be based on a minimum of 20 years of continuous natural daily flow records, and maximum diversion rates are less than or equal to the 80th percentile of daily flows over the period of record.

The steps in calculating this flow threshold are as follows:

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

This threshold does not apply where data requirements cannot be met. In such cases, appropriate assessment methodologies must be employed, as detailed in Lewis et al, 2003. Where proponents propose to divert greater amounts of water (either by decreasing the minimum flow requirement or increasing the maximum diversion rate), specific detailed assessments must be undertaken to evaluate the risk to fish and fish habitat (see Assessment Methods).

This flow threshold is intended to maintain connectivity through the diversion section, to maintain invertebrate production (which may, among other values, be a food source for fish-bearing reaches downstream) and to provide occasional high flow events to maintain gross stream morphology. Projects using this guideline should be assessed to ensure these objectives are met. We also recommend that, where synthesized data are used, the diversion rules be annually adjusted during a period of at least five years, based on continuous discharge data collected from a gauge installed on the target stream.

The fishless stream diversion rule can be calculated or approximated with relatively simple data requirements. Where detailed physical and biological information is collected, it may be possible to exceed these diversion rates.

3.4 Rationale for recommended flow threshold for fishless streams

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

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

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

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

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

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

3.5 Recommended flow threshold for fish-bearing streams

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

In addition to the flow thresholds, proponents must also demonstrate that project flows are adequate to support fish during migration and spawning periods. This would typically require investigation of passage over flow-dependent barriers, or provision of pulse flows in rain-dominated systems. These issues are not universal, and are usually very site-specific where they do occur. They are therefore difficult to incorporate into a guideline.

The flow threshold must be based on data that meet requirements as described in Section 3.2. For example, calculations must be based on a minimum of 20 years of continuous natural daily flow records, and maximum diversion rates are less than or equal to the 80^{th} percentile of mean natural daily flows over the period of record.

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

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

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

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

Using this formula the percentile for each month will vary between 20^{th} and 90^{th}.

This flow threshold does not apply where data requirements cannot be met. In such cases, appropriate assessment methodologies must be employed, as detailed in Lewis et al, 2003. Where proponents propose to divert greater amounts of water (either by decreasing the minimum flow requirement or increasing the maximum diversion rate), specific detailed assessments must be undertaken to evaluate the risk to fish and fish habitat (see Assessment Methods).

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

The fish-bearing stream diversion rule allows a substantial volume of water to be diverted, though less than the fishless stream rule. The rule can be calculated or approximated with relatively simple data requirements. Where detailed physical and biological information is collected, it may be possible to exceed these diversion rates.

3.6 Rationale for recommended flow threshold for fish-bearing streams

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

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

The primary regulatory considerations with respect to stream flows and fish have been the Fisheries Act and supporting policies. Of particular importance is the determination of whether an altered flow regime constitutes a harmful alteration, disruption or destruction (HADD) of fish habitat. It is this component of federal policy that is usually used to assess proposed water use projects, yet it is difficult to determine HADD thresholds in relation to flow without the collection of considerable site-specific information.

The “natural flow regime” approach was therefore adopted, which tries to quantitatively describe and then maintain key aspects of the natural hydrograph (Poff et al. 1997; Richter et al. 1996, 1997; Trush et al. 2000) . The approach does not purport to accurately define minimum flow requirements at all times and locations. Instead, it merely implies that predicting the biological response to different types of alteration is difficult, and preserving key aspects of the natural hydrograph is most likely to maintain the physical aspects of streams on which fish and other ecosystem components depend.

The proposed minimum flow threshold of 90th percentile flow during the low flow month is based on the knowledge that this is a frequently observed naturally occurring low flow, and times of low flow are a frequent bottleneck in fish production in streams. Applying this threshold value and allowing extraction of water above this threshold will not exacerbate the low flow issue. When calculated as a monthly percentile flow the threshold will more accurately reflect true low flow values than a percentage of MAD, since it will vary among streams depending on hydrologic region (i.e., hydrograph type). Finally, the guideline assumes that run-of-river water use projects will utilize a maximum diversion rate that is less than or equal to the 80th percentile of daily flows over the period of record. If this assumption is satisfied then flows in excess of this amount will remain in the diversion section of the stream and provide (albeit with lower frequency and duration) physical forces necessary to maintain overall stream morphology, and instream and riparian habitat. **Specifying both a minimum flow to be retained in the stream channel and a maximum diversion amount is an important part of preserving key components of the natural hydrograph.**

4.0 ADDITIONAL CONSIDERATIONS

4.1 Compliance monitoring

Compliance monitoring is fairly straightforward and would simply monitor water use to ensure that a user is complying with the conditions of a water licence. This should be done through installation and maintenance of continuous recording flow gauges for measuring instream flows and diversions. The main benefit of compliance monitoring is to ensure that water use is quantified and recorded, and to assess and encourage compliance. Hubert et al. (1990), noted poor compliance in their study area and make a strong argument for requiring compliance monitoring. Where synthesized flow data are used to set flow thresholds, compliance monitoring will allow the diversion rules to be updated based on empirical continuous discharge data collected directly from the target stream.

In some circumstances, it may be necessary to expand compliance monitoring beyond hydrometric monitoring to include monitoring of water quality, channel morphology, or other physical state conditions. It may also be necessary to include monitoring for habitat compensation works. Monitoring requirements may be specified as part of an authorization to operate.

4.2 Biotic response monitoring

Biotic response monitoring is more difficult and would involve assessing whether compliance with flow decisions results in the expected outcomes on the target ecological resources (i.e., fish populations, fish habitat, invertebrate production, etc.). Biotic response monitoring is often more costly than compliance monitoring, since biological responses are difficult to measure and variable in space and time. The need for monitoring was universally acknowledged during development of these guidelines. A comprehensive monitoring program to evaluate the effectiveness of the guidelines will be considered as an implementation issue by agencies. Such a program requires the development of technical details for biotic response monitoring. Project-specific monitoring requirements may be specified as part of an authorization to operate.

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APPENDIX A. WORKED EXAMPLE OF THE PROPOSED FLOW THRESHOLDS FOR FISHLESS STREAMS -- SARITA RIVER, VANCOUVER ISLAND

This appendix presents an example to demonstrate how the flow thresholds are calculated and applied for fishless streams. The example used is a coastal system (Sarita River, west coast of Vancouver Island). An example for an interior system (Pennask Creek, southern interior, Okanagan) is presented in a separate Appendix. The Sarita River flow record was obtained from the Hydat database maintained by Water Survey Canada. **The Sarita River is fish-bearing, but we apply the fishless flow thresholds to allow a comparison to the fish-bearing stream thresholds** (see subsequent Appendices).

Sarita River

Natural flows

Patterns of natural flow in the Sarita River are shown in Figure 1 and Figure 2. Statistical summaries are presented in Table 1. The Sarita River is characterized by low flows during late summer, and high flow events during rain storms, sometimes in association with spring snowmelt. August is the calendar month with the lowest median flows; the highest flows occur primarily in spring and fall.

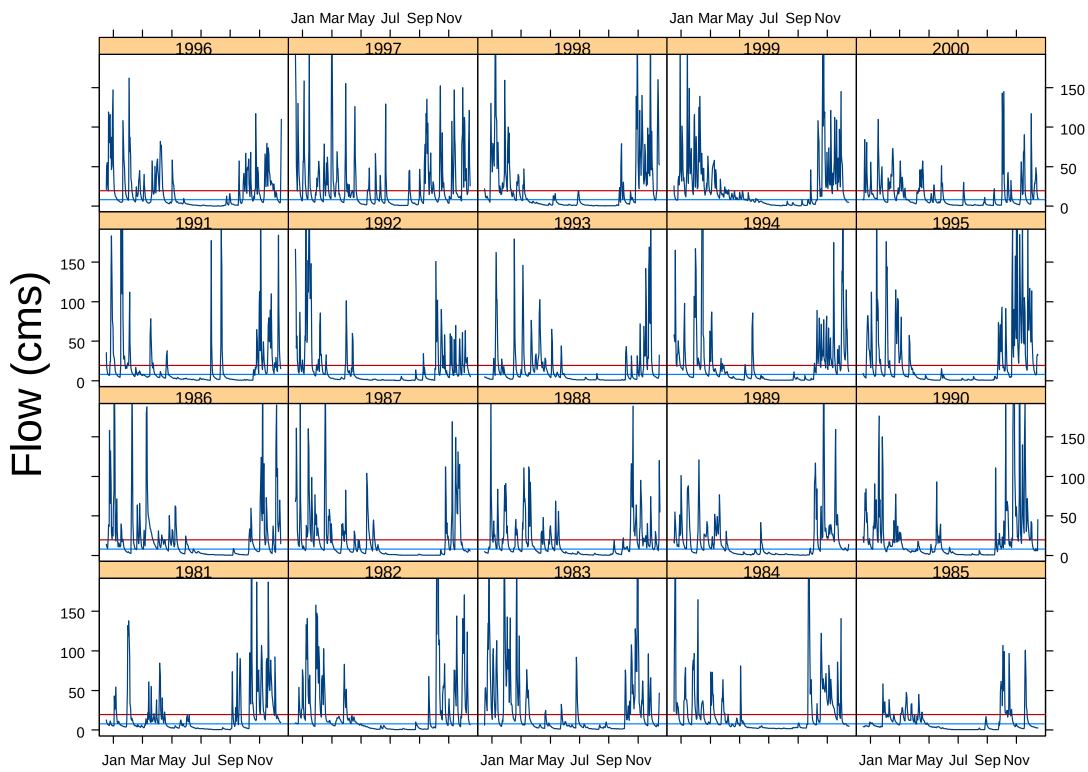

Figure 1. 20 years of mean daily flows for the Sarita River. The y axis is limited to 50% of the maximum mean daily flow on record to enhance resolution for low flow periods. Mean annual discharge is indicated by the horizontal red line; median annual discharge is indicated by the blue horizontal line. These plots allow one to visualize variation in timing, magnitude, and duration of flows from one year to another.

