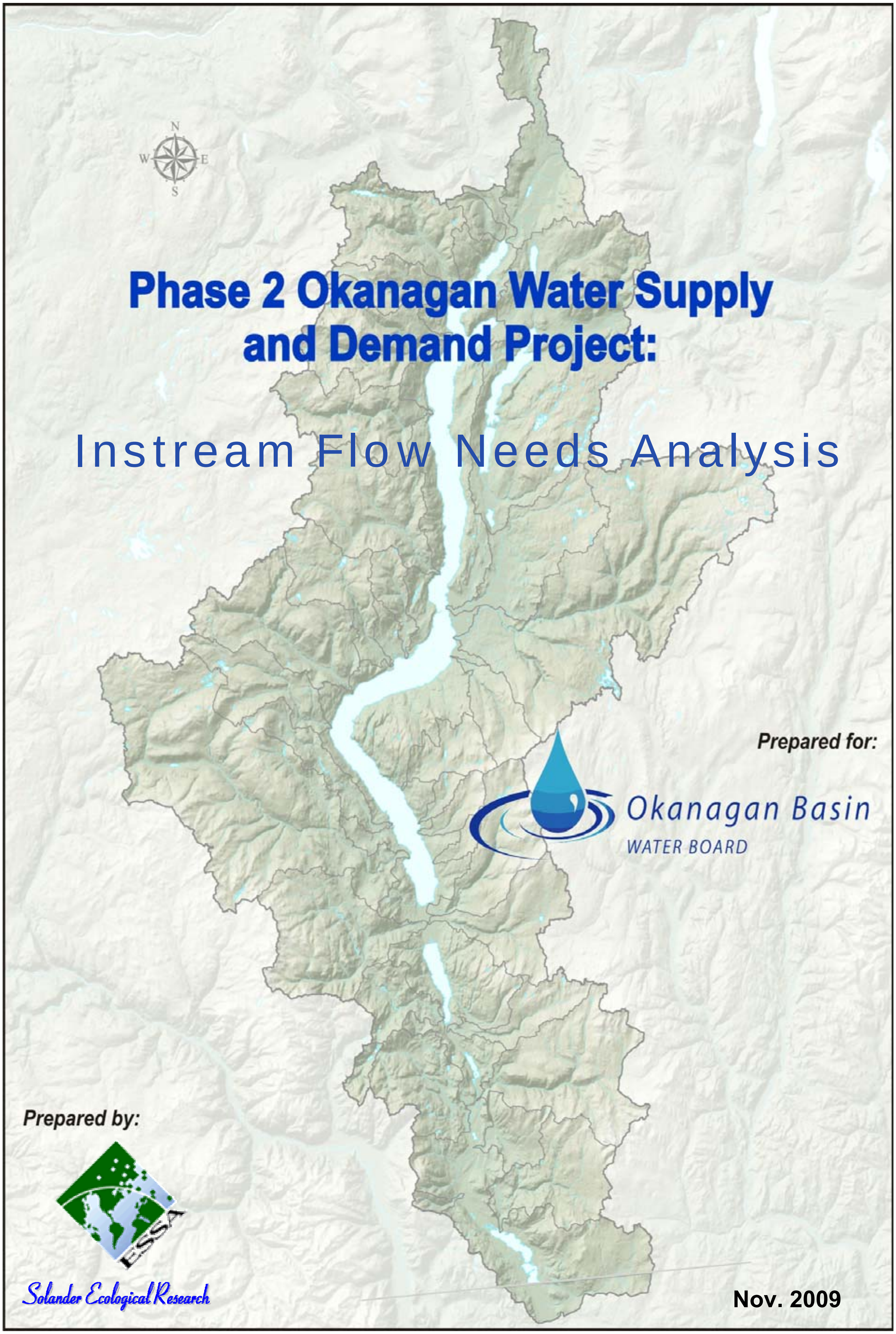


Phase 2 Okanagan Water Supply and Demand Project:

Instream Flow Needs Analysis

Prepared for:

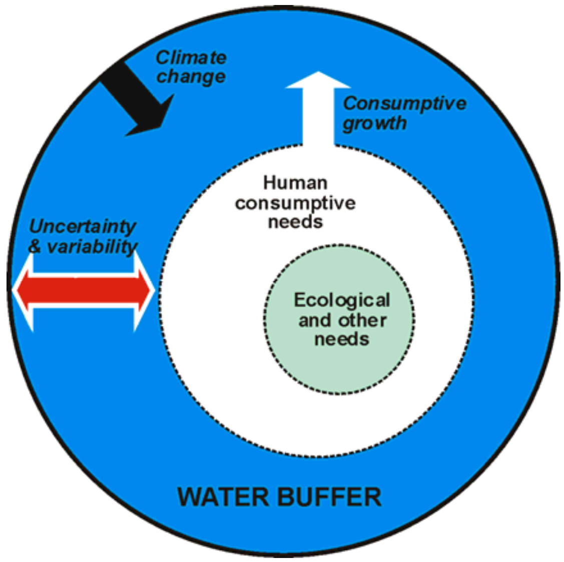
Okanagan Basin WATER BOARD

Prepared by:

ESSA

Solander Ecological Research

Nov. 2009



Instream Flow Needs Analysis for the Okanagan Water Supply & Demand Project

Prepared for:

Okanagan Basin Water Board
1450 KLO Road
Kelowna BC V1W 3Z4

Prepared by

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November 2009

Citation: ESSA Technologies Ltd. and Solander Ecological Research. 2009. Instream Flow Needs Analysis for the Okanagan Water Supply & Demand Project. Report prepared for the Okanagan Basin Water Board (OBWB), Kelowna, BC. 152 p.

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Nov. 3, 2009

Okanagan Basin Water Board
1450 KLO Road
Kelowna BC V1W 3Z4
c/o Brian Guy
Summit Environmental Consultants Ltd.
#200 – 2800 29th Street
Vernon, BC V1T 9P9

Dear Mr. Guy,

Re: Letter of Transmittal—Instream Flow Needs Analysis (draft) for the Okanagan Water Supply & Demand Project. Reference OBWB 08-007

ESSA Technologies Ltd. and Solander Ecological Research are extremely pleased to enclose three bound hard-copies, one unbound copy, and one electronic copy on CD of our final report entitled "Instream Flow Needs Analysis for the Okanagan Water Supply & Demand Project." This final report includes additional sections, supporting text and figure revisions requested on Oct. 13, 2009 by the IFN Committee after review of our earlier draft report. The major report revisions that have been completed based on Committee comments are:

- Inclusion of a discussion of the value of a natural flow regime for maintaining a range of aquatic ecosystem processes.

- Inclusion of a 25th percentile of weekly naturalized flows as an arbitrary lower flow reference level to assist readers making comparisons relative to naturalized and BCIFN/meta-analysis flows, with commentary on the significance of these for the range of production that biota may achieve. This 25th percentile flow is provided in the report figures.

- Exemplary figures used to illustrate the report's main points have been revised as suggested by the IFN Committee (e.g., focus only on rainbow trout and kokanee). Text for figure legends has been adjusted to be more specific to the IFN methods we employed. Multiple species interpretations are retained in the appendices.

- Inclusion of a consolidated section in the discussion that deals with the management implications of landscape-scale pressures on aquatic habitats in the context of meta-population dynamics (dispersal, recolonization and seasonal to decadal scale refuges, importance of groundwater refuges within streams, regional strongholds among streams etc.)

Our analysis and this report represent a significant undertaking: provision of alternative default and site specific instream flow guidelines for 36 sub-basin tributary streams in the Okanagan Basin that support fish populations. As described in our report, these guidelines rely on two major methodologies for systems where detailed site specific and species specific biophysical data are unavailable. We believe we have exceeded the RFP requirements with respect to providing alternative risk cases (prediction intervals) and we are also excited to provide a first-order hydrologic risk assessment of seasonal vulnerability based on the exceedance probability concept emphasized during the Water Supply/Demand (WSD) User Needs Assessment phase. This first pass risk assessment based on naturalized flows does not make any ecological vs. socio-economic value trade-offs; that would require a participatory stakeholder process beyond the scope of this study. Nevertheless, it defines a method of integrating the complex time- location- risk preference- species- and life-stage dimensions that must be taken into account when defining instream flow needs.

Possible future steps the Steering and Instream Flow Needs Committees may wish to consider include:

1. Re-running the exceedance probability risk analysis in this report vs. **net water availability** time series following completion of water balance modelling scenarios. This is required to enable a proper ecological vulnerability for setting fish protection priorities;
2. Enhancing the prototype *desktop* reporting tools used by our team (and demonstrated to the IFN committee in April 2009), and releasing it on a pilot basis to select water license managers;
3. Based on the results of #2 (or instead of-), simplify and web-enable one or more of these reports inside the WSD Web-Reporting Tool to allow wider dissemination and use throughout the Okanagan basin fish/water management community;
4. Support a research project that explicitly considers water temperature requirements and impacts on recommended flow thresholds. Decreased flows due to water extraction activities combined with climate warming, particularly in late summer, is now widely considered a primary reason for increased stream temperatures in many areas, with consequent negative effects on cold/cool water fish; and
5. Preparing short summaries of these results for different stakeholders. In the interim, our Executive Summary and Frequently Asked Questions (FAQ) section will provide valuable summaries of the extensive analysis results provided in our report.

We hope that this report will provide an important reference for Okanagan instream flow needs negotiations in the coming years. On behalf of our team (Todd Hatfield, Clint Alexander, David Marmorek, Russell Smith, David Carr and Katy Bryan) thank-you for the opportunity to contribute to this very important project in the Okanagan Basin.

Yours Sincerely,

Marc Porter
Systems Ecologist
ESSA Technologies Ltd.

Executive Summary

The Okanagan River and tributary streams throughout the basin provide critical spawning and rearing habitat for salmon, trout and other resident fish species. As a result of increasing water demands, dams for flood control and continuing land development, fish habitat in many subbasin watersheds has been impacted or even eliminated. The Okanagan Water Supply and Demand Project was initiated in response to increasing concern over the remaining amount of surplus water available for continued growth and the impacts of climate change on water supplies and environmental water needs. A major task within our instream flow needs (IFN) project was to use modeled information on "*naturalized flows*"[1] to determine IFN for fish and other aquatic biota at specific areas (called "nodes") that have been defined for the Okanagan Water Supply and Demand Project. These nodes consist of key tributary mouths, mainstem lakes, and key locations along the Okanagan River. For the first time, this report documents a comprehensive approach for defining basin-wide default instream flow needs where site specific data on biophysical linkages does not exist. The approach uses a combination of two peer reviewed IFN methodologies for standard setting that are accepted in the scientific literature and supported by provincial and federal government biologists. Where available, these "default" guidelines are supplemented by instream flow recommendations that currently exist following site-specific IFN studies or water use planning agreements.

Our first IFN method was the Hatfield and Bruce (2000) meta-analysis approach, based on over 1500 habitat vs. flow curves from 127 physical habitat simulation (*PHABSIM*) studies throughout western North America. We used this method to generate regression-based predictions of *optimal flows* for spawning and rearing of kokanee, sockeye, rainbow trout, steelhead, Chinook and coho salmon. While this approach helps to define optimal flows for rearing/spawning salmonids, it does not assess required flows for other fish species, other biota, wetland linkages, channel evolution, etc. Therefore we incorporated *BCIFN* Phase II instream flow guidelines to generate minimum flows required for broader ecosystem needs (Hatfield *et al.* 2003). The BCIFN method estimates *minimum flow* thresholds throughout the year to maintain the key features of a particular stream's natural hydrograph and minimize risk to fish and other aquatic biota. The BCIFN approach also caps recommended extraction/allocation of water from a stream at a defined threshold (a maximum diversion rate). We subtracted this recommended maximum diversion rate from the weekly naturalized flows to calculate a recommended *watershed conservation flow*. The intent of watershed conservation flows is to ensure sufficient water remains in the streams during the high flow months to fulfill geomorphic needs and promote broader ecological functions. Watershed conservation flows are required in roughly one in five to one in ten years.

The instream flow recommendations in this report are largely based on the needs of fish, especially "sentinel" indicator species (e.g., kokanee, sockeye, rainbow trout). Thus, the instream flows recommended do not represent a true ecosystem assessment for all types of aquatic and riparian organisms. Such an undertaking would require a much larger project, one that included considerable time and resources for field assessments and monitoring. We have however made an effort to consider how our default guidelines do or do not support the requirements for a number of other aquatic-dependent organisms which are federally or provincially listed as species of concern.

Another important feature of this report are alternative IFN "scenarios", which represent different mixes of IFN method, focal species/life-stage and *risk tolerances*. For example, Chinook and coho salmon IFN

[1] These italicized items are defined in the glossary on page xi

needs were also evaluated even though they are not currently present in Okanagan tributary streams. These may be useful in the evaluation and design of future restoration initiatives. The IFN scenario results for Okanagan nodes are presented in a variety of formats – as weekly IFN values for nodes uploaded to the OKWaterDB, as graphical representations of weekly IFN recommendations (minimal and optimal flows) at individual nodes, as tables of exceedance probability matrices (linked to "traffic light" plots in some cases) across all tributary nodes, and as hazard maps of inherent hydrologic risk for a subset of IFN scenarios.

It is very important to recognize that consideration of socio-economic water demands and the appropriate ecological trade-offs were *outside* the scope of this study. Anthropogenic water needs are typically readily available from regulatory authorities (e.g., water license information) and at the forefront of legal agreements (e.g., flood protection, recreational flow needs). Where we were able to acquire water use agreement information related directly to fish flow needs, as in the case of Okanagan River, Trout Creek and Mission Creek, we compared these instream flow targets to the default guidelines generated by our BCIFN and meta-analysis methods.