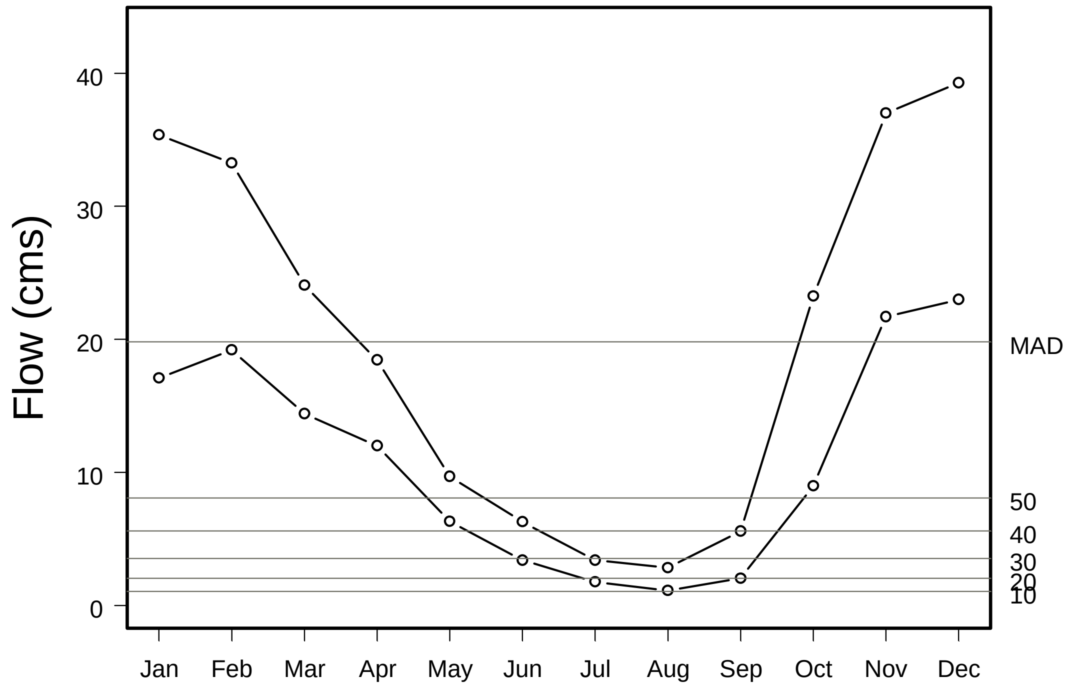

Figure 2. Monthly summaries of mean daily flows for the Sarita River. The upper hydrograph line is based on the mean of mean daily flows; the lower hydrograph line is based on median of mean daily flows. Several horizontal lines are provided for reference: mean annual discharge, and the 10th, 20th, 30th, 40th and 50th percentile of flows over the period of record.

Table 1. Summary statistics for Sarita River broken down by calendar month and over the period of record (PoR).

	mean	median	min	max	10th %ile	20th %ile	30th %ile	40th %ile	50th %ile	60th %ile	70th %ile	80th %ile	90th %ile	month
Jan	35.38	17.1	1.99	677	4.98	7.112	9.4	12.34	17.1	24.5	35.42	51.38	83.62	Jan
Feb	33.26	19.2	1.84	362	5.151	8.016	10.81	15	19.2	23.8	32.18	48.1	82.19	Feb
Mar	24.07	14.4	1.62	318	5.356	7.36	9.29	11.5	14.4	17.96	24.1	34.96	51.88	Mar
Apr	18.44	12	1.47	294	5.01	6.568	8.47	10.1	12	14.7	18	24.32	39.01	Apr
May	9.68	6.31	0.947	126	2.156	3.252	4.206	5.234	6.31	7.84	9.81	12.7	18.6	May
Jun	6.28	3.4	0.637	110	1.178	1.7	2.267	2.79	3.4	4.26	5.49	7.48	12.32	Jun
Jul	3.38	1.76	0.345	129	0.724	0.892	1.15	1.42	1.76	2.18	2.74	3.68	5.65	Jul
Aug	2.82	1.11	0.283	199	0.487	0.643	0.806	0.935	1.11	1.33	1.78	2.35	4.54	Aug
Sep	5.57	2.04	0.307	152	0.591	0.815	1.04	1.456	2.04	2.75	3.96	6.36	11.93	Sep
Oct	23.26	8.98	0.293	595	1.09	2.042	3.62	6.044	8.98	13.3	21.32	34.8	65.1	Oct
Nov	37	21.7	0.682	535	5.349	8.13	11.6	15.9	21.7	28.9	39.3	56.04	84.73	Nov
Dec	39.29	23	1.54	490	6.51	9.062	12.6	17	23	30.6	41.94	59.44	90.24	Dec
PoR	19.8	8.09	0.283	677	1.04	2.04	3.54	5.594	8.09	11.5	17	27.3	51.3	PoR

Threshold calculations for fishless streams

The fishless stream thresholds are determined in four steps.

1. **Determine non-fish bearing status.** Determining the fish-bearing status of all streams in the project area is perhaps the most basic of biological information needs. In the absence of reliable data all streams will be considered fish-bearing. Appropriate

methods for determining fish presence and absence are detailed in the Assessment Methods guidebook (Lewis et al. 2003). We will assume here that non-fish bearing status has been adequately assessed and signed off by a certified professional (e.g., R.P.Bio.).

2. **Obtain 20+ years of daily flow records.** Empirical historic flow records are often not available for streams of interest. We will assume here that a certified professional (e.g., P.Eng.) has developed and certified a high-quality flow record consisting of 20 or more years of mean daily flows. The flow file used here was obtained from Water Survey Canada; there has been no attempt to "naturalize" the flow record to correct for land and water uses. Proponents will, however, need to complete this task.

3. **Calculate maximum diversion rate.** The maximum diversion rate is set at 80th percentile and is a simple calculation based on the entire period of record taken from Step 2. For the Sarita River the 80th percentile is 27.3 cms, as noted in Table 1.

4. **Calculate minimum flow.** The minimum flow threshold is set from a series of steps.
    a. **Calculate median of mean daily flows in each month.** The median of mean daily flows is calculated and tabulated. Monthly medians are indicated in column 3 of Table 1.
    b. **Select minimum from these values.** The minimum monthly value in column 3 of Table 1 is 1.11 cms corresponding to the month of August.
    c. **Set this as an annual minimum flow threshold.** The minimum flow threshold is set to 1.11 cms for all calendar months.

Results

The flow thresholds are indicated in Figure 3. In essence this guideline permits diversion of flows within the band demarcated by the two dark blue lines. Flows below the band are not available for diversion, and would combine with "residual flows" above the band when present. Post-project flows and diversion flows are indicated in Figure 4 and Figure 5. Figure 6 shows the streamflow available for diversion under the fishless and the fish-bearing flow thresholds. Clearly, substantially more water is made available for diversion in fishless streams.

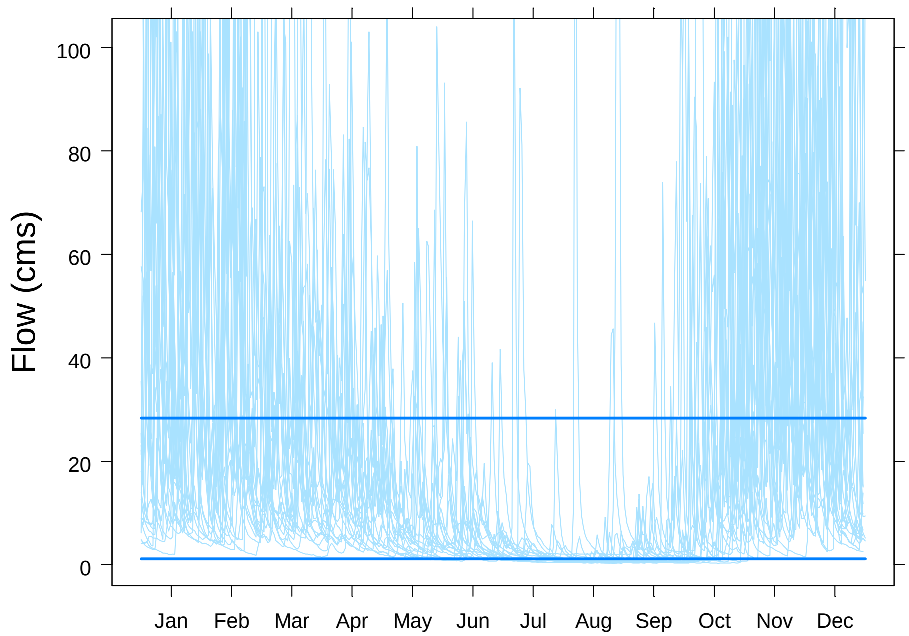

Figure 3. Natural mean daily flows (light blue) for the Sarita River, with flow time series superimposed for each year on record. The dark blue lines show the minimum and maximum diversion thresholds as calculated using the proposed guideline for fishless streams.

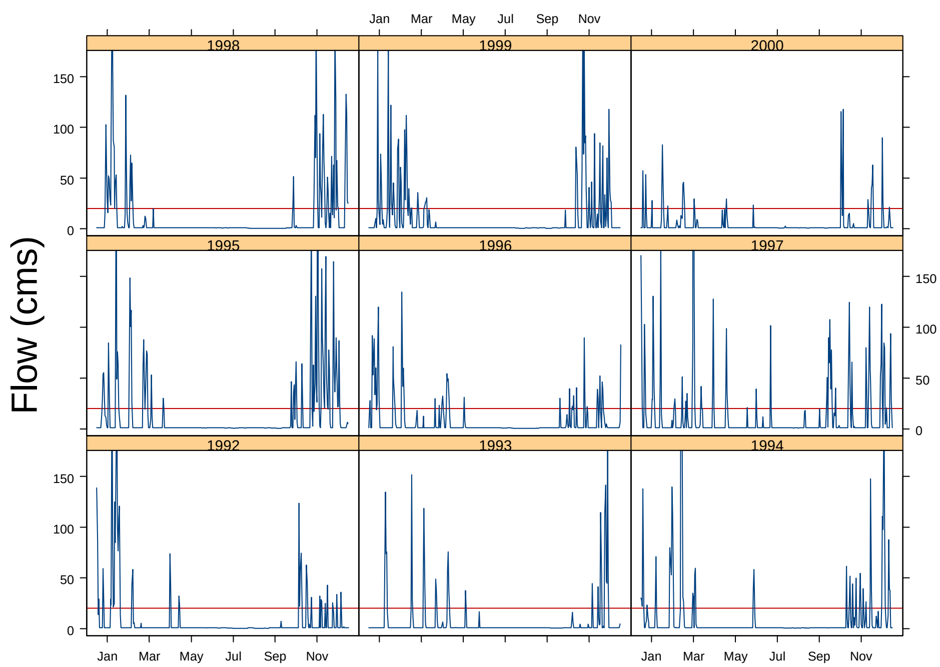

Figure 4. Simulated post-project flows for the Sarita River using the proposed fishless stream diversion thresholds. (Note: the purpose is to understand the effects of the threshold; in reality this stream is fish-bearing.) The y-axis is limited to 50% of the maximum natural mean daily flow on record. The horizontal red line represents natural MAD.

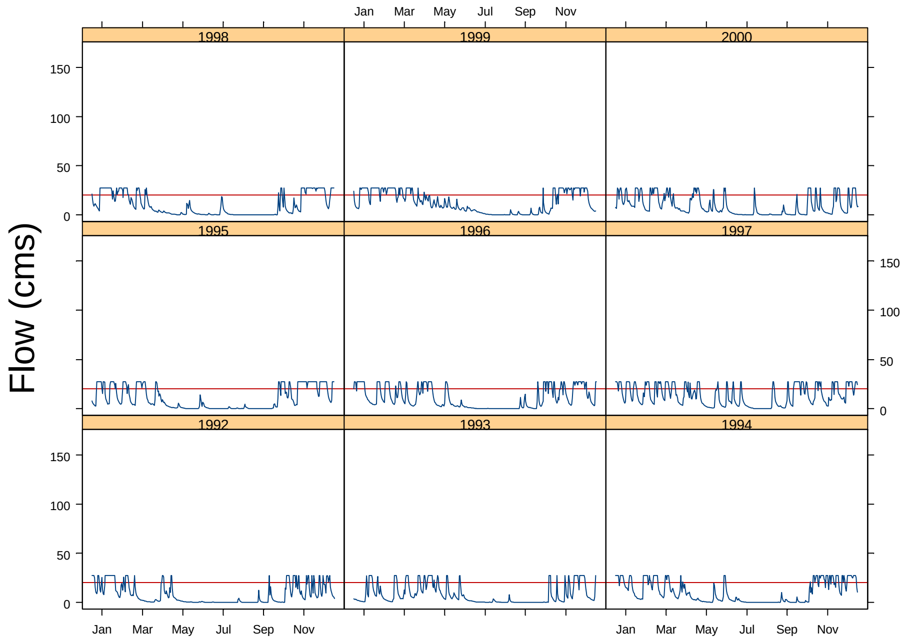

Figure 5. Simulated diversion flows using the proposed fishless stream diversion threshold for the Sarita River. The y-axis is limited to 50% of the maximum natural mean daily flow on record. The horizontal red line indicates natural MAD.

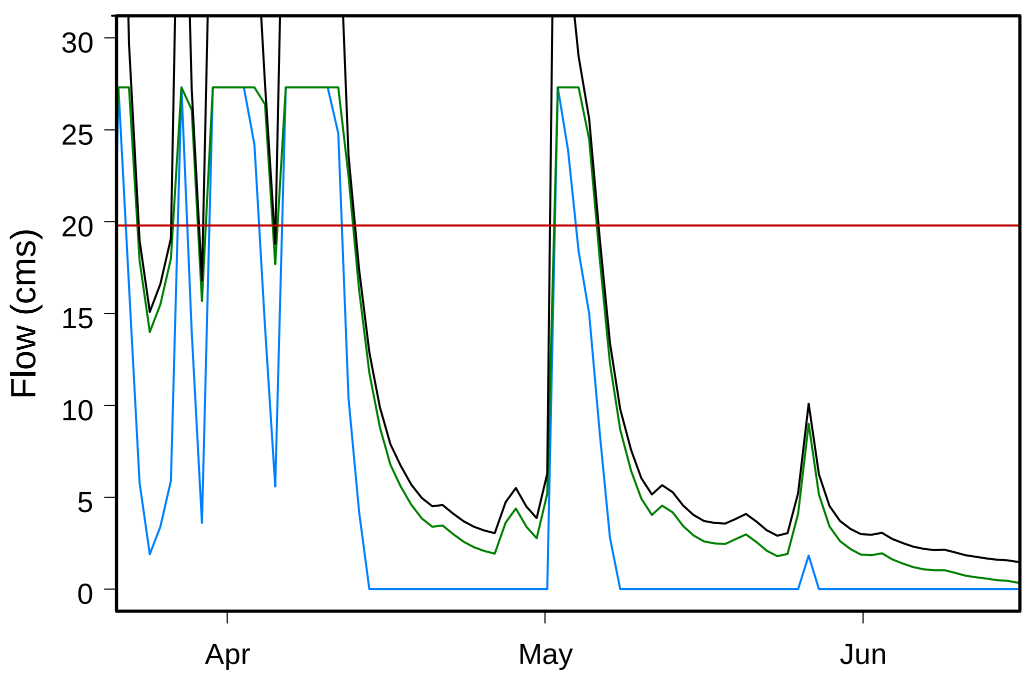

Figure 6. Comparison of total stream flow (black line) during three calendar months in 1996, availability for diversion using the fishless stream flow threshold (green), and availability for diversion using the fish-bearing stream flow threshold (blue). The horizontal red line indicates mean annual discharge. See Appendix C for a worked example of the fish-bearing streamflow thresholds for the Sarita River.

APPENDIX B. WORKED EXAMPLE OF THE PROPOSED FLOW THRESHOLDS FOR FISHLESS STREAMS -- PENNASK CREEK, SOUTHERN INTERIOR

This appendix presents an example to demonstrate how the flow thresholds are calculated and applied for fishless streams. The example used is an interior system (Pennask Creek, southern interior). An example for a coastal system (Sarita River, west coast of Vancouver Island) is presented in a separate Appendix. For the purposes of this exercise we have assumed that surface flows in Pennask Creek are relatively unaffected by water or land uses, so we made no attempt to "naturalize" the records. The flow file used was obtained from Water Survey Canada records. **Pennask Creek is fish-bearing, but we apply the fishless flow thresholds to allow a comparison to the fish-bearing stream thresholds** (see subsequent Appendices).

Pennask Creek

Natural flows

Patterns of natural flow in Pennask Creek are typical of many interior streams, and are shown in Figure 1 and Figure 2. Statistical summaries are presented in Table 1. Pennask Creek is characterized by a prolonged snowmelt freshet in spring, with low flows extending from late summer through winter. January is the calendar month with the lowest median flows; the highest flows generally occur in May and June.

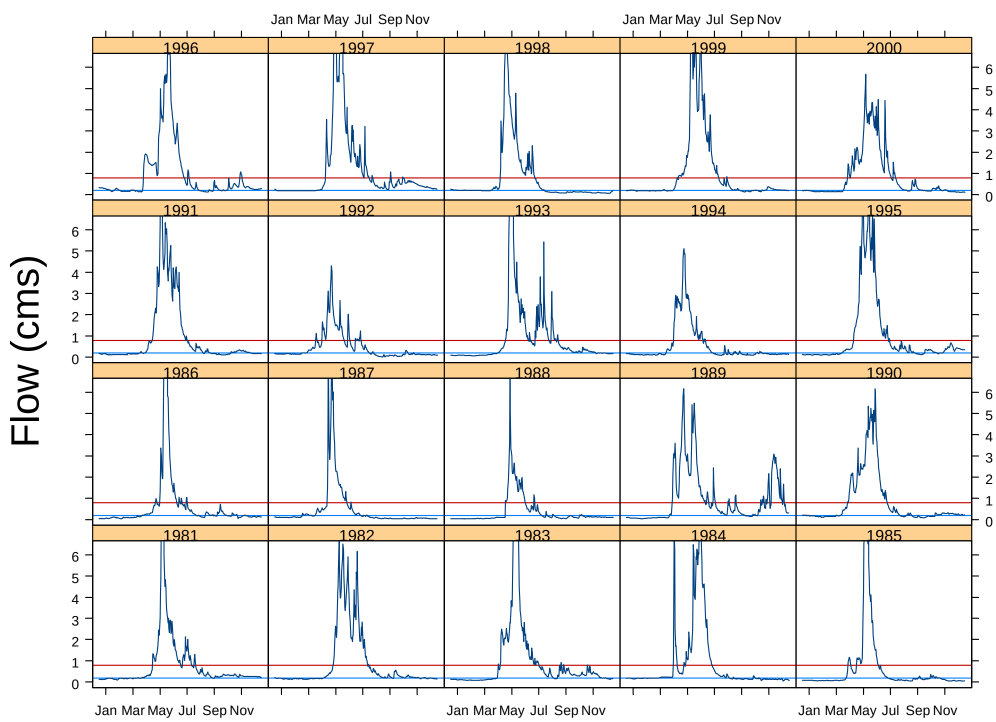

Figure 1. 20 years of mean daily flows for Pennask Creek. The y axis is limited to 50% of the maximum mean daily flow on record to enhance resolution for low flow periods. Mean annual discharge is indicated by the horzontal red line; median annual discharge is indicated by the blue horizontal line. These plots allow one to visualize variation in timing, magnitude, and duration of flows from one year to another.

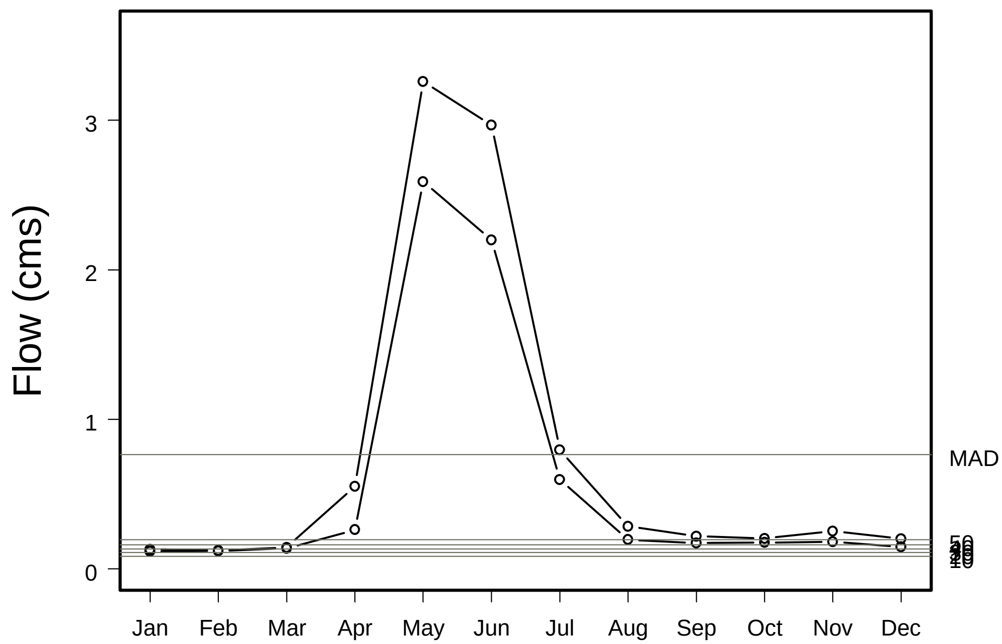

Figure 2. Monthly summaries of mean daily flows for Pennask Creek. The upper hydrograph line is based on the mean of mean daily flows; the lower hydrograph line is based on median of mean daily flows. Several horizontal lines are provided for reference: mean annual discharge, and the 10th, 20th, 30th, 40th and 50th percentile of flows over the period of record.

Table 1. Summary statistics for Pennask Creek broken down by calendar month and over the period of record (PoR).

	mean	**median**	**min**	**max**	**10th %ile**	**20th %ile**	**30th %ile**	**40th %ile**	**50th %ile**	**60th %ile**	**70th %ile**	**80th %ile**	**90th %ile**	**month**
Jan	0.13	0.117	0.027	0.334	0.072	0.082	0.093	0.107	0.117	0.141	0.161	0.182	0.201	Jan
Feb	0.123	0.119	0.029	0.305	0.069	0.088	0.096	0.108	0.119	0.133	0.147	0.164	0.179	Feb
Mar	0.143	0.137	0.045	0.513	0.082	0.092	0.108	0.119	0.137	0.148	0.164	0.182	0.2	Mar
Apr	0.552	0.261	0.061	6.99	0.105	0.139	0.17	0.211	0.261	0.333	0.462	0.756	1.471	Apr
May	3.26	2.59	0.092	12.8	0.899	1.398	1.78	2.15	2.59	3.148	3.993	4.872	6.502	May
Jun	2.966	2.2	0.251	17.7	0.705	1.03	1.34	1.77	2.2	2.768	3.516	4.462	6.06	Jun
Jul	0.796	0.597	0.079	6.15	0.172	0.267	0.375	0.465	0.597	0.738	0.919	1.16	1.65	Jul
Aug	0.284	0.196	0.012	3.1	0.065	0.101	0.128	0.165	0.196	0.244	0.301	0.4	0.615	Aug
Sep	0.218	0.173	0.019	1.15	0.062	0.088	0.116	0.144	0.173	0.205	0.246	0.32	0.442	Sep
Oct	0.204	0.176	0.033	0.933	0.079	0.105	0.127	0.147	0.176	0.205	0.238	0.289	0.345	Oct
Nov	0.252	0.181	0.045	3.09	0.091	0.119	0.133	0.15	0.181	0.212	0.246	0.294	0.415	Nov
Dec	0.2	0.147	0.04	2.94	0.074	0.102	0.115	0.127	0.147	0.169	0.2	0.238	0.282	Dec
PoR	0.763	0.194	0.012	17.7	0.083	0.109	0.133	0.161	0.194	0.252	0.387	0.844	2.2	PoR

Threshold calculations for fishless streams

The fishless stream thresholds are determined in four steps.