Here is a synopsis of key findings:

- *Naturalized* flows at individual nodes varied in their ability to achieve optimal fish flows for different salmonid species during critical life-stage periods. In general, however, naturalized flows were sufficient in most years to achieve mean optimal flows for rainbow trout and steelhead spawning but often failed to provide optimal flows for kokanee and sockeye spawning in tributaries in which they occur, or for (hypothetical) spawning of Chinook and coho in selected key tributaries. Achievement of optimal rearing flows for rainbow trout, steelhead and coho varied throughout their year-long residence in the streams but optimal flows were generally achieved within the shorter time period of Chinook rearing.
- Tributary nodes in the northeast section of the Basin displayed a better inherent ability to achieve IFN flows defined for different species and during different time periods of the year, whereas the opposite seemed to be the case for tributary nodes in the northwest section of the Basin (i.e., poorer ability to meet IFNs).
- These results reflect the fact that the Okanagan is a naturally dry region, and even in the absence of human water use (as illustrated by naturalized flows), flows are frequently sub-optimal for fish production when considering the flow levels these species prefer throughout their range.

We compared exceedance probabilities for select regulated flows and naturalized flows (this comparison was not possible for most nodes as we did not have the net water availability time series that are to be generated by the water balance modelling project). This comparison indicated that at some nodes recommended BCIFN minimum risk flows were achieved more frequently in the late summer dry period **with regulated flows** than with naturalized flows. This was presumably due to increased storage in some watersheds during the freshet with subsequent release of this stored water later in the summer. However, regulated flows generally met BCIFN minimum risk flow thresholds less often than naturalized flows during other critical time periods (e.g., mid-winter). Increased water storage (where possible) linked to ecological releases targeting critical fish needs represents a valid management avenue for better achievement of instream flows needs – especially in the context of projected future climate change. Developing such strategies (e.g., ecological water reserves) requires an acceptance that instream values have a right comparable to anthropocentric rights (though the relative weights of these rights will vary case by case, and with human values). Historically water has often been allocated among priority rights holders first with instream needs being allocated as an afterthought or only if "excess" water exists. Hopefully this value-system will evolve with future implementation of the Okanagan Sustainable Water Strategy, which emphasizes attaining a better balance between human and ecosystem needs.

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Frequently Asked Questions (FAQs)

Q1: What is the major difference between BCIFN minimum risk and optimal fish flow meta-analysis (Hatfield and Bruce 2000) guidelines? Do they target the same ecological objectives?"

A: No, they don't target the same ecological objectives nor do they use the same assumptions. The Provinces' Phase II Instream Flow Guidelines For Fish (BCIFN) provide a set of seasonally-adjusted (monthly) recommended thresholds for minimum risk flows and allowable water diversion based on a natural flow regime approach. Maintaining these recommended minimum risk flows and allowable diversions is expected to result in low risk to fish, fish habitat, and overall productive capacity. These flows are not to be interpreted as minimum flows required to "adequately" protect aquatic biota. As one proceeds below these thresholds the likelihood of flow-related constraints on aquatic productivity increases. The BCIFN thresholds are intended to be risk-averse because of general uncertainties in fish-flow relationships, but also because they are to be used in situations where there is little or no site-specific information. Another way of coming to terms with these guidelines is through the notion of "burden of proof". The BCIFN guidelines place the burden to prove that there are no unacceptable deleterious consequences on water extraction activities on proponents of such activities. Doing so in a credible fashion will almost always require site-specific assessments of impacts.

The available evidence indicates that there is not a simple 1 to 1 relationship between risk to the fish resource and amount of water used. At times water levels can be severely limiting for fish; in other instances large changes in flow appear to have little effect on fish production. This means that the "right balance" between water use and fish protection is difficult to predict, and may be different for each stream. It is expected that flow criteria may be adjusted on a site-specific basis to reflect the local environment, provided appropriate data are collected (Hatfield et al. 2003).

Alternatively, the Hatfield and Bruce (2000) meta-analysis approach identifies the particular instream flows that are considered *optimal* (i.e., maximizes the PHABSIM index for stream microhabitat) for different salmonid species at different stages of their life-cycle. These flows likewise are thus not minimum flows required to "adequately" protect aquatic biota. The main difference from BCIFN guidelines are that the meta-analysis approach focuses on optimal flows for specific salmonid species' life stages at different times of the year. BCIFN guidelines more generally identify minimum instream flows required in general to maintain healthy, functioning streams for multiple species.

Q2: Isn't it true that fish could do just fine without all this water? In 2003 (as in the 1930s) there was much less water than shown by the BCIFN/meta-analysis values, and the fish still survived and persist today. So aren't you over-exaggerating fish needs?"

A: It is true that fish populations have evolved to withstand environmental perturbations. If they had not they would have long since gone extinct. The flows described herein are based on a wide range of studies across North America with multiple peer reviews; the IFN values are an "unexaggerated' best estimate of the needs of fish and other organisms in order that they face minimum stress. Readers need to appreciate that there is a major difference between just "hanging on" and recommendations for instream flows that provide a high likelihood of maintaining highly productive fish populations and resilient ecosystems.

A key concept worth keeping in mind when considering this question is *resilience* – the capacity of an ecosystem to tolerate disturbances without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary. As human development and water extraction activities spread and become more homogeneous throughout the Okanagan basin, more and more pressures are exerted on fish populations. Land-use development that removes access to *pristine productive* habitats with BCIFN-like flows eliminates the refuge habitats that fish populations would have historically inhabited when waiting out drought. Ultimately, the choice of instream flows depends on: (i) ecological objectives (e.g., maintaining diverse, resilient communities vs. allowing sensitive species to be extirpated in favour of the hardiest organisms, and accepting lower local diversity); (ii) personal value systems and (iii) the larger *spatial* strategic environmental management framework in place for fish protection in the Okanagan. For instance, one could choose to protect a number of representative, productive, *pristine* sub-basins as ecological reserves where human development and water extraction were forbidden or highly constrained, and allow intensive development elsewhere. ***Were*** **this the present situation in the Okanagan Basin (it is not) it might be possible for more environmentalists to answer "yes" to this question.**

Q3: In the summer dry period, meta-analysis flows look like they're actually enhancement flows, right?"

A: Yes. If there were more water available during these periods, we would expect rearing salmonid species to benefit (i.e., achieve closer to optimal production at these times). Extraction activities will only further exacerbate the natural stresses to these populations. Our analysis shows that for a number of sub-basins, fish populations are already under stress due to the semi-arid climate regime and hydrology in the Okanagan Basin.

Q4: During the winter/summer dry weeks of the year, it looks like there's no water at all left to allocate in fish bearing streams. From a fish standpoint, is this true? Doesn't this mean we have to add new storage in order to consider allowing further water allocations in these streams?"

A: Our analysis shows that for a number of sub-basin systems, a variety of fish populations are already under stress due to the semi-arid climate regime and hydrology in the Okanagan Basin. Therefore, yes, in many cases further water extraction activities will further exacerbate stress to these populations. As one proceeds below these thresholds the likelihood of flow-related constraints on aquatic productivity increases. The BCIFN minimum risk thresholds indicate when it is inadvisable (from a fish perspective) to remove flow but also indicate the times and amounts of flow that can be safely diverted when water is plentiful. Adding new water storage is one possible response to enable water extraction and meet instream flow needs, so long as the rule-curves and operating procedures for these reservoirs do in fact explicitly take instream flow needs into account. This includes the spawning period when reservoir releases may tend to be lower than natural flows. The flow thresholds herein may help increase priority for study effort toward the collection of relevant data to resolve conflicts between proposed water uses and instream flows for fish (e.g., site-specific detailed assessments).

Q5: Why does the BCIFN minimum risk method move in monthly time-steps when the fundamental time-step of the Okanagan water supply/demand study is weekly?"

A: The BCFIN method is designed to develop recommended monthly (not weekly) flow thresholds based on variable percentiles of flow for each month based on *daily* flow data collected over a 20+ year time period. For the Okanagan study we are limited to estimates of naturalized *weekly* flows (some with considerable uncertainty) over a shorter 11 year period. Although conceptually the BCIFN approach could be adapted to be expressed as a weekly value an 11-yr time series with estimates of weekly naturalized flow values does not represent enough data (or enough precision) to adapt the BCIFN approach to a weekly time scale.

Q6: These BCIFN minimum risk flow thresholds are generally much higher than some of the criteria used historically in the province (e.g., 20% MAD criteria for rearing, etc.). Why?"

A: Past standard setting methods for instream flow thresholds used in B.C. have generally suffered from three weaknesses: the high degree of professional judgment embedded in the method, the absence of peer-reviewed publications and the lack of biological validation. Such historic criteria are not necessarily wrong, but at this point cannot be adequately supported with existing data.

Q7: In the Okanagan, what processes are in place to resolve fish vs. human water trade-offs?"

The flow thresholds identified in this report emphasize the needs of fish for minimum stress. *Clearly*, other human uses also need to be considered when allocating water. Water use conflicts often arise where minimizing ecological risks create suboptimal water supplies for other resources or interests. We cannot anticipate these cases, and we expect project proponents and the relevant agencies in the Okanagan to undertake studies and negotiations to assess the appropriate balance of trade-offs. This ideally would involve multi-stakeholder evaluations of alternatives and tradeoffs amongst competing objectives, inside a formal Water Use Planning framework. WUP studies also typically include technical evaluations of site-specific biophysical linkages and conditions.

Depending on who is at the table and the terms of reference, WUPs can be formal agreements for how water will be shared between licensees while still providing adequate flows for fish and wildlife. The goal of a WUP is to avoid litigation by achieving consensus on a plan that satisfies the range of water use interests at stake. Detailed guidelines for preparing Water Use Plans have been prepared by an inter-agency committee including BC Hydro, the Province, and Fisheries and Oceans Canada. In British Columbia, the *Water Act* gives priority to senior licence holders under the first-in-right, first-in-line doctrine. This means that during shortages the newest licence holders are legally obliged to stop diverting water first. The *Fisheries Act* also provides legal avenues to remedy deleterious effects on fish habitat, such as when instream flow rights for fish are inadequate. The use of the *Water Act*, its bailiff procedure, or law suits brought by Fisheries and Oceans Canada or First Nations is a litigious approach usually generating a suboptimal distribution of winners and losers. In WUPs, priority rights are set off the table – that is, people with senior rights do not demand that others concede to their needs. The process is intended to be collaborative and cooperative, including a variety of stakeholders in decision-making who are interested in fair, stable solutions over the long-haul.

Q8: Does your analysis take into account water temperature requirements and impacts?"

A: No it does not. Neither the BCIFN guidelines or Hatfield-Bruce (2000) meta-analysis approach explicitly consider temperature requirements or impacts in their recommended flow thresholds. Future work should seek to incorporate water temperature modeling as decreased flows, particularly in late summer, are considered a primary reason for increased stream temperatures in many areas, with consequent negative effects on cold/cool water fish. For example, activities that reduce cool groundwater flows to surface streams can significantly increase temperature stress to fish populations and global warming is expected to further exacerbate these problems. A variety of tools are now available in B.C. for assessing risks to fish populations within temperature sensitive streams which could be explored within future stages of analysis.

Organization of this Report

This report lays out a framework for calculating instream flow needs (IFN) for salmonids, other aquatic biota and general ecosystem processes at Okanagan Basin stream "nodes".

- Methods for calculating default weekly **recommended minimum risk** instream flow thresholds, **maximum diversion rates** and recommended **minimum conservation flows** based on the province's BCIFN methodology are described in section 2.5 and results of these analyses are presented in section 3.1.3 and in Appendix B.
- Methods for calculating instream flows that **optimize** spawning and rearing habitat for particular salmonid species based on a meta-analysis of PHABSIM studies are described in section 2.4 and results of these analyses are presented in section 3.1.4 and in Appendix B.
- **Alternative methods** for calculating instream flow needs based on the Fish/Water Management tool (www.ok.fwmt.net) and existing/draft water use plans for two other Okanagan creeks are presented in section 2.6. Results of these analyses for the Okanagan River mainstem, and Trout and Mission Creeks are presented in section 3.3.
- An **exceedance probability and hazard mapping** approach for assessing the inherent hydrologic sensitivity of different tributary nodes is described in section 2.9 and results based on this approach are presented in section 3.5 in both tabular and map-based formats.
- All data (and supporting metadata) relating to these calculated weekly instream flow needs at each node have been uploaded and can be accessed from the **Okanagan Water Database** (OkWaterDB) website (www.essa.com/okwaterdb).

Note: Due to the large number of scenarios and variable combinations used in our analysis, most of the graphs and maps in this report *cannot* be made suitable for black and white printing. Hard-copies of this report should therefore be printed in **color**.

Glossary

Adaptive management: A process whereby management decisions can be changed or adjusted based on additional biological, physical or socioeconomic information.

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

Anadromous: Fish that mature in seawater but migrate to fresh water to spawn.

Backwater: an off-shoot from the main channel with little flow and where the water surface elevation is maintained by conditions in the main channel acting on the downstream end of the backwater.

Base flow: the minimal volume of water that a river needs to stay healthy over time. Such flows are generally expected to provide a continuous flow through the channel. The flow may be limited to a narrow area of the channel but will provide flow connectivity between habitats in the channel. If the base flows are compromised repeatedly the expectation is that critical habitats will be seriously impaired or disappear, with significant consequences for persistence of dependent fauna and flora.

BCIFN minimum risk flow thresholds for fish-bearing streams: A seasonally-adjusted threshold for alterations to natural stream flows. The BCIFN minimum flow threshold is designed to be conservative and represents the recommended flow level to be retained in a stream. Below this threshold there is a reasonable likelihood of flow-related constraints on aquatic productivity. BCIFN minimum risk flow thresholds are calculated as percentiles of mean natural daily (or in the case of this study – weekly) 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 can be allocated during high flow months than during low flow months.