1. **Determine non-fish bearing status.** Determining the fish-bearing status of all streams in the project area is perhaps the most basic of biological information needs. In the absence of reliable data these streams will be considered fish-bearing. Appropriate methods for determining fish presence and absence are detailed in the Assessment

Methods guidebook (Lewis et al. 2003). We will assume here that non-fish bearing status has been adequately assessed and signed off by a certified professional (e.g., R.P.Bio.).

2. **Obtain 20+ years of daily flow records.** Empirical historic flow records are often not available for streams of interest. We will assume here that a certified professional (e.g., P.Eng.) has developed and certified a high-quality flow record consisting of 20 or more years of mean daily flows. The flow file used here was obtained from Water Survey Canada; there has been no attempt to "naturalize" the flow record to correct for land and water uses. Proponents will, however, need to complete this task.

3. **Calculate maximum diversion rate.** The maximum diversion rate is set at 80^{th} percentile and is a simple calculation based on the entire period of record taken from Step 2. For Pennask Creek the 80^{th} percentile is 0.844 cms, as noted in Table 1.

4. **Calculate minimum flow.** The minimum flow threshold is set in a series of steps.
   - **a. Calculate median of mean daily flows in each month.** The median of mean daily flows is calculated and tabulated. Monthly medians are indicated in column 3 of Table 1.
   - **b. Select minimum from these values.** The minimum monthly value in column 3 of Table 1 is 0.117 cms corresponding to the month of September.
   - c. **Set this as an annual minimum flow threshold.** The minimum flow threshold is set to 0.117 cms for all calendar months.

Results

The flow thresholds are indicated in Figure 3. In essence this guideline permits diversion of flows within the band demarcated by the two dark blue lines. Flows below the band are not available for diversion, and would combine with "residual flows" above the band when present. Post-project flows and diversion flows are indicated in Figure 4 and Figure 5. Figure 6 shows the streamflow available for diversion under the fishless and the fish-bearing flow thresholds. Clearly, substantially more water is made available for diversion in fishless streams.

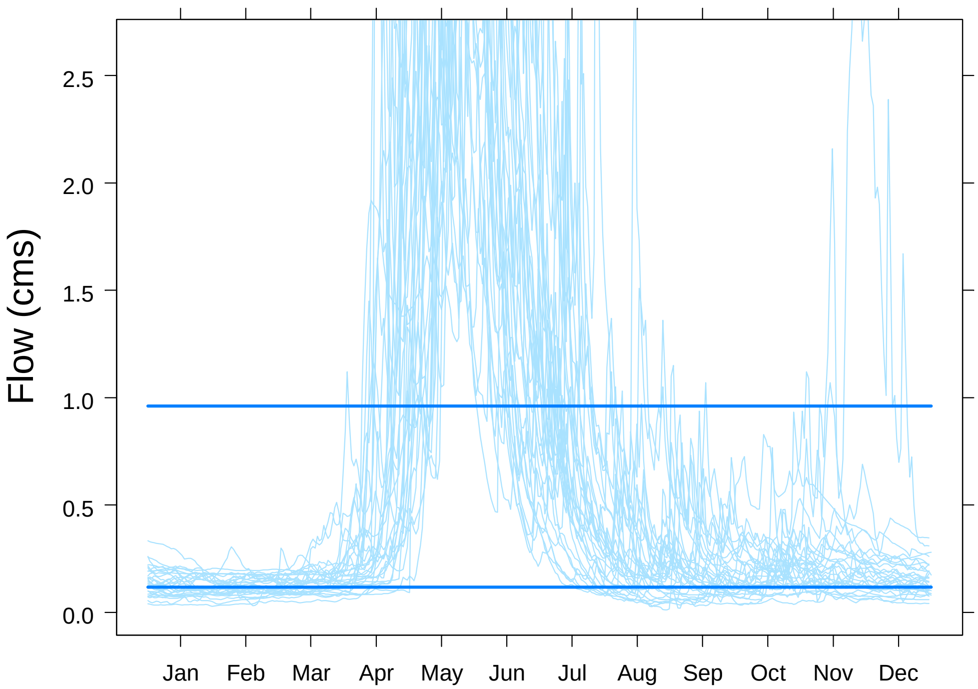

Figure 3. Natural mean daily flows (light blue) for Pennask Creek, with flow time series superimposed for each year on record. The dark blue lines show the minimum and maximum diversion thresholds as calculated using the proposed guideline for fishless streams.

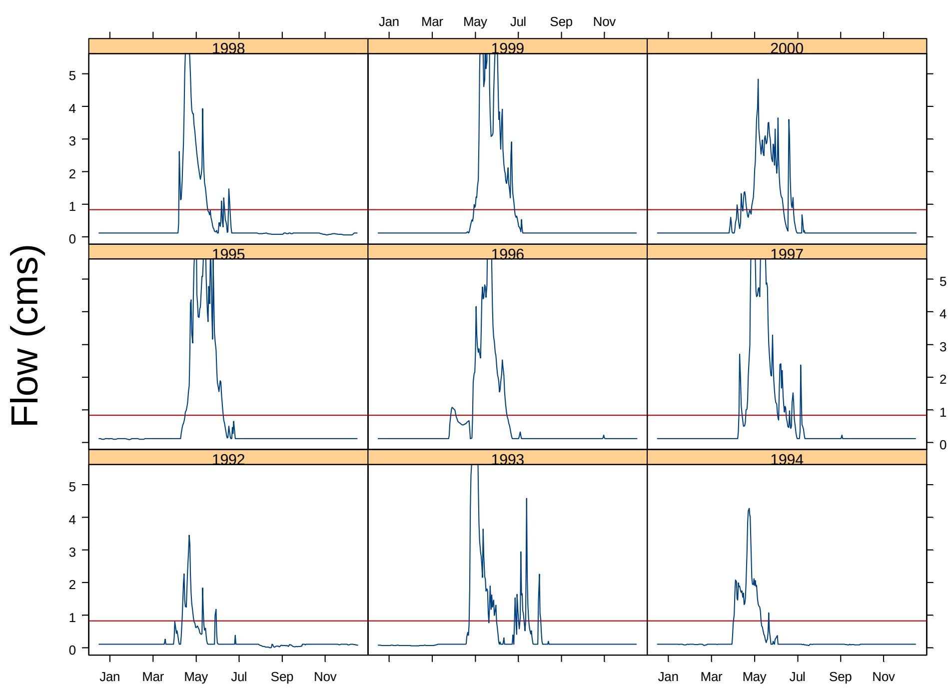

Figure 4. Simulated post-project flows for Pennask Creek using the proposed fishless stream diversion thresholds. (Note: the purpose is to understand the effects of the threshold; in reality this stream is fish-bearing.) The y-axis is limited to 50% of the maximum natural mean daily flow on record. The horizontal red line represents natural MAD.

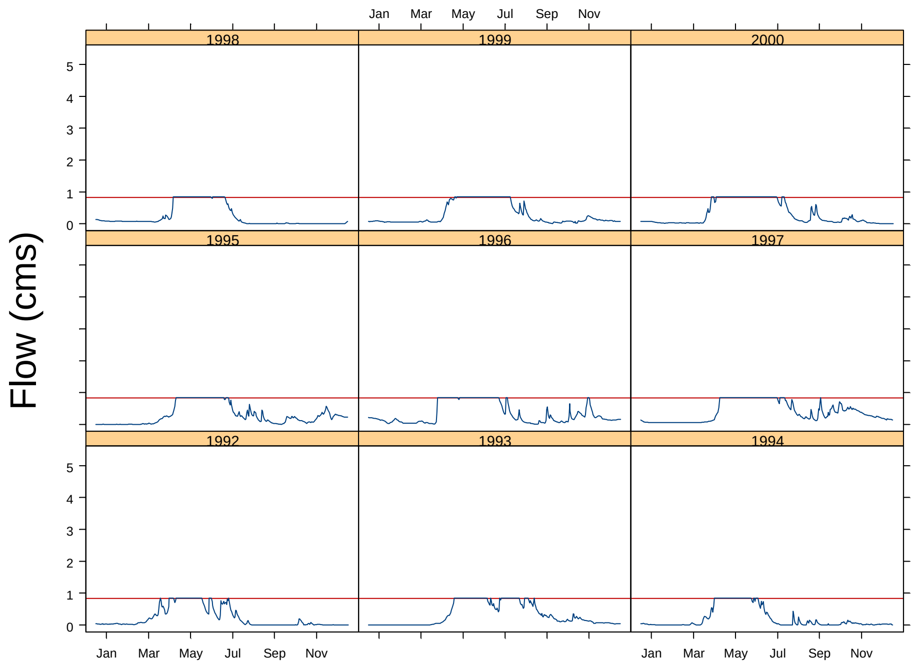

Figure 5. Simulated diversion flows using the proposed fishless stream diversion threshold for Pennask Creek. The y-axis is limited to 50% of the maximum natural mean daily flow on record. The horizontal blue line represents natural MAD.

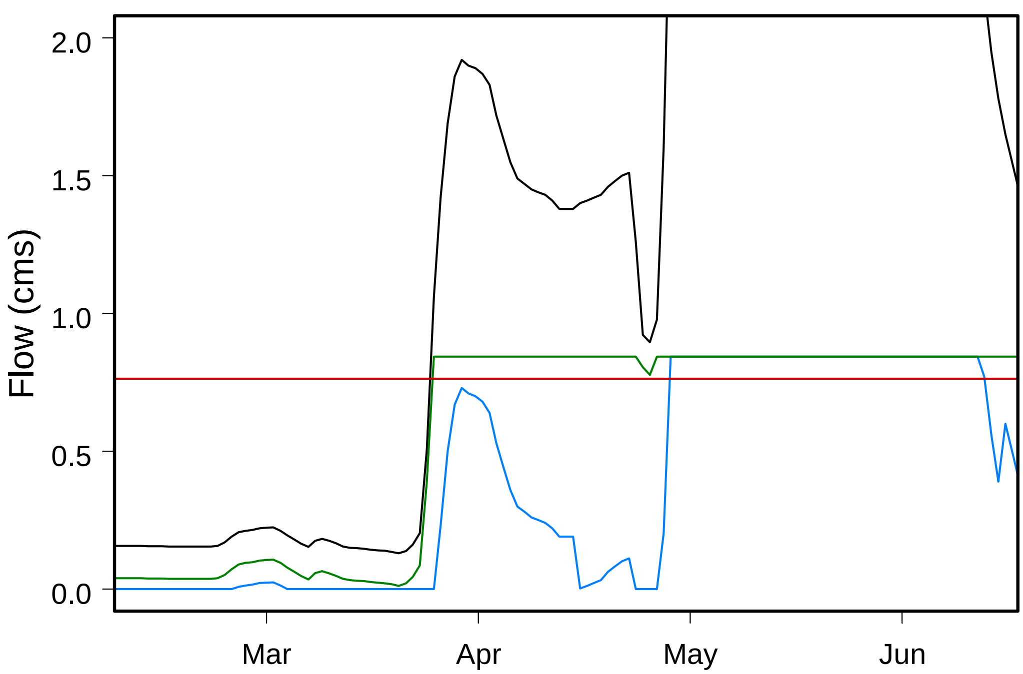

Figure 6. Comparison of total stream flow (black line) during four calendar months in 1996, availability for diversion using the fishless stream flow threshold (green), and availability for diversion using the fish-bearing stream flow threshold (blue). The horizontal red line indicates mean annual discharge. See Appendix D for a worked example of the fish-bearing streamflow thresholds for Pennask Creek.

APPENDIX C. WORKED EXAMPLE OF THE PROPOSED FLOW THRESHOLDS FOR FISH-BEARING STREAMS -- SARITA RIVER, VANCOUVER ISLAND

This appendix presents an example to demonstrate how the proposed flow thresholds are calculated and applied for a fish-bearing stream. The example used is a coastal system (Sarita River, west coast of Vancouver Island). An example for an interior system (Pennask Creek, southern interior) is presented in a separate Appendix. The Sarita River flow record was obtained from the Hydat database maintained by Water Survey Canada.

Sarita River

Natural flows

Patterns of natural flow in the Sarita River are shown in Figure 1 and Figure 2. Statistical summaries are presented in Table 1. The Sarita River is characterized by low flows during late summer, and high flow events during rain storms, sometimes in association with spring snowmelt. August is the calendar month with the lowest median flows; the highest flows occur primarily in spring and fall.

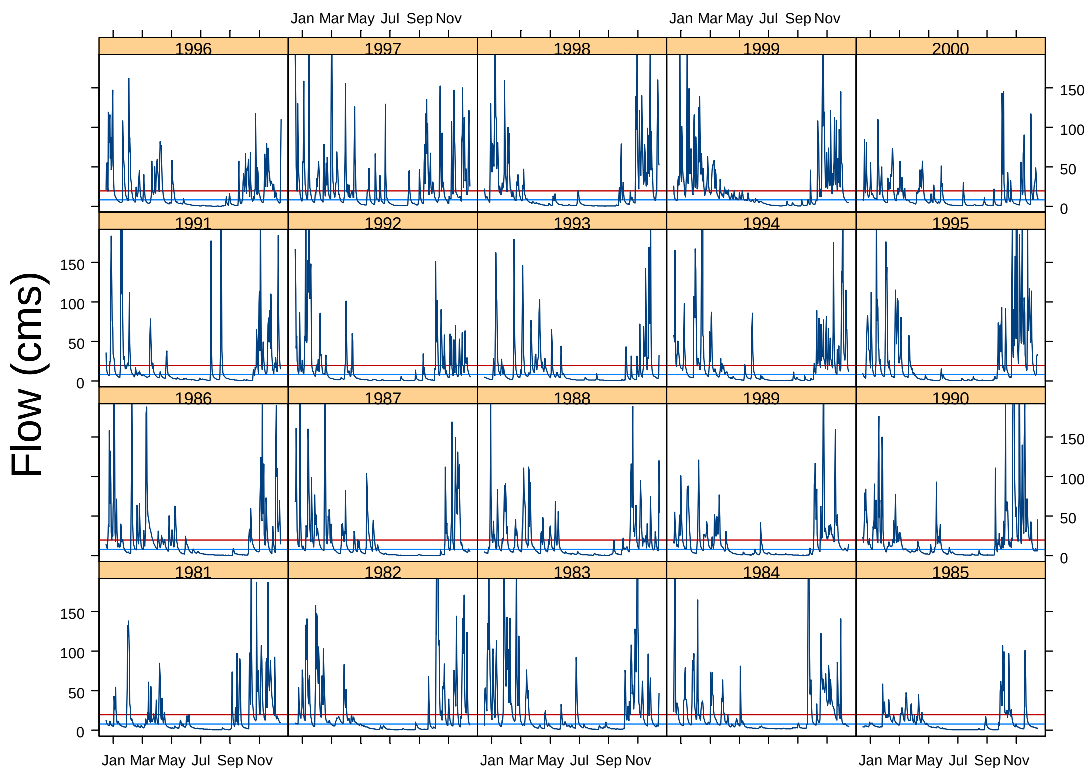

Figure 1. 20 years of mean daily flows for the Sarita River. The y axis is limited to 50% of the maximum mean daily flow on record to enhance resolution for low flow periods. Mean annual discharge is indicated by the horzontal red line; median annual discharge is indicated by the blue horizontal line. These plots allow one to visualize variation in timing, magnitude, and duration of flows from one year to another.

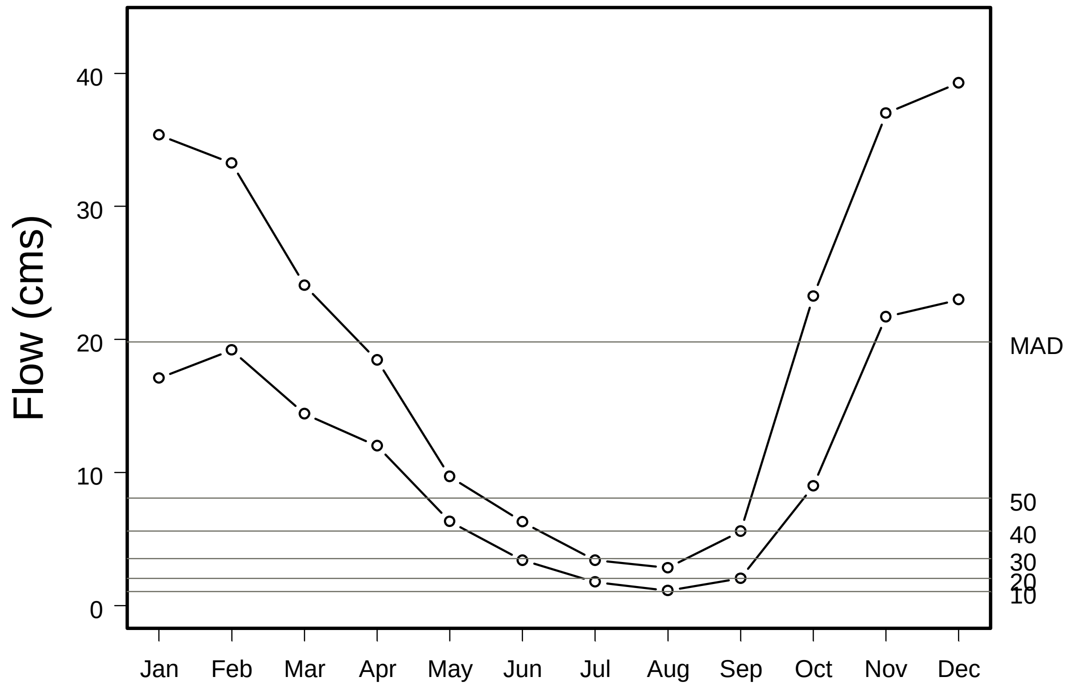

Figure 2. Monthly summaries of mean daily flows for the Sarita River. The upper hydrograph line is based on the mean of mean daily flows; the lower hydrograph line is based on median of mean daily flows. Several horizontal lines are provided for reference: mean annual discharge, and the 10th, 20th, 30th, 40th and 50th percentile of flows over the period of record.

Table 1. Summary statistics for Sarita River broken down by calendar month and over the period of record (PoR).

	mean	median	min	max	10th %ile	20th %ile	30th %ile	40th %ile	50th %ile	60th %ile	70th %ile	80th %ile	90th %ile	month
Jan	35.38	17.1	1.99	677	4.98	7.112	9.4	12.34	17.1	24.5	35.42	51.38	83.62	Jan
Feb	33.26	19.2	1.84	362	5.151	8.016	10.81	15	19.2	23.8	32.18	48.1	82.19	Feb
Mar	24.07	14.4	1.62	318	5.356	7.36	9.29	11.5	14.4	17.96	24.1	34.96	51.88	Mar
Apr	18.44	12	1.47	294	5.01	6.568	8.47	10.1	12	14.7	18	24.32	39.01	Apr
May	9.68	6.31	0.947	126	2.156	3.252	4.206	5.234	6.31	7.84	9.81	12.7	18.6	May
Jun	6.28	3.4	0.637	110	1.178	1.7	2.267	2.79	3.4	4.26	5.49	7.48	12.32	Jun
Jul	3.38	1.76	0.345	129	0.724	0.892	1.15	1.42	1.76	2.18	2.74	3.68	5.65	Jul
Aug	2.82	1.11	0.283	199	0.487	0.643	0.806	0.935	1.11	1.33	1.78	2.35	4.54	Aug
Sep	5.57	2.04	0.307	152	0.591	0.815	1.04	1.456	2.04	2.75	3.96	6.36	11.93	Sep
Oct	23.26	8.98	0.293	595	1.09	2.042	3.62	6.044	8.98	13.3	21.32	34.8	65.1	Oct
Nov	37	21.7	0.682	535	5.349	8.13	11.6	15.9	21.7	28.9	39.3	56.04	84.73	Nov
Dec	39.29	23	1.54	490	6.51	9.062	12.6	17	23	30.6	41.94	59.44	90.24	Dec
PoR	19.8	8.09	0.283	677	1.04	2.04	3.54	5.594	8.09	11.5	17	27.3	51.3	PoR

Threshold calculations for fish-bearing streams

The fishless stream thresholds are determined in a series of eight steps.

1. **Determine fish-bearing status.** Determining the fish-bearing status of all streams in the project area is perhaps the most basic of biological information needs. In the absence of reliable data these streams will be considered fish-bearing. Appropriate methods for determining fish presence and absence are detailed in the Assessment Methods guidebook (Lewis et al. 2003). The Sarita River is known to be fish-bearing, with

Chinook, Chum, Coho, Pink and Sockeye Salmon, Cutthroat Trout, Dolly Varden, Kokanee, Rainbow Trout, and Steelhead.

2. **Obtain 20+ years of daily flow records.** Empirical historic flow records are often not available for streams of interest. The flow file used here was obtained from Water Survey Canada; there has been no attempt to "naturalize" the flow record to correct for land and water uses. Proponents will, however, need to complete this task.