Channel forming flow: A theoretical discharge that, if maintained indefinitely, would produce the same channel geometry as the natural long-term hydrograph. Often referred to as the bankfull flow, dominant flow, effective flow, or a flow of a specified recurrence interval, typically between the mean annual and 5-year peak flow.

Channel maintenance flow: The range of flows that transports bedload sediment through the channel network, prevents constriction of the channel by sediment and vegetation, and sustains channel bank and floodplain vegetation.

cms: Cubic meters per second (measure of streamflow or discharge).

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

Critical period stream flows: Stream flows during life history stages that are critical for fish growth, survival and production.

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

Dry year: A time period with a given probability of representing dry conditions; for example, a given year may be as dry or drier than 80% of all other similar periods.

Ecosystem: A complex of living organisms interacting with nonliving chemical and physical components that form and function as a natural environmental unit.

Exceedance probability: The probability of an event exceeding others in a similar class.

Flow: The movement of a stream of water or other mobile substance from place to place. Also referred to as discharge.

Freshet: Increased flows caused by melting snows or rain

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

Hydrograph: A graph showing the variation in discharge (flow) over time.

IFIM: The Instream Flow Incremental Methodology

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

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

Instream flow need (IFN): The amount of water flowing through a natural stream course that is needed to sustain, rehabilitate, or restore the ecological functions of a stream in terms of hydrology, geomorphology, biology, water quality, and connectivity.

Larvae: Immature forms that must pass through one or more metamorphic changes before becoming an adult.

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

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

Mean annual discharge (MAD): The rate of streamflow or the volume of water flowing at a location for the individual year or multi-year period of interest. MAD is obtained by dividing the sum of all the individual daily flows by the number of daily flows recorded for the year. If mean annual flows are available for each year of the record, their sum may be divided by the number of years of record to obtain the long-term mean annual flow for the period of record.

Metapopulation: a group of spatially separated populations of the same species which interact at some level and regularly exchange genes.

Minimum flow: The lowest streamflow required to protect some specified aquatic function as established by agreement, rule, or permit.

Natural flow: The flow regime of a stream as it would occur under completely unregulated conditions; that is, not subjected to regulation by reservoirs, diversions, or other human works.

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

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

Nodes: Areas that have been defined within the Okanagan Basin, consisting of key tributaries (at their mouths), mainstem lakes, residual areas and key locations on the Okanagan River. These represent the fundamental spatial units governing surface water for the purposes of the Phase 2 Okanagan Water Supply and Demand project.

Optimum flows for fish (OFF): Stream flows that maximize the limiting or critical habitat for a specific fish species according to hydraulic suitability criteria using depth, velocity and substrate in a weighted useable area or weighted useable width analysis (WUA or WUW). Although optimum flows are not a mandatory requirement for flow management, they are a useful benchmark to determine the relationships among flow, habitat availability and fish production potential.

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

PHABSIM: The Physical HABitat SIMulation system; a set of software and methods that allows the computation of a relation between streamflow and physical habitat for various life stages of an aquatic organism or a recreational activity.

Residual Node: A special kind of node representing a residual area within Okanagan water balance modeling. Residual areas generally possess only ephemeral streams with fish are typically absent and thus were excluded from IFN analysis. Exceptions to this are 4 residual area nodes of interest where small, permanent streams are considered to be present and where rainbow trout and/or kokanee are known or considered likely to be present at some point in the year: E-5 (node 25), W-8 (node 27), W-12 (node 37), and E-11 (node 54).

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

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

Risk tolerance: In the context of this report the use of the best estimate of optimal fish flows (OFF) has a 0.5 probability of being too low, and a 0.5 probability of being too high (i.e., balanced risks). Using the 25th percentile prediction interval (PI) for OFF has higher risk tolerance – there's a 0.75 probability of being too low, and a 0.25 probability of being too high. The 75th percentile prediction interval for OFF has a lower risk tolerance – a 0.25 probability of being too low, and a 0.75 probability of being too high.

Standard setting: A streamflow policy or technique that uses a single, fixed rule to establish minimum flow requirements.

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

Suitability: A generic term used in IFIM to indicate the relative quality of a range of environmental conditions for a target species.

Tributary: A stream feeding, joining, or flowing into a larger stream at any point along its course, or into a lake.

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

Watershed conservation flows (WCF): Flows that address fundamental ecosystem requirements of aquatic habitats including channel formation/maintenance, invertebrate production, and fish production. In general, these flows represent overall ecosystem requirements to support sustainable fish production.

Weighted usable area (WUA): The wetted area of a stream weighted by its suitability for use by aquatic organisms.

Wet year: A water year characterized by above average discharge.

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

1 Introduction

1.1 Background

The Okanagan Basin consists of headwater lakes, tributary streams that flow to lakes and the river at the valley bottom, six large main valley lakes and Okanagan River. The basin crosses the international border with the United States and ultimately drains into the Columbia River. Many of the headwater lakes have been dammed at their outlets and are regulated for domestic and irrigation water supplies. Most tributary streams flow into Okanagan Lake, but a few enter other lakes and the Okanagan River. The streams are driven by snow melt so that their peak flows occur over a two-month period in spring, which is followed by low water flow in summer, autumn, and winter. This pattern of annual flow is out of synchrony with human water uses, especially irrigation, which peaks in summer and early autumn. Water withdrawals from streams are a significant issue, affecting the quality and quantity of fish habitat available. The Okanagan River and tributary streams provide critical habitat for numerous fish species, including spawning habitat for kokanee and sockeye salmon, and rearing/spawning habitat for Chinook, rainbow and steelhead trout and other resident species. As a result of water withdrawals, dams for flood control and continuing land development fish habitat has been severely impacted (or eliminated) throughout the Okanagan Basin (COBTWG 2005).

The Province of B.C. initiated a Water Supply and Demand Project in 2004 in response to increasing concern over impacts to fish habitat and the sustainability of water use in the Okanagan Basin, to evaluate developing water issues in the Okanagan Basin. Phase 1 of this work (Summit Environmental Consultants Ltd. 2005) identified and catalogued relevant data sources, identified data gaps, and developed a strategy for completing Phase 2. The Okanagan Basin Water Board (OBWB), along with provincial and federal agencies and First Nations, then initiated Phase 2 of the project. Two primary tasks for Phase 2 were developed in parallel. These first of these was a surface water hydrology and hydrologic modeling study which has now been completed (Summit 2009). The second task was to use information on "naturalized' flows for 1996–2006 (provided by the surface water hydrology and hydrologic modeling study) to determine instream flow needs (IFN) for specific areas ("nodes") that have been defined within the Okanagan Basin. These nodes consist of key tributary mouths, mainstem lakes, and key locations on the Okanagan River. The instream flow requirements study is the focus of this report, framing an IFN analysis on information provided by the surface water hydrology study (Summit 2009) as well as past work completed for the Okanagan Fish-Water Management Tools project (Alexander *et al.* 2008).

1.1.1 Methods considered

The influence of water flows on aquatic species, particularly salmonids, is well established in the scientific literature (e.g., McCullough 1999; Oliver and Fidler 2001; and Richter and Kolmes 2005). Specific flow assessment methods are also well documented (e.g., EA Engineering Science and Technology 1986, Jowett 1997, Instream Flow Council 2002). A great deal of work has been completed recently in B.C. to review this literature and bring forward recommended instream flow standards for aquatic biota, with considerable amounts of consultation amongst provincial and federal agencies (Hatfield *et al.* 2002; Hatfield *et al.* 2003). More than 50 approaches are available for assessing minimum or optimum instream flow needs for fish (e.g., EA Engineering Science and Technology 1986; Jowett 1997). Available instream flow assessment techniques can be categorized in different ways (e.g., Jowett 1997, Summit Environmental Consultants 1998, Sawada *et al.* 2002), but a useful distinction is between what can be called "standard-setting methods," and "empirical methods." Hatfield *et al.* (2002) reviewed a range of *standard setting methods* that use existing data and simple assumptions, including the Tennant method and modifications of it, the wetted perimeter method, the wetted usable width or toe-width method (Rushton 2000; Washington Department of Ecology 2003), the BC modified-Tennant flow method (Ptolemy and Lewis 2002), and the Hatfield-Bruce meta-analysis approach (Hatfield and Bruce 2000). They also reviewed *empirical methods* that rely on field measurements (e.g., IFIM and PHABSIM (Bovee 1982), 2D and 3D approaches (e.g., USFWS 2001), and adaptive management experiments which monitor fish responses before and after a change in flow (Alexander *et al.* 2006). The most quantitative method involves "*biophysical modeling*" based on targeted field assessment studies designed to quantify flow-modulated survival rates of different life-history stages of fish (e.g., dewatering/scouring flows, emergence timing models, rearing habitat limitations associated with low flows). This is the approach used by the Canadian Okanagan Basin Technical Working group in developing the Okanagan Fish/Water Management Tool for Okanagan Lake and River (Alexander and Hyatt 2008).

For both standard setting and empirical methods the objective is to protect aquatic resources, but the level of information required, the metric used, and the time and cost needed to undertake the tasks may be substantially different. Given the limited time frame for this project, we must rely purely on standard setting methods, though we also recommend a longer term field-based monitoring approach to test the IFN recommendations. Hatfield *et al.* (2002) emphasize that all standard setting methods, as well as empirical approaches like PHABSIM, are essentially hypotheses which need to be tested through well designed monitoring programs. Hence, recognition of uncertainty in IFN recommendations is critical.

In section 2 we propose development of instream flow recommendations for the Okanagan based principally on a combination of two standard-setting techniques: predictions of PHABSIM *optima* (Hatfield and Bruce 2000) and minimum risk flow thresholds from the BC Instream Flow Guidelines for Fish (Hatfield *et al.* 2003) (hereafter BCIFN). We have selected these two IFN methods for this project based on a number of criteria such as the inherent limitation of site-specific data in the Okanagan (feasibility and practicality), history of application in B.C., peer acceptance, inherent uncertainties in the method and ability to quantify those uncertainties, data input availability and data output structure as required for the OkWaterDB.

1.2 Project scope and objectives

The general objective of the instream flow needs study was to summarize the state of knowledge of instream flow needs throughout the Okanagan Basin, and recommend and implement a method for determining default instream flow needs. The methods used were to be consistent with the scoping decisions of the larger water supply and demand study, namely its spatial resolution (flows measured at tributary river mouth "nodes"), base period (1996-2006) and weekly time-step. In the vast majority of cases the method also had to be capable of operating with scant data on site-specific biophysical relationships between fish and flow.

Tasks required to determine instream flow requirements for the Okanagan Water Supply and Demand Project included:

1. Comprehensive review of previous methods used for evaluating instream flow requirements to maintain the integrity of aquatic and riparian ecosystems within the Okanagan Basin, including information recently developed in the Okanagan Fish Water Management Tools project.
2. Development of a practical, defensible methodology based on naturalized streamflows that would allow:

- Determination of instream flow needs and water level requirements (e.g., in lakes and the mainstem Okanagan River) for fish and other key indicator species in Okanagan nodes. Salmonid fishes of management concern in the Okanagan were the focus, but consideration was also given to aquatic "species of concern" meeting criteria under either Canada's Species at Risk Act or BC Conservation Centre "sensitive or threatened" species lists.
- Determination of instream flow requirements that meet general geomorphic and off-channel connectivity functions.
- Establishment of relationships among watershed conservation flows, optimum flows for fish, and critical period stream flows for aquatic biota.
- Recognition of the existence of legal agreements at Okanagan nodes (conservation flow licences and negotiated instream flows agreements).
- Identification of uncertainties inherent in the recommended IFN analysis methods, data or indicators.
- Establishment of an index for determining risk of individual nodes failing to meet IFNs for aquatic biota.

3. Generation of recommended weekly instream flow needs (IFN) for the 1996-2006 period for the subset of surface nodes with permanent flowing water in the Okanagan Basin.
4. Upload of all data and related metadata from this project to the Okanagan Water Database (OkWaterDB)—the master database that has been built to house daily or weekly values of the various water supply and demand variables developed during Phase 2 of the Water Supply and Demand Project.

Our methodology for realizing these objectives is described in section 2.

The potential spatial scope of this project involved a total of 81 key locations ("nodes") within the Okanagan Basin that have been defined by the Okanagan Water Supply and Demand Study Working Group. These nodes consist of key tributaries (at their mouths), mainstem lakes, and key locations on the Okanagan River mainstem (**Figure 1.1**). Water balance equations have been developed for each type of node. These equations identify the key water supply and demand terms that govern water inputs, outputs, and changes in storage at each node. Of this total, a subset of 45 locations were identified by the Instream Flow Technical Committee that had permanent, year round flow and were considered definitely or likely to support fish populations. These represented the initial node locations considered within our IFN analyses. Lake nodes and nodes for the Okanagan River mainstem were further removed from this subset list as these nodes do not (at least currently) have naturalized flow data that we can use as inputs for IFN calculations (although flow needs for these nodes may be addressed by other operating rules in place for the Okanagan River). A final total of 36 tributary stream nodes in the Okanagan Basin were evaluated within our IFN analyses.

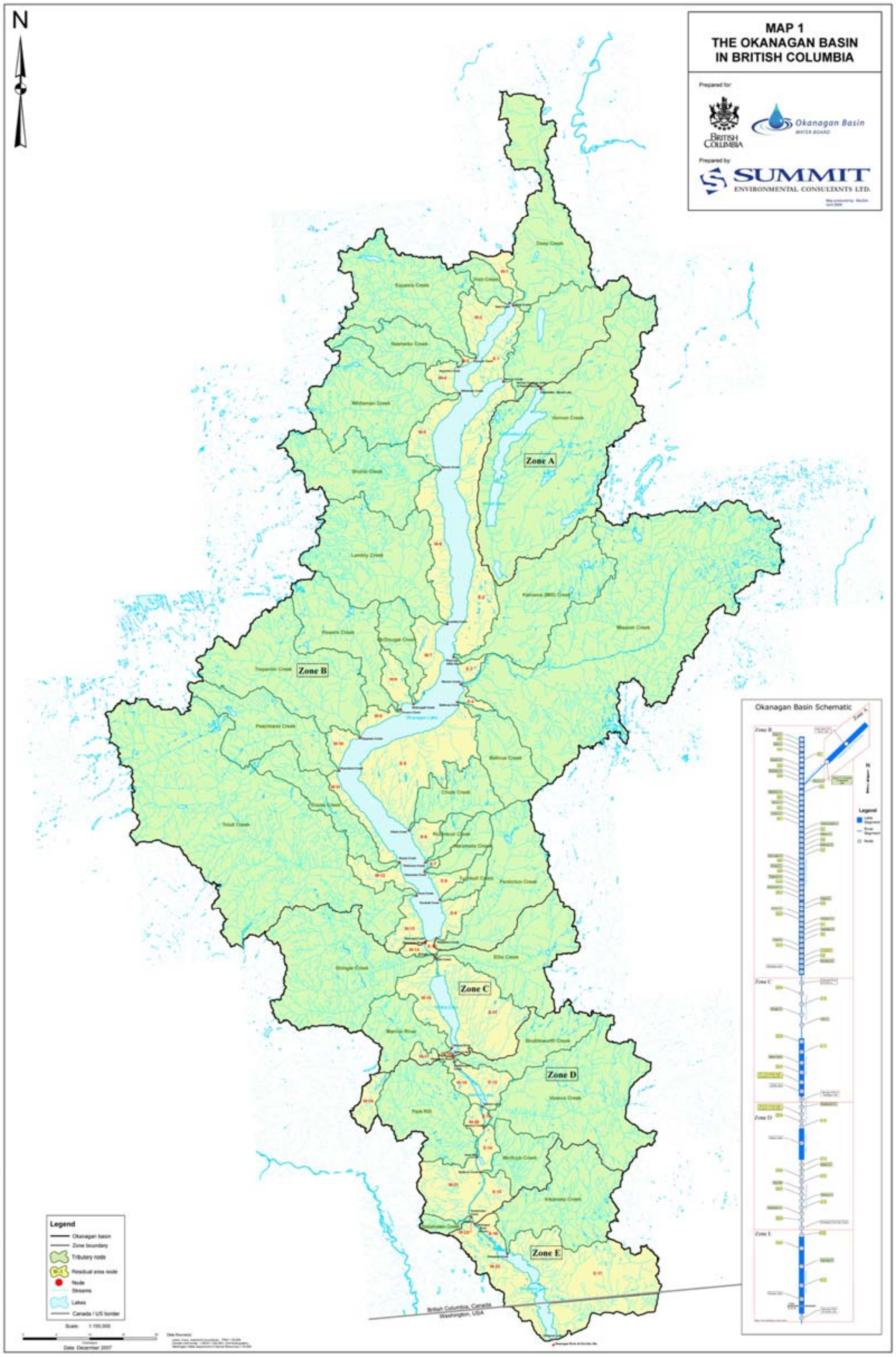


Figure 1.1. Okanagan Basin illustrating the surface "nodes" adopted for the Okanagan Water Supply and Demand Project (provided by Summit Environmental Consultants Ltd., April 2009).

In this study we used the Water Supply & Demand Study Working Group 11-year standard period (1996 to 2006) of evaluation. However, some of the calculations used in our analysis consider a longer time series to avoid time trend bias (i.e., see MAD correction described in section 2.4.4) and to reflect the longer-term evolutionary adaptations of our focal fish species. Additionally, it should be noted that as the calculated IFN values represent single averages determined across the 11 years of "naturalized flow" data the weekly IFN values uploaded to the OkWaterDB are repeated for each year of the 1996–2006 period (i.e., default weekly IFN values that are the same in each year). As such, cross-year statistical analyses should not be performed with the IFN values that have been uploaded to the OkWaterDB.

1.2.1 Project oversight

The Okanagan Basin Water Board (OBWB), along with provincial and federal agencies and First Nations are completing Phase 2 of the Okanagan Water Supply and Demand Project. The goals for Phase 2 include determination of the **current** supply of and demand for water throughout the Okanagan Basin; development of a model (or linked suite of models) that routes water from tributaries into main valley lakes and downstream into Osoyoos Lake that can be used to examine water management alternatives, and identification of potential **future** changes in both water supply and demand. A Steering Committee with representation from the major project funders and other agencies provided guidance and leadership to the Phase 2 study. A Working Group composed of about 20 individuals from various agencies and stakeholders is responsible for project implementation. This group provided the technical expertise and local knowledge to drive the project. A Project Manager was responsible for overseeing the completion of the Phase 2 work. The Phase 2 project prospectus is available on the OBWB website at: www.obwb.ca/fileadmin/docs/Supply_Demand_Phase_2_Prospectus.pdf.

Within the overall team structure for the Okanagan Water Supply Project) are a series of Technical Committees tasked with completing specific analyses required within the project (see **Figure 1.2**). These consist of technical committees for the Hydrologic and Water Balance Model, Water Use, Lake Evaporation, Groundwater, and Instream Flow. The **Instream Flow Needs Technical Committee** that provided oversight for the work undertaken in this report consisted of Kim Hyatt (Chair, DFO), Phil Epp (MOE), Howie Wright (ONA) and Brian Guy (Summit Environmental Ltd.).

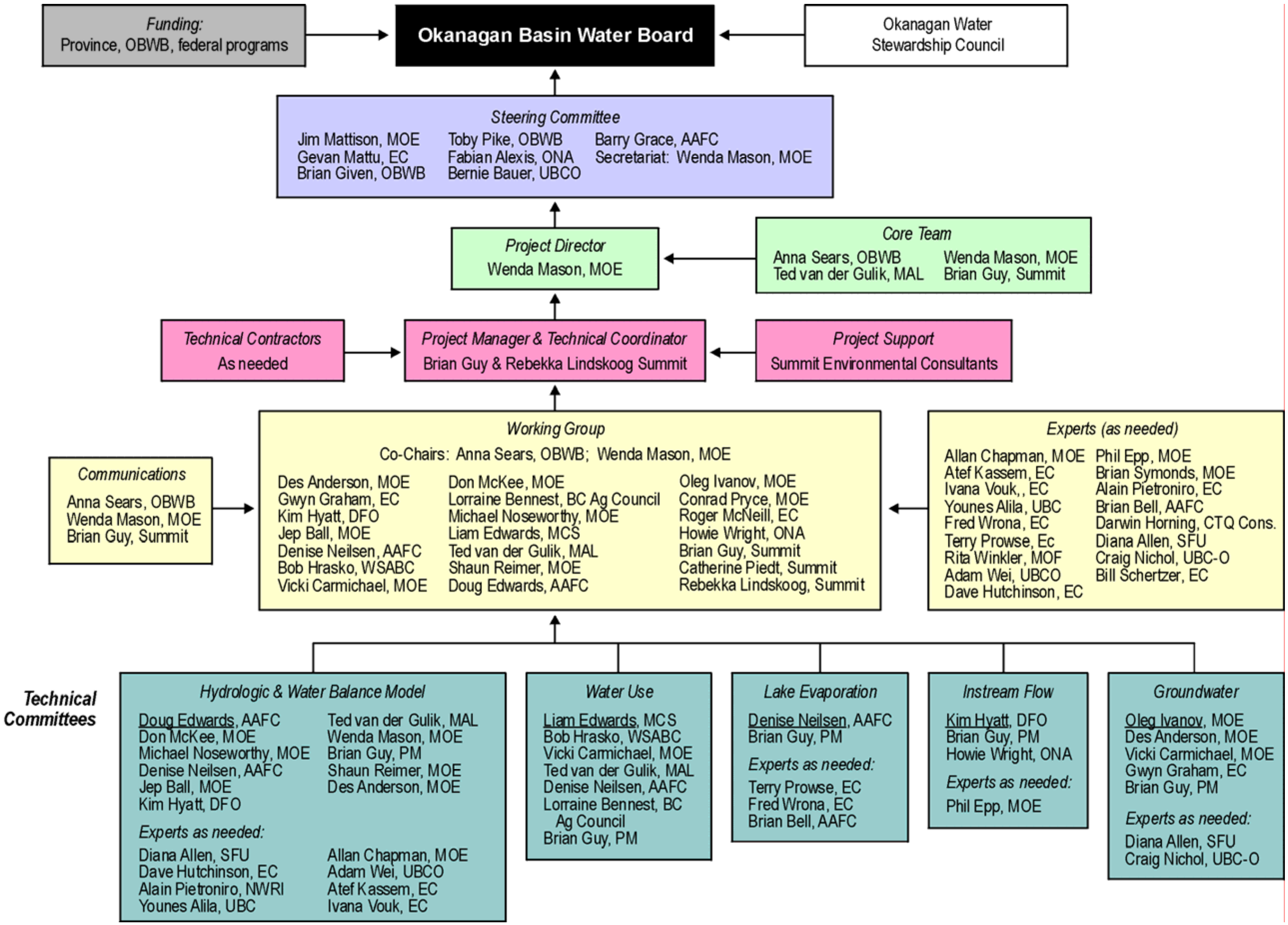


Figure 1.2. Okanagan Water Supply & Demand Study team structure.

1.3 Interpretation and appropriate use of guidelines

This study does not attempt to address value trade-off decisions between fish and other socio-economic considerations. Further, this study was not a field assessment project—we did not determine through experimentation and monitoring site and population specific biophysical responses of fish survival to flows[2] throughout the Okanagan Basin. The default flow guidelines in this report, particularly the British Columbia Instream Flow Needs (BCIFN) guidelines, are known to provide a conservative first filter (*minimum risk* flows, not minimum flows). The BCIFN flow guidelines essentially allow for very low risk to all fish (Todd Hatfield, pers. comm. 2008). Whether this is *too conservative* depends on ecological objectives and individual values, and what additional information is available to use to make finer grained recommendations. Rather than the stance: "prove to me that the fish need these flows", the BCIFN guidelines place the burden to prove that there are no unacceptable deleterious consequences on proponents of water extraction activities. The BCIFN (Hatfield et al. 2003) report clearly states the objectives behind the flows, and for these objectives the authors and reviewers of the method believe it generates a reasonable first filter estimate of minimum risk. Likewise, the strengths and weaknesses of PHABSIM methods (the backbone of the meta-analysis approach used in this study to provide optimal fish flows (Hatfield and Bruce 2000)), are well documented (Castleberry et al. 1996; Williams 1996). If one has different ecological or social objectives or additional and appropriate site specific data, instream flow results will differ from the default guidelines presented herein. In those cases where the amount of water set aside for fish is different (often lower) than these guidelines, a detailed local study (e.g., local hydraulics, biophysical flow-life stage survival assessment) has been performed and/or value trade-offs made with respect to water licensing, flood protection or power production.

Our instream flow guidelines are largely based on needs of fish, especially "sentinel" indicator species (e.g., kokanee, sockeye, rainbow trout). Thus, the instream flow guidelines in this report do not represent a true ecosystem assessment for all types of aquatic and riparian organisms. We have however made an effort to consider how our default guidelines do or do not support the requirements for a number of other organisms such as the Rocky Mountain ridgeback mussel, which is listed as a species of concern under Canada's Species at Risk Act. On the other side of the ledger, because socio-economic flow requirements are readily available from regulatory authorities and generally are at the forefront of legal agreements (e.g., flood protection, recreational flow needs), our analyses do not document these needs. Where we were able to acquire water use agreement information related directly to fish flow needs, as in the case of Okanagan River, Trout Creek and Mission Creek, we obtained these instream flow targets for comparison with the default guidelines generated by our core BCIFN and meta-analysis methods.

This report provides a range of different instream flow guidelines. Some of these guidelines differ because they are the result of different methodologies (e.g., BCIFN minimum risk vs. meta-analysis optimal flows). Some guidelines differ *within* a method because they target *different* ecological objectives that should be satisfied at *different* frequencies (e.g., watershed conservation flows targeting geomorphic channel maintenance processes 1 in every 5 to 10 years vs. annual minimum instream flows for fish). Some instream flow guidelines are specific to individual species and life-stages. Others are the upper and lower prediction intervals associated with a particular mean prediction, showing more and less conservative guidelines based on the uncertainty in the underlying data used to generate the mean prediction. Still others represent site specific instream flow recommendations that are either biophysically

[2] The major exception is the Okanagan River mainstem, where guidelines for sockeye salmon egg, fry and smolt survival have been determined based on detailed site-specific monitoring and derivation of biophysical fish-flow survival relationships. This work, conducted by the Canadian Okanagan Basin Technical Working Group (Alexander and Hyatt 2008), and built into the Okanagan Fish/Water Management Tool (OKFWM; www.ok.fwmt.net), was translated to weekly flow guidelines for purposes of the present study.

based (Okanagan River mainstem) or “negotiated flows” that embed value trade-offs (Trout Creek and Mission Creek).

Given the “menu” of instream flow choices in this report, **readers are strongly cautioned against making the false assumption that the evidence in support of- and objectives for these different guidelines are the same – in most cases they are not.**

2 Methods

2.1 Principles

There are a number of complexities and challenges to selecting an appropriate methodology for determining IFN in a scientifically defensible manner. The following points constitute the set of principles that guided our approach to completing this assignment.

Separate science from human values

In our experience science and human values are often combined and the boundaries between them ambiguous when applied in the context of decision making. For instance, in some cases scientists may inappropriately be asked to make assumptions about social values when developing and applying benchmarks to measurable indicators. Given the regulatory context and potential for public scrutiny, we believe the IFN method should be as scientifically defensible as possible and that human values should be integrated into decision making processes in a transparent way. The level of risk assumed for a given decision on instream flows should be made explicit.