3. **Calculate maximum diversion rate.** The maximum diversion rate is set at 80th percentile and is a simple calculation based on the entire period of record taken from Step 2. For the Sarita River the 80th percentile is 27.3 cms, as noted in Table 1.

4. **Calculate median of mean daily flows in each month.** The median of mean daily flows is calculated and tabulated. Monthly medians are indicated in column 3 of Table 1.

5. **Order monthly values from step 4 in sequence from lowest to highest.** The following table orders monthly medians for the Sarita River in ascending order.

month	median
Aug	1.11
Jul	1.76
Sep	2.04
Jun	3.4
May	6.31
Oct	8.98
Apr	12
Mar	14.4
Jan	17.1
Feb	19.2
Nov	21.7
Dec	23

6. **Set the flow threshold in the lowest flow month.** The minimum flow threshold in the low flow month is set equivalent to the 90th percentile of mean daily flows in that month.

7. **Set the flow threshold in the highest flow month.** The minimum flow threshold in the highest flow month is set equivalent to the 20th percentile of mean daily flows in that month. The results of steps 6 and 7 are shown in the following table.

month	median	percentiles	minimum flow threshold
Dec	23	20	9.06
Nov	21.7		
Feb	19.2		
Jan	17.1		
Mar	14.4		
Apr	12		
Oct	8.98		
May	6.31		
Jun	3.4		
Sep	2.04		
Jul	1.76		
Aug	1.11	90	4.54

8. **Set the flow thresholds for all other months.** Flow thresholds in the remaining months are calculated as a percentile of mean daily flows in that month, where the percentile is calculated as between 20th and 90th according to the formula:

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

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

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

month	median	percentiles	minimum flow threshold
Dec	23	20	9.06
Nov	21.7	24.2	9.63
Feb	19.2	32.2	11.6
Jan	17.1	38.9	11.9
Mar	14.4	47.5	13.5
Apr	12	55.2	13.2
Oct	8.98	64.8	16.4
May	6.31	73.4	10.6
Jun	3.4	82.7	8.27
Sep	2.04	87	9.72
Jul	1.76	87.9	5.15
Aug	1.11	90	4.54

Results

The flow thresholds are indicated in Figure 3. In essence this guideline permits diversion of flows within the band demarcated by the two dark blue lines. Flows below the band are not available for diversion, and would combine with "residual flows" above the band when present. Post-project flows and diversion flows are indicated in Figure 4 and Figure 5. Figure 6 shows the streamflow available for diversion under the fishless and the fish-bearing flow thresholds. Clearly, substantially more water is made available for diversion in fishless streams.

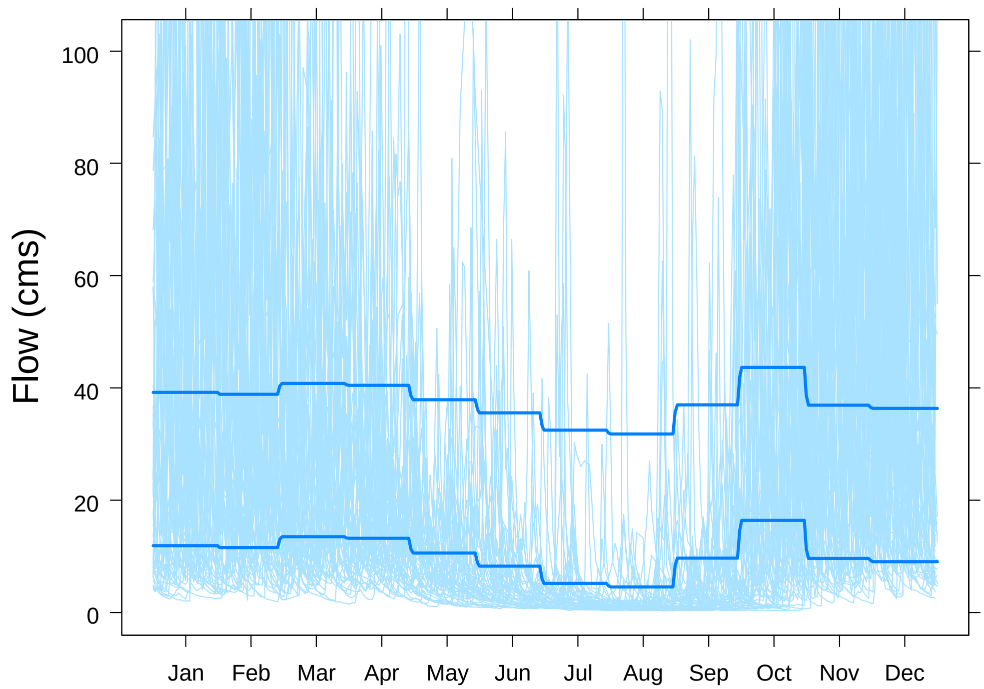

Figure 3. Natural mean daily flows (light blue) for the Sarita River, with flow time series superimposed for each year on record. The dark blue lines show the minimum and maximum diversion thresholds as calculated using the proposed guideline for fish-bearing streams.

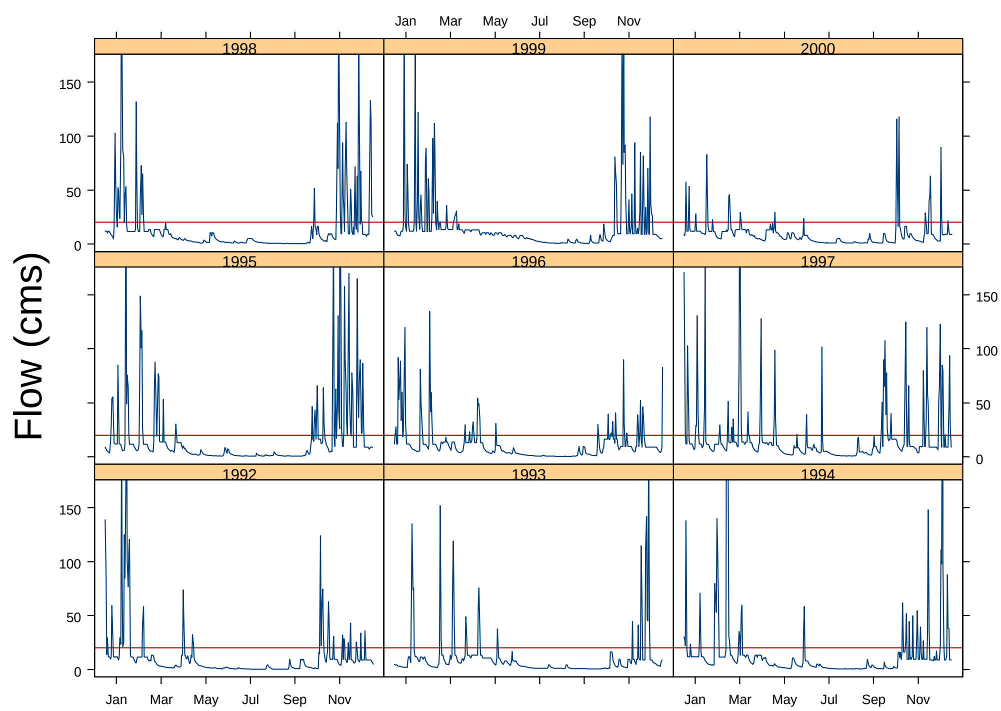

Figure 4. Simulated post-project flows for the Sarita River using the proposed fish-bearing stream diversion thresholds. The y-axis is limited to 50% of the maximum natural mean daily flow on record. The horizontal red line represents natural MAD.

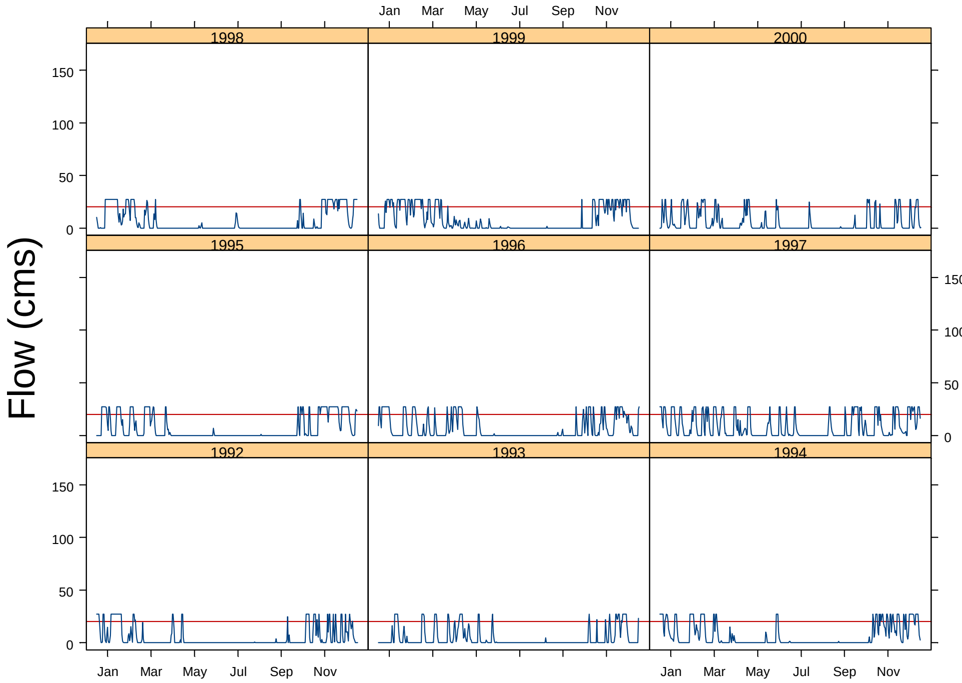

Figure 5. Simulated diversion flows using the proposed fish-bearing stream diversion threshold for the Sarita River. The y-axis is limited to 50% of the maximum natural mean daily flow on record. The horizontal red line represents natural MAD.

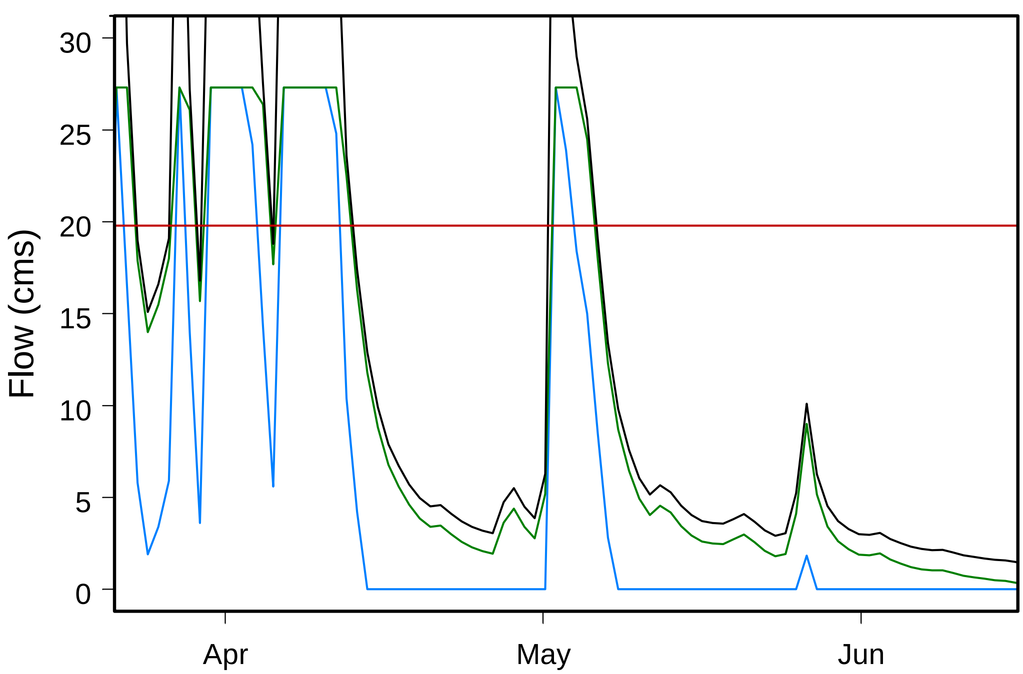

Figure 6. Comparison of total stream flow (black line) during three calendar months in 1996, availability for diversion using the fishless stream flow threshold (green), and availability for diversion using the fish-bearing stream flow threshold (blue). The horizontal red line indicates mean annual discharge. See Appendix A for a worked example of the fishless streamflow threshold for the Sarita River.

APPENDIX D. WORKED EXAMPLE OF THE PROPOSED FLOW THRESHOLDS FOR FISH-BEARING STREAMS -- PENNASK CREEK, SOUTHERN INTERIOR

This appendix presents an example to demonstrate how the proposed flow thresholds are calculated and applied to a fish-bearing stream. The example used is an interior system (Pennask Creek in the Southern Interior). An example for a coastal system (Sarita River on the west coast of Vancouver Island) is presented in a separate Appendix. For the purposes of this example we have assumed that surface flows in Pennask Creek are relatively unaffected by water or land uses, so we made no attempt to "naturalize" the records. The flow file used was obtained from Water Survey Canada records.

Pennask Creek

Natural flows

Patterns of natural flow in Pennask Creek are typical of many interior streams, and are shown in Figure 1 and Figure 2. Statistical summaries are presented in Table 1. Pennask Creek is characterized by a prolonged snowmelt freshet in spring, with low flows extending from late summer through winter. January is the calendar month with the lowest median flows; the highest flows generally occur in May and June.

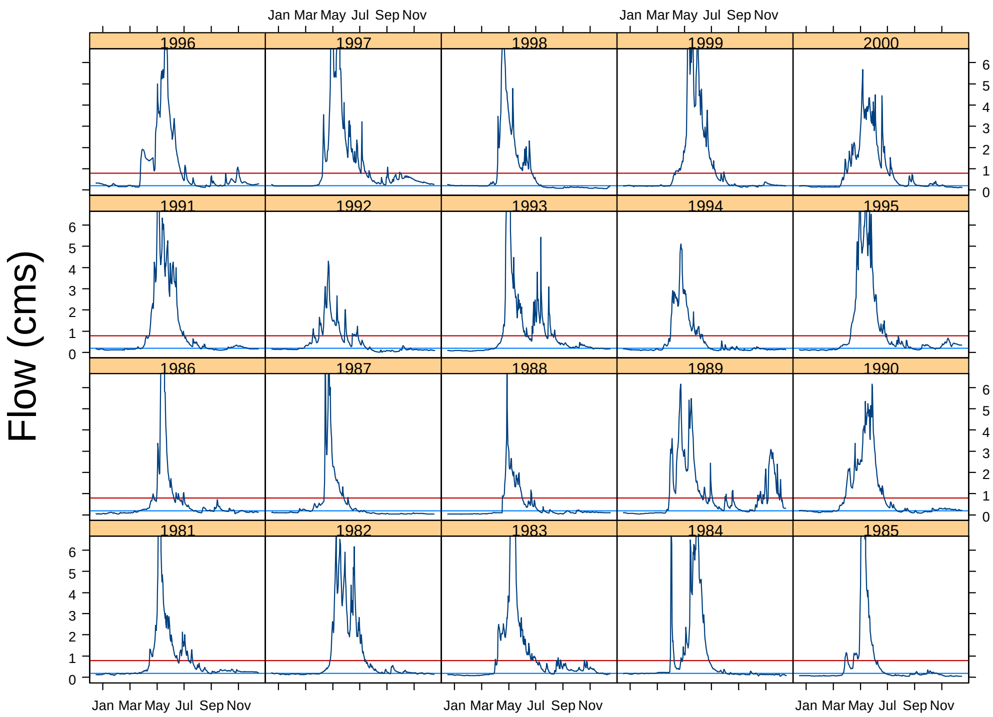

Figure 1. 20 years of mean daily flows for Pennask Creek. The y axis is limited to 50% of the maximum mean daily flow on record to enhance resolution for low flow periods. These plots allow one to visualize variation in timing, magnitude, and duration of flows from one year to another.

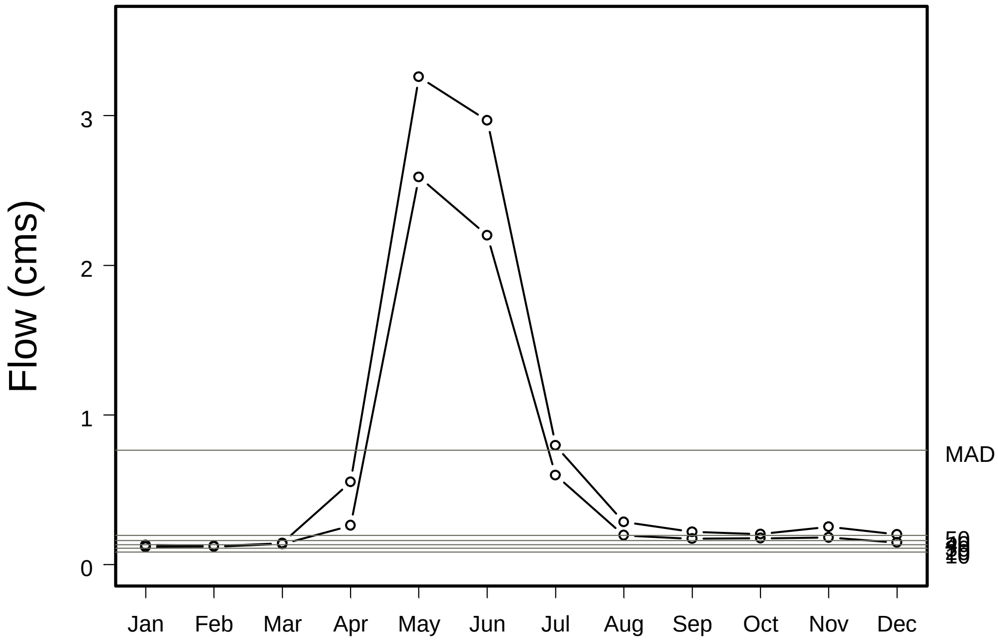

Figure 2. Monthly summaries of mean daily flows for Pennask Creek. The upper hydrograph line is based on the mean of mean daily flows; the lower hydrograph line is based on median of mean daily flows. Several horizontal lines are provided for reference: mean annual discharge, and the 10th, 20th, 30th, 40th and 50th percentile of flows over the period of record.

Table 1. Summary statistics for Pennask Creek broken down by calendar month and over the period of record (PoR).

	mean	median	min	max	10th %ile	20th %ile	30th %ile	40th %ile	50th %ile	60th %ile	70th %ile	80th %ile	90th %ile	month
Jan	0.13	0.117	0.027	0.334	0.072	0.082	0.093	0.107	0.117	0.141	0.161	0.182	0.201	Jan
Feb	0.123	0.119	0.029	0.305	0.069	0.088	0.096	0.108	0.119	0.133	0.147	0.164	0.179	Feb
Mar	0.143	0.137	0.045	0.513	0.082	0.092	0.108	0.119	0.137	0.148	0.164	0.182	0.2	Mar
Apr	0.552	0.261	0.061	6.99	0.105	0.139	0.17	0.211	0.261	0.333	0.462	0.756	1.471	Apr
May	3.26	2.59	0.092	12.8	0.899	1.398	1.78	2.15	2.59	3.148	3.993	4.872	6.502	May
Jun	2.966	2.2	0.251	17.7	0.705	1.03	1.34	1.77	2.2	2.768	3.516	4.462	6.06	Jun
Jul	0.796	0.597	0.079	6.15	0.172	0.267	0.375	0.465	0.597	0.738	0.919	1.16	1.65	Jul
Aug	0.284	0.196	0.012	3.1	0.065	0.101	0.128	0.165	0.196	0.244	0.301	0.4	0.615	Aug
Sep	0.218	0.173	0.019	1.15	0.062	0.088	0.116	0.144	0.173	0.205	0.246	0.32	0.442	Sep
Oct	0.204	0.176	0.033	0.933	0.079	0.105	0.127	0.147	0.176	0.205	0.238	0.289	0.345	Oct
Nov	0.252	0.181	0.045	3.09	0.091	0.119	0.133	0.15	0.181	0.212	0.246	0.294	0.415	Nov
Dec	0.2	0.147	0.04	2.94	0.074	0.102	0.115	0.127	0.147	0.169	0.2	0.238	0.282	Dec
PoR	0.763	0.194	0.012	17.7	0.083	0.109	0.133	0.161	0.194	0.252	0.387	0.844	2.2	PoR

Threshold calculations for fish-bearing streams

The fishless stream thresholds are determined in a series of eight steps.

1. **Determine fish-bearing status.** Determining the fish-bearing status of all streams in the project area is perhaps the most basic of biological information needs. In the absence of reliable data these streams will be considered fish-bearing. Appropriate methods for determining fish presence and absence are detailed in the Assessment Methods

guidebook (Lewis et al. 2003). Pennask Creek is known to be fish-bearing, with chinook, coho, kokanee, rainbow trout and sockeye present in the system.

2. **Obtain 20+ years of daily flow records.** Empirical historic flow records are often not available for streams of interest. The flow file used here was taken from Water Survey of Canada records. The flow file used here was obtained from Water Survey Canada; there has been no attempt to "naturalize" the flow record to correct for land and water uses. Proponents will, however, need to complete this task.

3. **Calculate maximum diversion rate.** The maximum diversion rate is set at 80th percentile and is a simple calculation based on the entire period of record taken from Step 2. For Pennask Creek the 80th percentile is 0.844 cms, as noted in Table 1.

4. **Calculate median of mean daily flows in each month.** The median of mean daily flows is calculated and tabulated. Monthly medians are indicated in column 3 of Table 1.