Explicitly consider uncertainties

Many challenging scientific uncertainties exist in developing recommended IFN flows – e.g., the absence of gauge records for many smaller water courses and the need to predict the flows for these systems; variability in response of aquatic biota and fish populations (Bradford and Heinonen 2008). In the domain of risk assessment and management it is generally recognized that decision making processes which ignore uncertainty typically lead to different outcomes than when uncertainties are explicitly considered (e.g., Morgan and Henrion 1990; Clemen 1996). For this reason, we believe an explicit consideration of uncertainties leads to better decision making and more scientifically defensible outcomes. Thus, wherever possible we explicitly considered uncertainties and explored the implications of multiple hypotheses on decision outcomes. Key uncertainties in this project include *input data uncertainty* (e.g., bias or lack of precision in flow estimates due to data gaps in flow records and errors in the assumptions used to fill them, lack of knowledge of aquatic species distributions), *parameter uncertainty* in both hydrologic and fish flow-habitat models, and *model error* (e.g., misrepresentation of how flow affects aquatic ecosystems, or misapplication of functional relationships developed in other river systems).

Leverage past work

The OBWB has a clear interest in building upon previous work undertaken in the Okanagan basin (e.g., work by Phil Epp of the Environmental Stewardship Division of MoE; existing or draft Water Use Plans; and Alexander and Hyatt 2008). We identified information from these studies and incorporated them into our overall methodological framework for recommending IFN flows at fish-bearing nodes. In addition, we attempted to build on past efforts in British Columbia to develop instream flow standards for fish, which have involved considerable consultation with provincial and federal scientists (Hatfield *et al.* 2003; Lewis *et al.* 2004). However, leveraging past work does not imply unconsidered emulation. We took advantage of previous efforts, but tailored the approach to the particular issues and available data relating to development of IFN recommendations for the Okanagan.

Design for the future

The initial implementation of any IFN method will be constrained by currently available data. Methods should not be assumed to be static, but should be expected to be refined and improved over time as better information becomes available, particularly with respect to data poor watercourses. The most powerful method for determining required instream flows is through well-designed adaptive management approaches that take advantage of natural or anthropogenic variations in flows, and monitor the response of local biota (e.g., distribution and abundance of resident fish populations) to these flow variations. While it is clearly not feasible to do this at all fish bearing nodes, it may be possible to classify stream nodes into a set of strata based on their attributes (e.g., perceived sensitivity, level of confinement, percent of groundwater contributions to flow, etc.) and then select one or two streams to monitor in the future from each of these strata.

2.2 Natural flow regime

A growing body of literature treats flow as the "master" variable regulating the form and function of riverine habitats through changes in parameters such as the frequency, magnitude, timing, duration, and rate of change of flow. Dam and water diversion related alterations of river flow regimes have been identified as one of three leading causes of declines in imperiled aquatic ecosystems (the others being nonpoint source pollution and invasive species; Richter et al. 1997, Pringle et al. 2000). Many river-dependent plants and animals are influenced by natural variations in river flow—so much so that they often possess traits that allow them to tolerate or exploit specific seasonal flow conditions. An emerging body of literature supports the notion that there are strong interconnections between flow regime and the species that have adapted to live within the riparian and aquatic environments. This has led to an evolution in ecological thinking away from minimum flow standards. Instead, streamflow as master variable is now widely accepted as the driver of many critical physiochemical characteristics of rivers, such as water temperature, channel geomorphology, and habitat diversity that limits the distribution and abundance of riverine species and regulates the ecological integrity of flowing water systems (Poff et al. 1997). This concept, also referred to as the "natural flow regime", has been investigated and summarized by Poff and Ward (1990), Ligon et al. (1995), Collier et al. (1996), Stanford et al. (1996), Poff et al. (1997), Friedman et al. (1998), Rood et al. (1998), Mahoney and Rood (1998), Richter and Richter (2000), Richter et al. (2003), Dilts et al. (2005), TNC et al. (2008). **Ultimately, the body of knowledge surrounding the pattern of changes in flow quantity, timing and variability now advocates a shift towards a *dynamic, state-dependent* approach to the quantification of ecological flow needs over simplistic "rules of thumb" and static minimum flows.**

Traditionally, approaches used for estimating environmental flow requirements for streams have often focused on the narrow intent of establishing minimum allowable flows for certain fish species (Poff et al. 1997). These approaches generally come with a primary aim of generating administrative simplicity and certainty: "*tell me the minimum flows needed so that I know how much water I can dam and divert to meet human needs*." But modern understanding of ecology (references in previous paragraph) clearly indicates that fish and other aquatic organisms require habitat features that cannot be maintained by minimum flows alone. For example, a range of flows are required to scour and revitalize gravel beds, to recruit and transport wood and organic matter, to provide periodic access to fringing wetlands, and to maintain other important features of channel and riparian dynamics. As shown by the Okanagan Fish/Water Management Tool (Alexander et al. 2008) and the Sacramento River Ecological Flows Tool (TNC et al. 2008), all of these ideas can be formed into a custom package of dynamic, state-dependent flow rules and guidelines for specific systems and focal species.

Lastly, it is important not to confuse natural flow regime theory with the idea of reverting all aquatic riparian systems back to their "historic pre-settlement conditions". Rather, re-establishing at least some level of this natural flow regime should provide significant ecological benefits and can serve as a useful initial management and restoration goal. Recognizing the natural variability of river flow and explicitly incorporating the five components of the natural flow regime (i.e., magnitude, frequency, duration, timing, and rate of change) into the broader management framework of Okanagan Basin water needs would constitute a major management advance over the traditional focus on minimum flows and just a few fish species.

2.3 Hierarchy of methods

Our recommended approach for determining recommended IFN flows at fish-bearing Okanagan nodes is a combination of two IFN methodologies for guideline setting that are accepted in the scientific literature and supported by BC government biologists. The two methods we recommend are also currently being used in tandem for developing instream flow needs for fish within the Nicola Water Use Management Plan (Hatfield 2009). Site-specific studies in the Okanagan which currently inform flow guidelines will supplement or supersede our general IFN recommendations in Okanagan River, Trout Creek, and Mission Creek. The overall methodological framework we have adopted for IFN recommendations is presented in **Figure 2.1**.

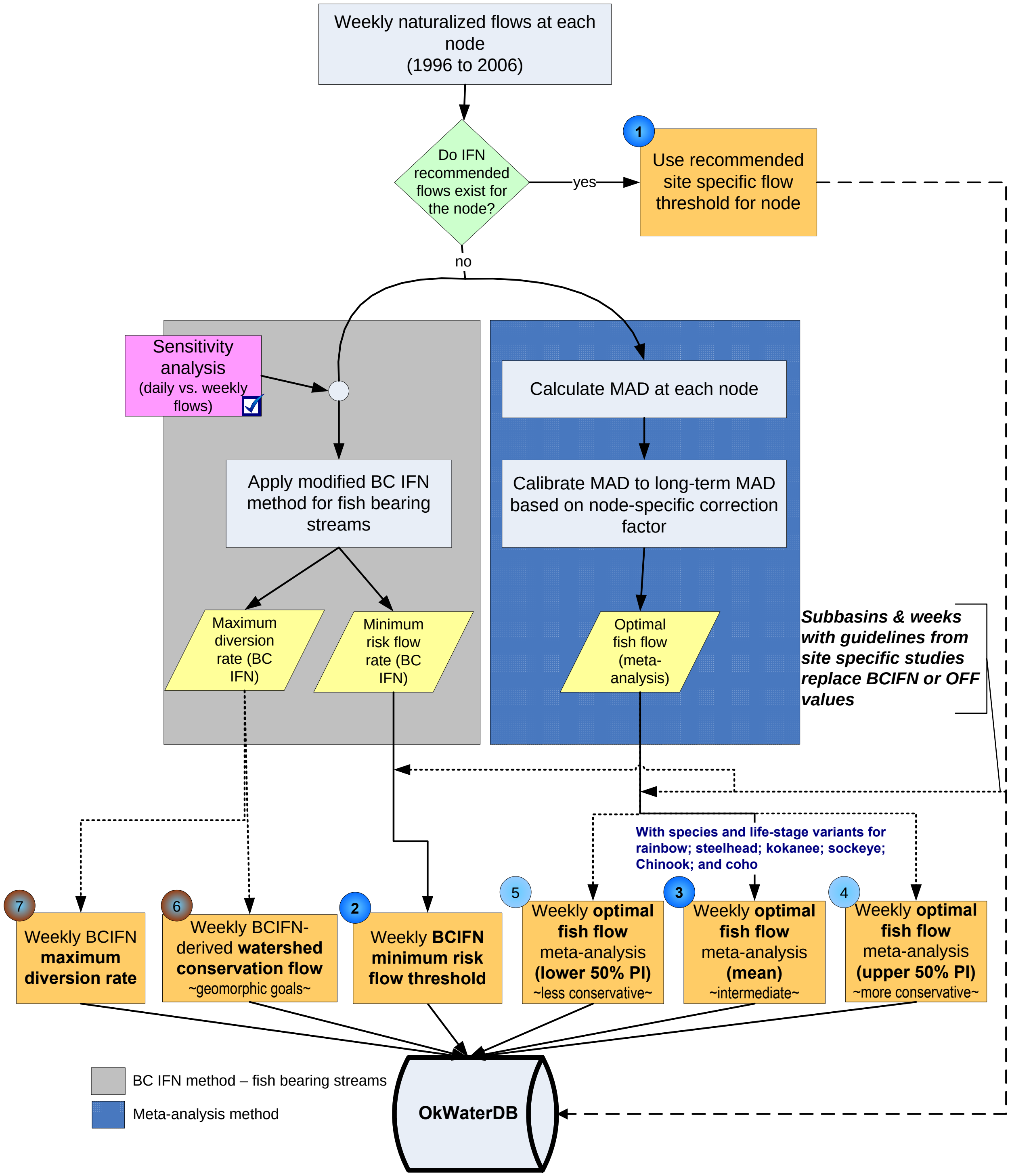


Figure 2.1. Overall approach used in this project for determining Okanagan Basin “node” specific recommended instream flows.

2.3.1 Fundamental input: naturalized streamflows

As part of Phase 2 for the Okanagan Water Supply and Demand project a surface water hydrology and hydrologic modeling study was completed by Summit Environmental Consultants Ltd. (Summit 2009) that:

1. summarized weekly and monthly discharges at nodes where flows are natural (i.e., not influenced by human activity);
2. estimated "naturalized" weekly flows at nodes where there is both gauged data and water use information for 1996-2006 (from the Water Management and Use study completed June 30, 2008 by Dobson Engineering Ltd.); and
3. estimated natural flows at other nodes in the Okanagan Basin using other site-specific approaches.

The summary of weekly natural and naturalized flows at the Okanagan nodes developed by this hydrology and hydraulic modeling provided the key input for the IFN recommendations developed by all three of our main methods used within this report. **Hence, the recommendations in this report rely heavily on the accuracy of these flows.**

2.3.2 Method categories

Method 1

Method 1 is the Hatfield and Bruce (2000) approach based on a meta-analysis of over 1500 habitat vs. flow curves from 127 PHABSIM studies throughout western North America. This approach provides regression-based predictions of optimal habitat vs. flow relationships (**optimal fish flows**) for a number of salmonid species (or all salmonids pooled as a group) for four life stages (principally adult spawning and juvenile rearing). Inputs required for the meta-analysis regressions are:

- MAD;
- latitude and longitude; and
- salmonid distributions and species-specific life stage timings.

Greater detail on the meta-analysis approach and validation of its use in the Okanagan is provided in section 2.4. The Hatfield and Bruce (2000) meta-analysis approach, however, does have the weakness of focusing only on flow needs for rearing/spawning salmonids and it does not incorporate other required flow elements at different times of the year (e.g., needs for other fish species, other biota, wetland linkages, channel evolution, etc.). Therefore we have incorporated a second general IFN method to determine flows for these broader ecosystem needs.

Method 2

Method 2 is the BCIFN Phase II instream flow guidelines (Hatfield *et al.* 2003) based on a threshold approach developed by the Province and DFO. This BCIFN approach generates recommended minimum instream flows based on historic variability in daily (or in our case – weekly) flow data. **BCIFN minimum risk flows** are calculated based on the stream's median flows in the lowest and highest flow months and then seasonally-adjusted based on percentiles of natural daily flows for each calendar month. The intent of this approach is to vary flow thresholds through the year to maintain the key features of a natural hydrograph. The BCIFN approach also caps extraction/allocation of water from a stream at a defined threshold (termed the **BCIFN maximum diversion rate**). Subtracting the maximum diversion rate from the weekly naturalized flow allows us to calculate a recommended **watershed conservation**

flow. The intent of watershed conservation flows is to leave sufficient water in the streams during the high flow months to fulfill geomorphic needs and promote broader ecological functions. Greater detail on the BCIFN approach and validation of a modified version that we developed for use with the Okanagan naturalized flows is provided in section 2.5.

Residual nodes in the Okanagan basin are areas that are considered most likely to be fishless. However, the Instream Flow Technical Committee advised that if a residual node is known to possess a small permanent flowing stream(s), then we would assume there are some fish present at the residual node (i.e., we will assume that all permanent streams in the Okanagan are likely to at least have rainbow trout or kokanee present at some point in time). Phil Epp of the Environmental Stewardship Division (MOE) has identified a subset of the residual areas (see residual nodes identified in **Table 2.2** and Appendix A) that have permanent flowing streams and could be considered potentially fish-bearing. For these residual areas (4 in total) we have also provided IFN recommendations. A practical issue that limits the application of our IFN methods in these residual areas is that naturalized flows cannot be made node specific, but instead must be generalized to the whole residual area. As such our recommended IFN flows must also be generalized to the entire residual area of interest.

Method 3

Method 3 is represented by information from site-specific flow studies that have been undertaken in the Okanagan Basin, which will vary based on the analytical approach used at the node. The subset of nodes from which site-specific information is currently available include the Okanagan River mainstem, Trout Creek and Mission Creek. Flow needs for the Okanagan River mainstem are derived from rules developed within the Okanagan Fish Water Management Tool (Alexander and Hyatt 2008). Trout Creek has established a Water Use Plan Operating Agreement (as of March 2005) in which required flows are based on a multiplier of real-time monitored flows at Camp Creek, which acts as a surrogate for a naturalized hydrograph in Trout Ck. Mission Creek also has a (draft) Water Use Plan that will similarly use a multiplier of real-time flows at a surrogate stream (Pearson Creek in this case) for determining required flows at Mission Creek (Phil Epp, pers. comm.).

2.4 Method 1: Meta-analysis of western North American PHABSIM studies

One of the most widely used detailed methods for determining instream flow needs is the instream flow incremental methodology (IFIM), developed in the 1970s by physical and biological scientists in the U.S. Fish and Wildlife Service. Accepted by many resource managers as an excellent tool for establishing habitat-flow relationships, it is the most widely used method in the United States (Reiser *et al.* 1989; Locke *et al.* 2008) and is commonly used in the rest of the world.

A major component of IFIM is a collection of computer models called the physical habitat simulation model (PHABSIM), which incorporates hydrology, stream morphology, and microhabitat preferences to generate relationships between river flow and habitat availability (Bovee 1982). Habitat availability is measured by an index called the weighted useable area (WUA), which is the wetted area of a stream weighted by its suitability for use by an organism. PHABSIM allows habitat–flow relationships to be developed for any life stage of any species and allows quantitative habitat comparisons at different (hypothetical) flows. Typically, PHABSIM produces bell-shaped habitat–flow curves (**Figure 2.2**). Such a curve indicates a single flow that maximizes WUA.

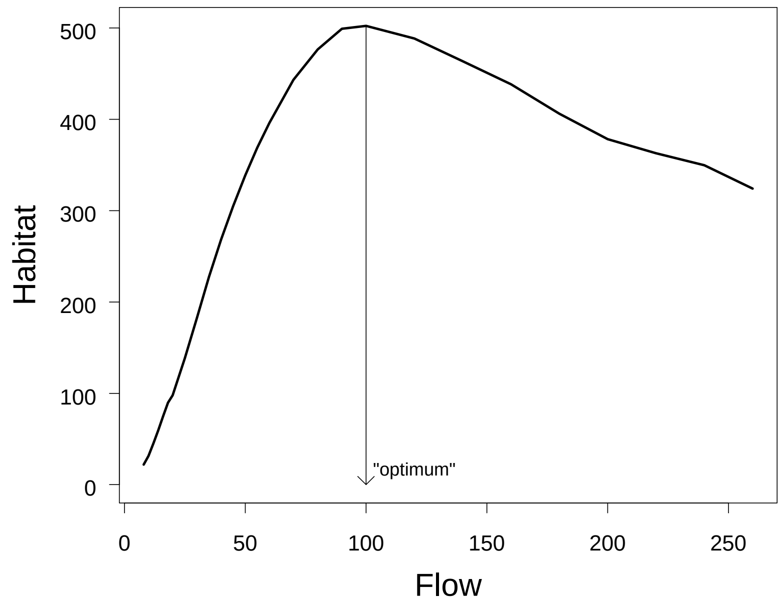


Figure 2.2. Incremental relationships between flow and habitat are often dome-shaped, like this hypothetical curve. The flow that maximizes an index of habitat availability is referred to here as the optimum flow for that species and life stage (from Hatfield and Bruce 2000).

One of the main attractions of PHABSIM and similar methods is that they produce an incremental (i.e., continuous) relationship of habitat vs. flow. Incremental relationships are especially useful when trade-offs are required (e.g., among species, life stages, or other interests like water withdrawals). PHABSIM normally requires substantial effort to collect and analyze data, a process that makes it impossible for use as an overview method.

Recently, a method to predict habitat vs. flow relationships has been developed by Hatfield and Bruce (2000). The method is based on a meta-analysis of over 1500 habitat vs. flow curves from 127 PHABSIM studies throughout western North America and employs regression analysis for prediction 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 (fry, juvenile, adult, spawning). The equations can be used to predict habitat vs. flow relationships in streams of different sizes and geographic locations, and to provide prediction intervals around this relation. The prediction intervals can be used to assign risk thresholds to the predicted optimum flows. For example, the upper bound of a 50% prediction interval means that 75% of streams can be expected to have an optimum flow of this value or less. While regressions have been developed in Hatfield and Bruce (2000) for four salmonid life stages we felt that only the regressions for juvenile rearing and adult spawning flows had sufficient underlying data to use for this study.

The required inputs for the meta-analysis are mean annual discharge (MAD) (in cms or cfs), latitude (in decimal degrees), longitude (in decimal degrees), and the salmonid species and life stage of interest. Separate regressions are available for Chinook, rainbow, steelhead, and “all salmonids pooled”. The “all salmonids pooled” regression can be used to predict flow needs for other salmonids not captured under the short list of named species. **Table 2.1** shows the MAD and latitude/longitude based regressions from Hatfield and Bruce (2000) that we used for calculation of species specific optimal fish flows at the Okanagan stream nodes.

Table 2.1. Equations used for predicting optimum flow for salmonid life stages from the mean annual discharge (MAD) of a stream and its latitude and/or longitude coordinates (from Hatfield and Bruce 2000). Adjusted R^2 values reported for regression models in Hatfield and Bruce (2000) were based on a resampling validation (i.e., bootstrapping). We used the species-specific regressions that had been developed for Chinook salmon, rainbow trout, and steelhead trout, and used the "all salmonids pooled" regression for other salmonid species in the Okanagan (e.g., kokanee, sockeye salmon).

Species	Life stage	Equation	df	Adjusted R^2
Chinook salmon	Juvenile	$-0.998 + 0.939 \cdot \log_e(\text{MAD})$	1, 51	0.705
	Spawning	$-51.710 + 0.682 \cdot \log_e(\text{MAD}) + 11.042 \cdot \log_e(\text{longitude})$	2, 52	0.735
Rainbow trout	Juvenile	$-15.543 + 0.539 \cdot \log_e(\text{MAD}) + 4.400 \cdot \log_e(\text{latitude})$	2, 96	0.775
	Spawning	$-12.037 + 0.598 \cdot \log_e(\text{MAD}) + 3.623 \cdot \log_e(\text{latitude})$	2, 71	0.711
Steelhead trout	Juvenile	$-8.482 + 0.593 \cdot \log_e(\text{MAD}) + 2.555 \cdot \log_e(\text{latitude})$	2, 51	0.770
	Spawning	$-33.064 + 0.618 \cdot \log_e(\text{MAD}) + 7.260 \cdot \log_e(\text{longitude})$	2, 41	0.805
All salmonids pooled*	Juvenile	$-6.119 + 0.679 \cdot \log_e(\text{MAD}) + 1.771 \cdot \log_e(\text{latitude})$	2, 320	0.653
	Spawning	$-12.392 + 0.660 \cdot \log_e(\text{MAD}) + 1.336 \cdot \log_e(\text{latitude}) + 1.774 \cdot \log_e(\text{longitude})$	3, 308	0.681

*The "all salmonids pooled" regression was used for determining the optimal flows for sockeye, kokanee and coho salmon. Coho are not currently present within the Okanagan Basin but were evaluated for potential recovery needs.

2.4.1 Fish presence/absence

Determining the fish-bearing status of nodes in the Okanagan Basin area provides the foundation for developing IFN recommended flows. Information on fish species presence at the nodes defined for the Okanagan Basin was extracted by ESSA staff from BC MOE'S Fish Inventory Data Queries (a100.gov.bc.ca/pub/fidq/fissSpeciesSelect.do) and Fish Wizard queries (www.fishwizard.com). These initial results were tabulated and submitted to BC MOE, DFO, and ONA staff biologists for review and adjustment based on local knowledge. Reviews of fish distributions were provided by Jerry Mitchell (BC MOE, Penticton), Margot Stockwell (DFO, Nanaimo) and Carla Davis (ONA).

Anadromous fish

Three species of anadromous salmon currently exist in the Okanagan Basin: sockeye, steelhead and Chinook. The Okanagan River sockeye population is one of only two populations of sockeye salmon remaining in the international Columbia River Basin. Okanagan steelhead have declined so precipitously in the U.S. Upper Columbia that they have been declared an endangered species (NOAA 2008 – Upper Columbia River Steelhead DPS) and until very recently little was known about their population size or distribution within the Canadian portion of the Okanagan (Long *et al.* 2006). Okanagan Chinook, although once an important part of tribal fisheries in the Okanagan, have now declined to the point that Canadian Okanagan Chinook have been designated as threatened by COSEWIC (COSEWIC 2006a) and are being considered for listing under SARA (DFO 2008). Coho and chum salmon, as well as anadromous white sturgeon and Pacific lamprey, were also historically indigenous to the Okanagan Basin but these have been extirpated from the Basin.

Resident fish

There is a diverse mix of resident fish in the Okanagan Basin. The resident species of primary management concern are kokanee and rainbow trout. Both species utilize many of the lakes and streams throughout the Basin. Other resident salmonids in the Basin include hatchery stocked lake trout, westslope cutthroat trout and brook trout, and possibly bull trout (Long 2003). Resident non-game fish include blue-listed chiselmouth, as well as burbot, whitefish, suckers, dace, sculpins and shiners, and numerous introduced species.

Distributions of native anadromous and resident salmonids found within streams and lakes (the delineated nodes with permanent water flow) in the Okanagan Basin are summarized in **Table 2.2**.

Four residual nodes (listed at the bottom of the table) were included in this summary as they were known to have flowing, permanent streams which could potentially support fish. All other residual node areas are considered to possess only seasonal, ephemeral streams and so were excluded from our IFN analyses. **Table 2.2** also includes hypothetical occurrences for coho (currently extirpated in the Okanagan) and Chinook salmon in some key tributary streams (Powers, Trepanier, Trout and Mission Creeks) in which these species do not currently occur. These hypothetical occurrences were included to allow some analysis of coho and Chinook flow requirements within tributary streams, so providing preliminary information in regards to potential future recovery needs for these species. Appendix A provides a more complete listing of all known fish species occurrences (native salmonids, as well as introduced salmonids and non-game fish) within each of the Okanagan tributary streams, as well as the Okanagan mainstem and lake nodes. IFN recommendations were not developed relating to fish flow needs in lakes or the Okanagan mainstem as naturalized flow data is not available for these nodes. Sockeye flow needs in the Okanagan River mainstem and Okanagan Lake are, however, captured within the Okanagan Fish Water Management tool.

Table 2.2. Occurrences of key native salmonid species in Okanagan Basin nodes. Unique species-specific optimal flows for rearing and spawning of rainbow trout, Chinook, and steelhead were calculated from regressions in Hatfield and Bruce (2000). Optimal flows for kokanee, sockeye, and coho were calculated from a common alternative regression from Hatfield and Bruce (2000) that is based on "all salmonid species pooled." IFN recommendations were not developed for fish species at the nodes shaded in grey (lakes, mainstem Okanagan River) as these nodes currently lack the naturalized flow data required as inputs for IFN analyses.

Node #	Node description	Rainbow trout	Chinook	Steelhead	Kokanee	Sockeye	*Coho*
1	Vernon Creek (at outlet of Kalmalka L.)	●			●		
2	Kalamalka - Wood Lake	●			●		
3	Deep Creek	●			●		
5	Irish Creek						
8	Equesis Creek	●			●		
10	Nashwito Creek	●			●		
12	Vernon Creek (mouth)	●			●		
14	Whiteman Creek	●			●		
16	Shorts Creek	●			●		
18	Lambly Creek	●			●		
20	Kelowna (Mill) Creek	●			●		
22	Mission Creek	●	p		●		p
24	Bellevue Creek	●					
26	McDougall Creek	●					
28	Powers Creek	●	p		●		p
30	Trepanier Creek	●	p		●		p
32	Peachland Creek	●			●		

Node #	Node description	Rainbow trout	Chinook	Steelhead	Kokanee	Sockeye	Coho
34	Chute Creek	●			●		
36	Eneas Creek	●			●		
38	Robinson Creek	●			●		
40	Naramata Creek	●			●		
42	Trout Creek	●	p		●		p
44	Turnbull Creek				●		
46	Penticton Creek	●			●		
47	Okanagan Lake	●			●		
48	Okanagan River at Penticton	●			●	●	
51	Shingle Creek	●			●		
52	Ellis Creek	●			●		
55	Marron River	●					
58	Skaha Lake	●			●	●	
59	Okanagan River at Okanagan Falls	●			●	●	
60	Shuttleworth Creek	●					
64	Vaseux Lake	●			●	●	
66	Vaseux Creek	●		●		●	
69	Park Rill						
71	Wolfcub Creek	●					
73	Testalinden Creek						
75	Okanagan River near Oliver	●	●	●	●	●	
78	Inkaneep Creek	●		●		●	
80	Osoyoos Lake	●	●	●	●	●	
81	Okanagan River at Oroville, WA.	●	●	●	●	●	
25	Residual area E-5 (Lebanon & Deeper Creek)						
27	Residual area W-8 (Westbank Creek)				●		
37	Residual area W-12 (Prairie Creek)	●			●		
54	Residual area E-11 (McLean Creek)	●			●		

● = species present at node

p = species not currently present within the tributary stream but potential presence here if species recovery should occur at some future date

Species colour coding in table corresponds to colours used to distinguish a particular species' optimal rearing/spawning flows in figures in the Results section

2.4.2 Fish species periodicity (critical periods for meta-analysis)

A life history or "species periodicity" table was developed for key salmonid species of management concern present in the Okanagan Basin. The periodicities indicate when particular life-stage-specific regressions from the Hatfield and Bruce (2000) meta-analysis would be applied for each species located at a stream node. **Table 2.3** displays the timing of adult/juvenile migration, spawning, incubation and rearing for stream rearing rainbow trout, steelhead and Chinook and the timing of adult/juvenile migration, spawning and incubation for lake rearing kokanee and sockeye. It also shows hypothetical periodicities for stream rearing coho salmon, using life stage information obtained from studies in the

Nicola River watershed (Hatfield 2009) as a surrogate. Coho salmon are not currently present in the Okanagan but have occurred historically and there is hope for their future recovery (Howie Wright, ONA, pers. comm.). Coho periodicities presented here are therefore interim dates to use until such time as coho might again return to Okanagan streams.