5. **Order monthly values from step 4 in sequence from lowest to highest.** The following table orders monthly medians for Pennask Creek in ascending order.

month	median
Jan	0.117
Feb	0.119
Mar	0.137
Dec	0.147
Sep	0.173
Oct	0.176
Nov	0.181
Aug	0.196
Apr	0.261
Jul	0.597
Jun	2.2
May	2.59

6. **Set the flow threshold in the lowest flow month.** The minimum flow threshold in the low flow month is set equivalent to the 90th percentile of mean daily flows in that month.
7. **Set the flow threshold in the highest flow month.** The minimum flow threshold in the highest flow month is set equivalent to the 20th percentile of mean daily flows in that month. The results of steps 6 and 7 are shown in the following table.

month	median	percentiles	minimum flow threshold
Jan	0.117	90.0	0.201
Feb	0.119		
Mar	0.137		
Dec	0.147		
Sep	0.173		
Oct	0.176		
Nov	0.181		
Aug	0.196		
Apr	0.261		
Jul	0.597		
Jun	2.2		
May	2.59	20.0	1.4

8. **Set the flow thresholds for all other months.** Flow thresholds in the remaining months are calculated as a percentile of mean daily flows in that month, where the percentile is calculated as between 20th and 90th according to the formula:

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

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

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

month	median	percentiles	minimum flow threshold
Jan	0.117	90.0	0.201
Feb	0.119	90.0	0.179
Mar	0.137	89.4	0.199
Dec	0.147	89.2	0.277
Sep	0.173	88.4	0.416
Oct	0.176	88.3	0.331
Nov	0.181	88.2	0.391
Aug	0.196	87.8	0.538
Apr	0.261	85.9	1.19
Jul	0.597	76.4	1.05
Jun	2.2	31.0	1.39
May	2.59	20.0	1.4

Results

The flow thresholds are indicated in Figure 3. In essence this guideline permits diversion of flows within the band demarcated by the two dark blue lines. Flows below the band are not available for diversion, and would combine with "residual flows" above the band when present. Post-project flows and diversion flows are indicated in Figure 4 and Figure 5. Figure 6 shows the streamflow available for diversion under the fishless and the fish-bearing flow thresholds. Clearly, substantially more water is made available for diversion in fishless streams.

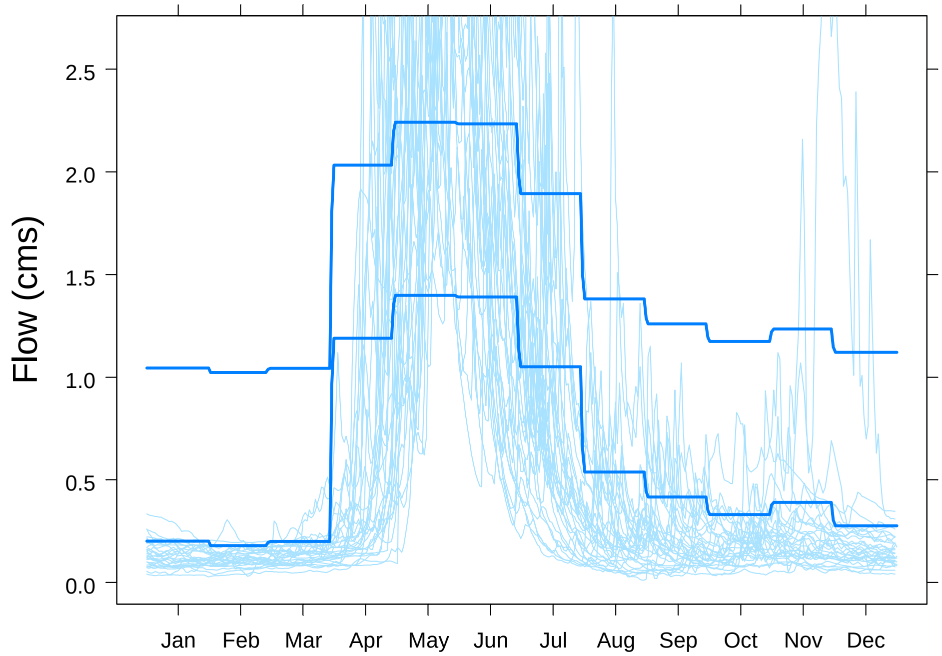

Figure 3. Natural mean daily flows (light blue) for Pennask Creek, with flow time series superimposed for each year on record. The dark blue lines show the minimum and maximum diversion thresholds as calculated using the proposed guideline for fish-bearing streams.

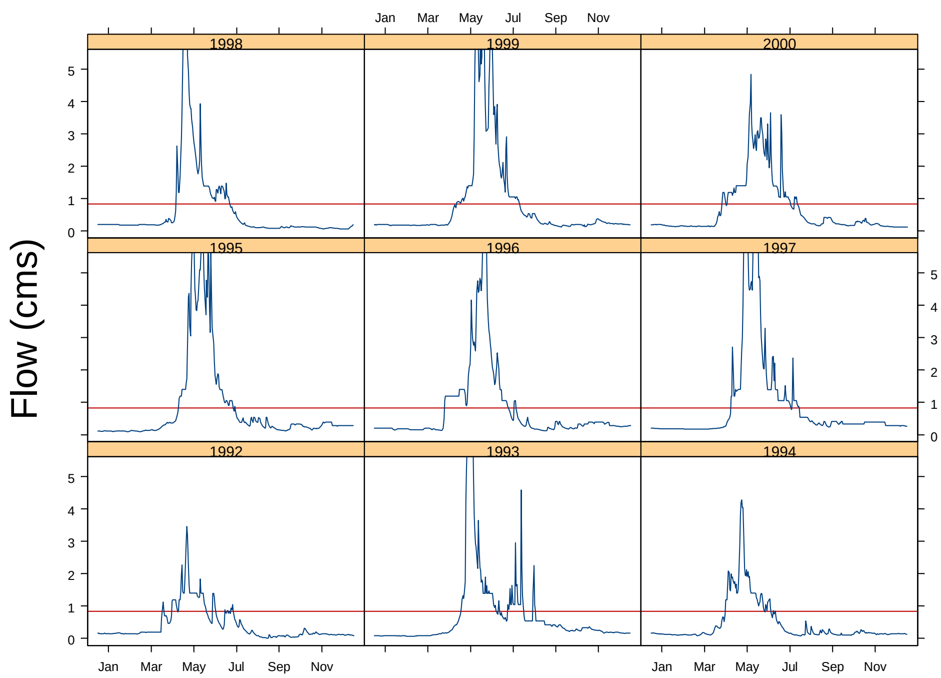

Figure 4. Simulated post-project flows for Pennask Creek using the proposed fish-bearing stream diversion thresholds. The y-axis is limited to 50% of the maximum natural mean daily flow on record. The horizontal red line represents natural MAD.

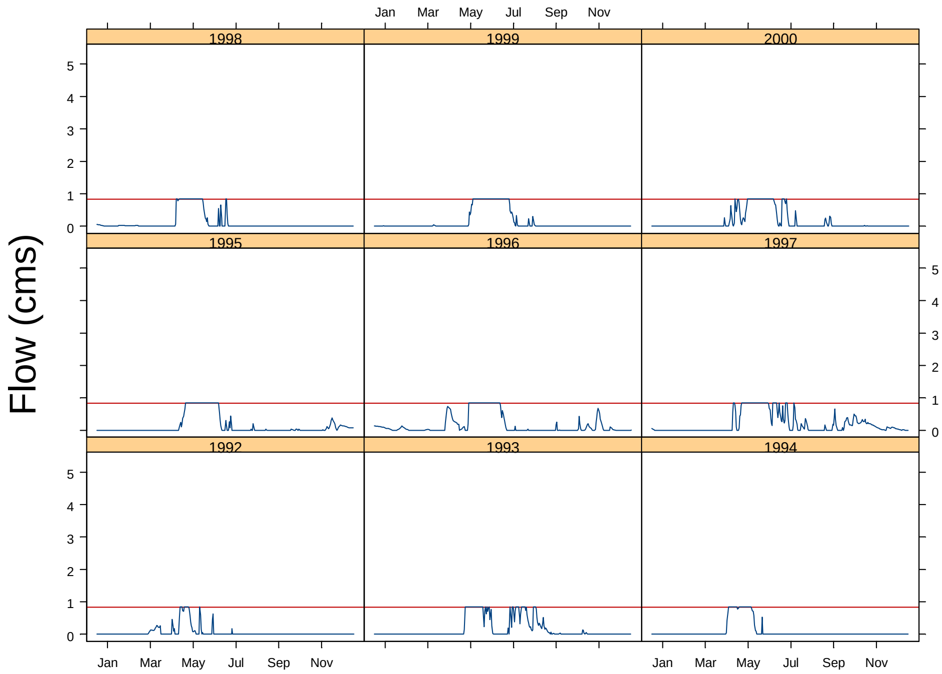

Figure 5. Simulated diversion flows using the proposed fish-bearing stream diversion threshold for Pennask Creek. The y-axis is limited to 50% of the maximum natural mean daily flow on record. The horizontal red line represents natural MAD.

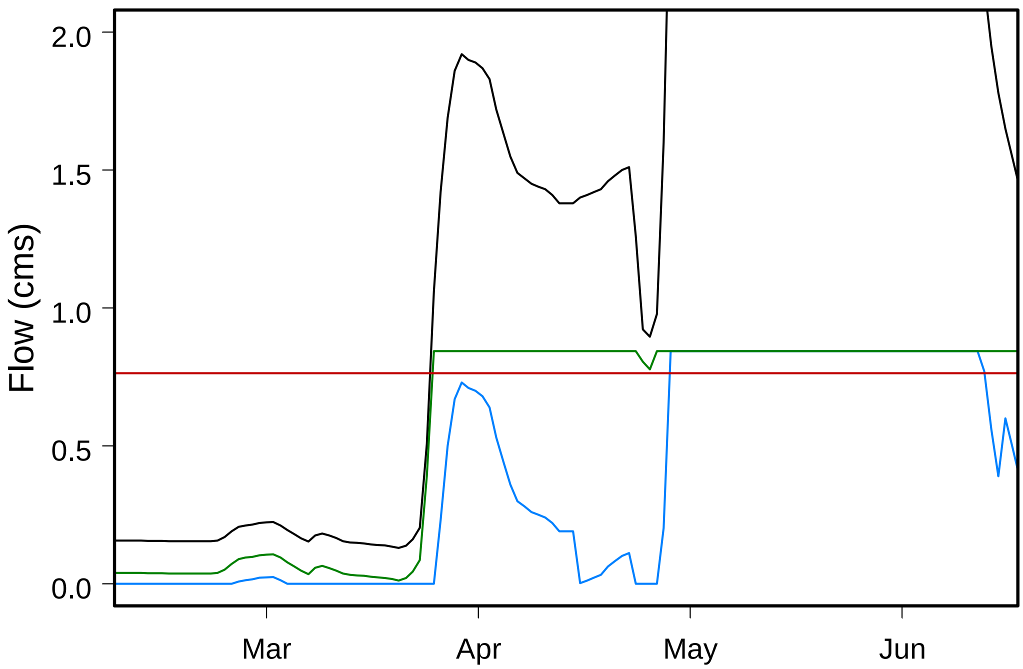

Figure 6. Comparison of total stream flow (black line) during four calendar months in 1996, availability for diversion using the fishless stream flow threshold (green), and availability for diversion using the fish-bearing stream flow threshold (blue). The horizontal red line indicates mean annual discharge. See Appendix D for a worked example of the fishless streamflow threshold for Pennask Creek.