Table 2.3. Salmonid species-specific life stage periodicities observed in Okanagan Basin streams.

Species	Life stage	# of weeks	Start date	End date
Rainbow trout	Adult migration	19	17-Mar	16-Jul
Rainbow trout	Spawning	10	17-May	16-Jul
Rainbow trout	Incubation	15	17-May	24-Aug
Rainbow trout	Rearing	52	1-Jan	31-Dec
Rainbow trout	Juvenile migration	9	1-May	30-Jun
Steelhead	Adult migration	16	17-Mar	26-Jun
Steelhead	Spawning	13	4-Apr	26-Jun
Steelhead	Incubation	15	17-May	26-Aug
Steelhead	Rearing	52	1-Jan	31-Dec
Steelhead	Juvenile migration	9	1-May	30-Jun
Chinook	Adult migration	17	17-Jul	8-Nov
Chinook	Spawning	5	17-Oct	15-Nov
Chinook	Incubation	21	17-Oct	8-Mar
Chinook	Rearing	5	1-Aug	31-Aug
Chinook	Juvenile migration	19	1-Mar	8-Jul
Kokanee	Adult migration	8	25-Aug	8-Oct
Kokanee	Spawning	7	1-Sep	8-Oct
Kokanee	Incubation	31	1-Sep	31-Mar
Kokanee	Juvenile migration	10	1-Apr	31-May
Sockeye	Adult migration	7	1-Aug	15-Sep
Sockeye	Spawning	8	16-Sep	31-Oct
Sockeye	Incubation	23	16-Sep	14-Feb
Sockeye	Juvenile migration	13	8-Feb	30-Apr
Coho*	Adult migration	12	16-Sep	30-Nov
Coho	Spawning	9	9-Oct	8-Dec
Coho	Incubation	31	9-Oct	8-May
Coho	Rearing	52	1-Jan	31-Dec
Coho	Juvenile migration	9	24-Apr	23-Jun

* Coho periodicities are based on information for coho salmon in the Nicola River watershed (Hatfield 2009)

The periodicity table for Okanagan salmonids was constructed by taking "generic" information on species life histories and adjusting this with input from MOE, DFO and ONA staff (identified in the previous section) based on their professional experience in the Okanagan. Life history timing will vary from year to year, depending in part on prevailing conditions. Therefore, where suggested periodicities for the different species varied across information sources we extended the defined windows of time for each life stage to capture all suggestions and ensure that we did not exclude critical times (i.e., we took the most conservative approach). Although we recorded species-specific life history timing for adult migration, spawning, incubation, rearing, and juvenile migration in **Table 2.3** only the time periods indicated for spawning and rearing were used for the framing of meta-analysis-based IFN recommendations. As minimal information currently exists on stream-specific differences in life-stage timing across the Okanagan Basin, the periodicity table captures only generic timings for a species and these are applied to all streams in which they are found. This summary could be adjusted in the future to account for stream-specific timing differences if more detailed information from individual streams becomes available.

It should also be noted that the described salmonid life stage periodicities are based on a 52 week period. The periodicity of each salmonid species' life stage was provided by agency biologists to the project either as an exact date (e.g., steelhead spawning from April 4th to June 26th, etc.), or as occurring during certain periods in a month divided into 4 weeks such as Chinook spawning from mid-October to mid-November. In the first case (i.e., where an exact date has been provided) this information has been directly mapped to a given 52 week block, so April 4th is within week 14 where week 14 starts on April 2nd and extends until April 8th inclusive. For the latter case when presence is given based upon a 4-week month this information has been mapped onto a 52 week schedule based on division of the 28/30/31 day-months into 4 periods as equally as possible. A 30-day month's week 1 and 3 are 8 days, and week 2 and 4 are 7 days. A 31-day month has 8 days for weeks 1, 2, and 3, and a 7 day fourth week. That is, week 3 is from the 17th to the 24th, and week 4 is from the 25th to the 31st. For both approaches some imprecision will have been introduced by going to a 52 week schedule. In all cases we will have likely erred on the conservative side by extending each defined life stage period to the start/end extents of the closest bracketed week.

2.4.3 Validation of meta-analysis approach for Canadian Okanagan streams

To assess the applicability of the meta-analysis to streams within the Canadian Okanagan we subsetted the original Hatfield and Bruce (2000) dataset for “Okanagan-like” samples (i.e., PHABSIM studies from similar biogeoclimatic zones as illustrated in **Figure 2.3**) and assessed whether the points were distributed differently than the rest of the data.

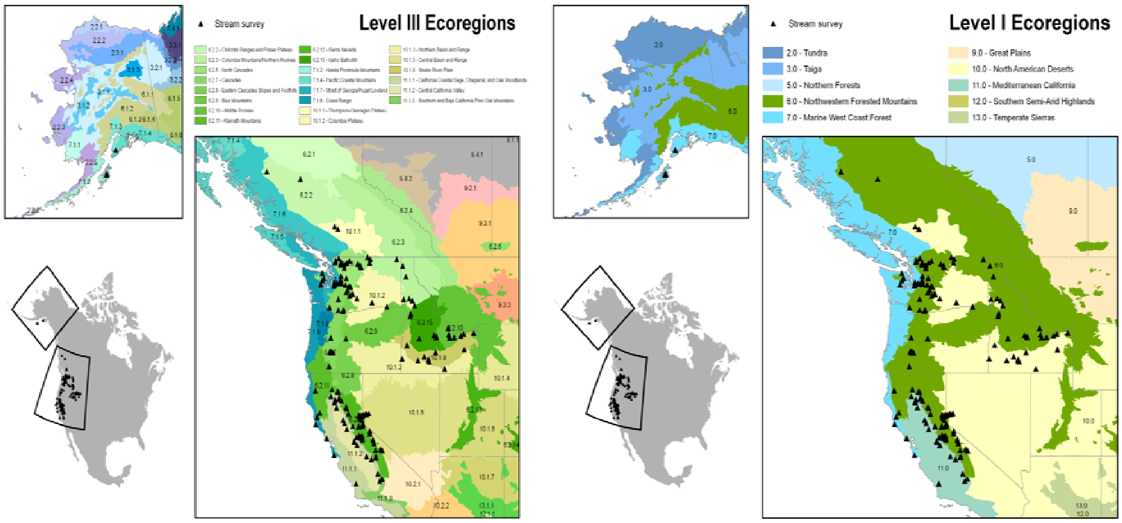


Figure 2.3. Locations of all PHABSIM studies used in the Hatfield and Bruce (2000) meta-analysis, overlaid with North American Ecoregions (from CEC 1997). Okanagan-like sites (determined from a Level III Ecoregion assessment) would be classified more broadly at the Level I Ecoregion scale as Category 10 (North American Deserts).

We determined that Okanagan-like systems were well-represented in the Hatfield and Bruce (2000) analyses, and **Figure 2.4** illustrates there are no obvious biases in the dataset. That is, the points span the full range of stream sizes, and optimal flows[3] are distributed more or less equally on either side of the regression lines.

[3] The term “optimum flow” is used as shorthand for a flow that maximizes a measure of habitat based on microhabitat suitability curves, and does not imply that other aspects of the flow regime can be ignored.

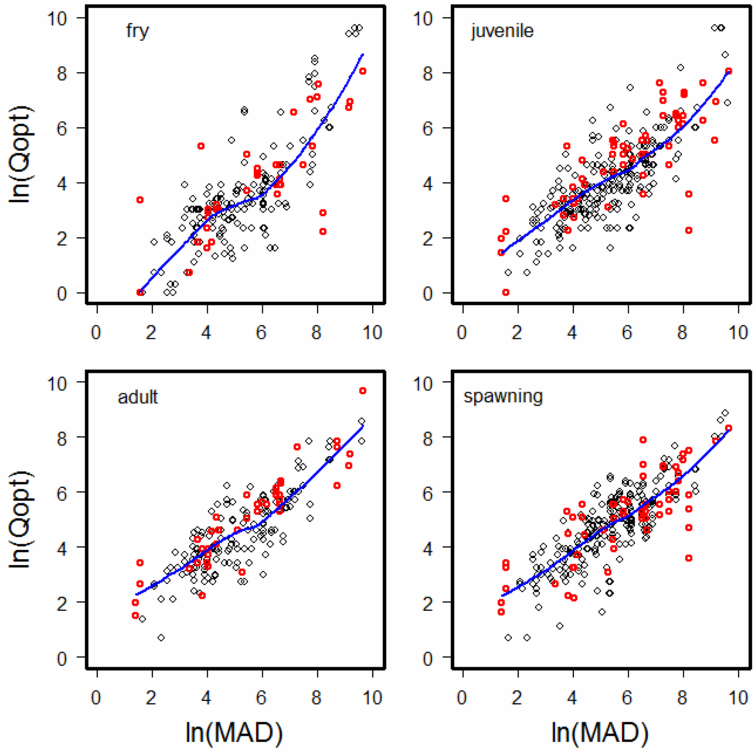


Figure 2.4. Distribution of "Okanagan-like" points (red) relative to the overall dataset used in Hatfield and Bruce (2000). The blue line represents a locally-weighted regression through all data points.

To assess the performance of the meta-analysis approach on specific Okanagan streams we undertook a further validation exercise using field data collected by Phil Epp of the Environmental Stewardship Division (MOE). Field data consisted of measured PHABSIM transects on several streams in the Okanagan Basin. This empirical data was compared to calculated optimal flow outputs from the meta-analysis from the same streams for comparison. The validation exercise allowed two contrasts: rainbow trout parr rearing and kokanee spawning. The meta-analysis predictions are calculated from the Hatfield and Bruce (2000) equations for rainbow juvenile, and from the equations for "all salmonids" spawning. Results are summarized below in **Figure 2.5** and **Figure 2.6**.

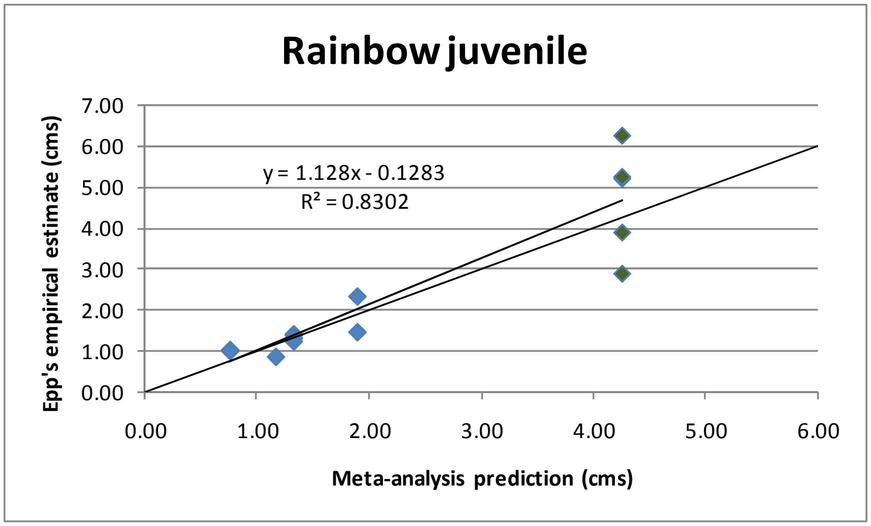


Figure 2.5. Relation between meta-analysis predictions and empirical estimates of optimal flows for rainbow parr in small Okanagan streams. The regression line spans the data range. A 1:1 line, which spans the range of the graph, is shown for reference. Points from Mission Creek are shown in green. The meta-analysis does a good job of predicting the site-specific results as indicated by the broad concordance between the 1:1 line and the regression line.

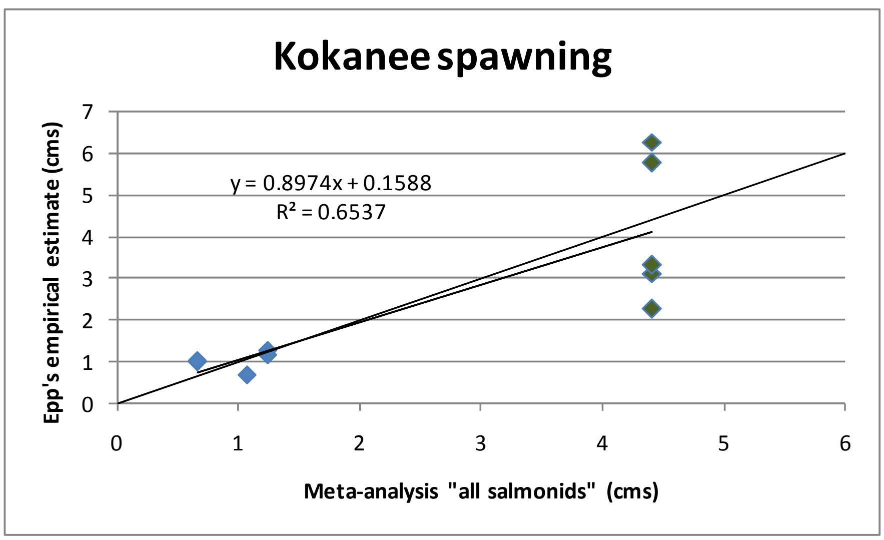


Figure 2.6. Relation between meta-analysis predictions and empirical estimates of optimal flows for kokanee spawning in small Okanagan streams. Since a separate equation is not available for kokanee, the "all salmonids" prediction is used as a proxy. The regression line spans the data range. A 1:1 line, which spans the range of the graph, is shown for reference. Points from Mission Creek are shown in green.

Output from the meta-analysis appeared to provide a reasonable prediction of optimal flows in small Okanagan streams, for these two species and life stages. The sample size is fairly small, but the empirical estimates of optimum flows closely follow the 1:1 reference line. Since the sample size is small and the points are not truly independent no formal statistical tests were conducted. The points for Mission Creek (MAD = 8.08 cms) provide an excellent example of how results are dependent on the morphology and substrate of the creek, which itself can vary substantially among sites and years. The meta-analysis prediction nevertheless approximates the average empirical condition.

This analysis is somewhat qualitative in nature and limited in scope, since it addresses only five streams, but we believe it provided reasonable support for our use of the meta-analysis to develop recommendations for optimal fish flows for salmonids at the Okanagan stream nodes. Additional validation will be possible in the future as more empirical work is completed.

2.4.4 MAD correction factor

Mean annual discharge (MAD) for each node is required for use with the Hatfield and Bruce (2000) meta-analysis approach using the 1996-2006 period of record. However, the 1996-2006 record included several years with exceptionally high annual streamflow yields resulting in elevated MAD values relative to those that would result from a longer dataset. This discrepancy made it necessary to develop corrections for the 1996–2006 MAD values.

To develop estimated MAD corrections for catchment nodes with short datasets (i.e., <20 years), a linear regression equation was generated using MAD corrections for 18 WSC stations (not necessarily stations in common with the nodes for this project) with long-term datasets from the Okanagan, Similkameen, West Kettle, and south Shuswap areas. The data were provided by Summit Environmental Consultants Ltd. The criterion for including each station in the regression was that at least 20 years of data were available including the 1996-2006 period of record. For each station, a MAD correction was calculated as MAD for the entire period of record divided by MAD for the 1996-2006 period of record.

The MAD corrections for the 18 stations were then regressed on several explanatory variables. The full model included catchment median elevation, catchment area, latitude and longitude at the catchment outlet, whether the catchment was natural or regulated (i.e. regulation status), and a classification for the hydrologic zone that the catchment resides within, as well as interactions and transformations for linearity. The final model was as follows:

$$\text{MAD correction} = -1158.8883 + 0.001426389 * \text{median elevation} - 0.0000004845979 * (\text{median elevation})^2 + 23.189663 * \text{latitude} - 9.7142254 * \text{longitude} + 0.19439899 * \text{latitude} * \text{longitude}$$

All variables in the final model were highly significant and the overall model was significant ($p = 0.001$) at explaining the MAD corrections. The amount of variance explained by the model (i.e., R^2) was 78% and the standard error of the estimated MAD corrections was 0.028. The final model suggested that the MAD correction varied non-linearly with median elevation of the catchment and with geographic position of the catchment outlet. The regulation status of each catchment was included in the full model due to its potential impact on MAD; however, the regression results and a t-test indicated that MAD correction did not depend on the catchment regulation status. The physical rationale for this outcome is that catchment regulation has a much lower potential to impact annual flows than to impact instantaneous flows, as flow is usually diverted during only a small portion of each year.

A MAD correction was approximated (i.e., predicted) for each catchment node by applying the final regression model. For 14 nodes the median elevation was lower than those used for developing the MAD correction model. Since MAD correction was highly sensitive to median elevation, the elevations for these 14 nodes were constrained to the lowest elevation in the regression dataset. The same issue existed for 3 nodes with regards to latitude, but was ignored as the MAD correction appeared relatively insensitive to latitude within our dataset. The final MAD corrections averaged 0.935 across the nodes and ranged from 0.868 to 0.994. Corrected MAD was then calculated for each node by multiplying the 1996-

2006 derived MAD by the estimated MAD correction. These corrected MADs were then used in the Hatfield and Bruce (2000) meta-analysis-based optimal flow regressions for each node.

2.5 Method 2: British Columbia Instream Flow Guidelines for Fish (BCIFN)

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) have developed the British Columbia Instream Flow Guidelines for Fish to aid in the process of setting instream flows in British Columbia streams. The guidelines deal specifically with instream flow requirements to support aquatic ecosystem values, and are made up of two main components, Flow Thresholds (Hatfield *et al*. 2003) and Assessment Methods (Lewis *et al.* 2003). The BCIFN method developed by Hatfield *et al.* (2003) for fish-bearing streams calculates recommended minimum instream flow thresholds based on daily stream discharge data over a 20+ year period of record. Thresholds are determined on a monthly basis and water diversions/allocations are restricted to periods when stream flows are greater than the corresponding thresholds. A maximum diversion rate (i.e., infrastructure limit) is defined as equivalent to the 80th percentile flow over the period of record is in effect at all times. During times when flows exceed the sum of the minimum flow threshold and the maximum diversion rate, diversions are restricted to the maximum diversion rate.

The BCIFN method for fish-bearing streams calculates the median of all daily flows for each calendar month (grouping all years together) and the monthly medians are then ordered from lowest to highest. The minimum instream flow threshold for the ***lowest*** median flow month is set to the 90th percentile of the mean daily flows for that month. Conversely, the minimum flow threshold for the ***highest*** median flow month is set to the 20th percentile of the mean daily flows for that month. The flow threshold for each of the other 10 months is also calculated as a percentile of mean daily flows in the respective month, but the percentile varies between 20th and 90th according to the following 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, and
$median_{max}$ is the month of highest median flows.

Figure 2.7 provides an example from Hatfield *et al*. 2003 that illustrates the mechanics of the BCIFN flow threshold approach. In essence the BCIFN guideline permits diversion/allocation of flows within the band demarcated by the two dark blue lines in the figure that represent the minimum and maximum diversion thresholds. Flows below the band are not available for diversion, and would combine with "residual flows" above the band when present.

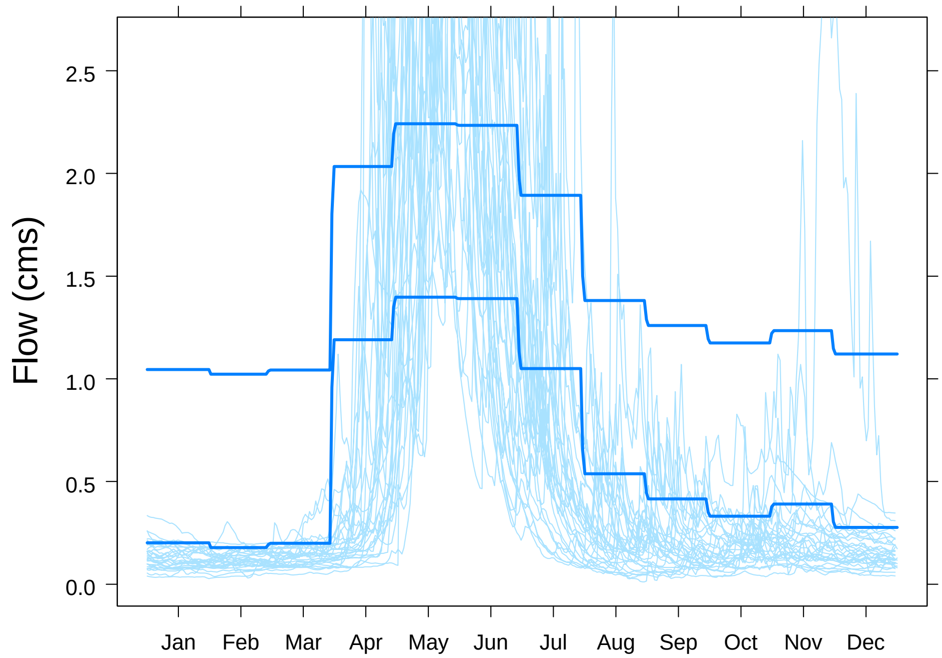


Figure 2.7. Natural mean daily flows (light blue) for Pennask Creek, with flow time series superimposed for each year on record. The dark blue lines show the minimum and maximum diversion thresholds as calculated using the proposed guideline for fish-bearing streams. Flows occurring between these two thresholds are available for diversion/allocation (example figure taken from Hatfield *et al.* 2003, Appendix D).

The BCIFN approach also includes a method that can be applied to fishless streams. For our project we did not apply this to any node. Residual areas defined for the Okanagan that had no perennial flow were considered fishless and were excluded from our IFN calculations.

For this project, streamflow data were provided as mean weekly flows (instead of mean daily flows) over a shorter period of record (1996-2006) than the standard 20+ years recommended for the BCIFN method. As a result, the BCIFN method required adjustment to accommodate these differences in data frequency and duration. Data were assessed over 4-week extents (referred to as periods in the analysis) instead of monthly extents for calculation of median/percentile flows. This data structure led to assessment of 13 periods instead of 12 months in the calendar year. With only 11 years of data and using only weekly data, percentile flows for each 4-week period of the calendar year were determined from 44 data points (i.e. 4 weekly flows per period multiplied by 11 years) instead of the 560–620+ data points (i.e. 28–31 daily flows per month multiplied by 20+ years) than would have been standard for the BCIFN approach. Similarly, calculation of the 80th percentile flow for setting the maximum diversion rate utilized 572 data points (i.e. 52 weekly flows per year multiplied by 11 years) instead of 7300+ data points (i.e. 365 daily flows per year multiplied by 20+ years of data) used typically for the BCIFN approach. The effects of these adjustments on determining minimum instream flow thresholds and maximum diversion rates are discussed in section 2.5.1

In addition to determining BCIFN minimum risk instream flow thresholds and BCIFN maximum diversion rates, results of our analyses were used to calculate a recommended minimum watershed conservation flow for each week of the calendar year. The watershed conservation flow establishes a target flow that should be attained in at least some years for the purpose of maintaining geomorphic processes and wetland linkages that are important for aquatic ecosystem function. Weekly watershed conservation flows were calculated as the maximum of the BCIFN minimum risk flow threshold and the mean regulated flow (i.e., naturalized flow minus BCIFN allowable diversion) over the period of record for each week. Functional watershed conservation flows will generally only occur during high flow months when flows may exceed the sum of the minimum flow threshold and the maximum diversion rate.

2.5.1 Exploratory analysis of altering data frequency and duration

Modifying the BCIFN approach to use weekly (instead of daily) flow data over only 11 years will have reduced the precision of the statistical results relative to the standard BCIFN approach (e.g., determination of the 90th percentile flow for the lowest flow period using only 44 instead of 560+ data point). There would not be any expected bias toward higher or lower thresholds, but results would be less precise simply due to calculations of summary statistics from a smaller sample size. As discussed previously, using weekly flow data required us to split the data into 4-week periods instead of monthly periods for analysis. This alteration resulted in an adjustment to the timing of transitions between thresholds. The overall impact of the timing change, however, is considered negligible.

To illustrate the impacts of using a streamflow dataset with lower frequency and duration, the BCIFN analysis was applied repeatedly to discharge data from two Water Survey of Canada (WSC) stations [Vaseux Creek above Solco Creek (#08NM171) and Whiteman Creek above Bouleau Creek (#08NM174)] using varying data frequencies and durations. Both catchments are considered natural (i.e., unregulated). Vaseux Creek is a 117 km^2 west-draining catchment in the south Okanagan and has a complete set of daily flow data spanning 1971–2006. Whiteman Creek is a 112 km^2 east-draining catchment in the north Okanagan, and has a mostly complete set of daily flow data spanning 1970-2006, other than several months of data that are missing from 1997. The BCIFN analysis was applied for each catchment 4 times: with daily data and the entire record (1970/71-2006), with weekly data and the entire record, with daily data and the 11-year record (1996-2006), and with weekly data and the 11-year record. Summary results from these analyses are provided in **Table 2.4**.

Table 2.4. Vaseux Creek above Solco Creek (WSC #08NM171) and Whiteman Creek above Bouleau Creek (WSC #08NM174). Average minimum instream flow thresholds, maximum diversion rates, and 1999 and 2001 diverted volumes (hypothetical). 1999 and 2001 had the highest and lowest mean annual discharges over the entire periods of record, respectively.

			1970/71-2006 Record		1996-2006 Record	
			Daily Data	Weekly Data	Daily Data	Weekly Data
Vaseux	Average Minimum Instream Flow Threshold (m^3/s)		0.82	0.84	0.86	0.89
	Maximum Diversion Rate (m^3/s)		1.10	1.16	1.29	1.28
	Volume Diverted (m^3)	1999	7,960,000	7,820,000	9,040,000	8,850,000
		2001	895,000	743,000	770,000	571,000
Whiteman	Average Minimum Instream Flow Threshold (m^3/s)		0.59	0.53	0.67	0.65
	Maximum Diversion Rate (m^3/s)		0.71	0.73	0.73	0.79
	Volume Diverted (m^3)	1999	5,030,000	5,410,000	4,750,000	5,090,000
		2001	705,000	908,000	508,000	389,000

The 1996-2006 period of record included several years with exceptionally high annual streamflow yields. As a result, the BCIFN analysis resulted in higher average minimum instream flow thresholds and higher maximum diversion rates for 1996-2006 than for 1970/71–2006, for both catchments. Aggregating daily data to weekly data resulted in increased average minimum instream flow thresholds for Vaseux Creek but decreases for Whiteman Creek. Aggregating to weekly data resulted in increased maximum diversion rates for Whiteman Creek for both periods of record, and for the 1971–2006 period for Vaseux Creek; whereas, the maximum diversion rate for Vaseux Creek decreased slightly for the 1996–2006 period.

Higher maximum diversion rates generated by use of the 1996–2006 weekly record would hypothetically allow greater diversions in high flow years like 1999, whereas, higher average minimum instream flow thresholds with the 1996–2006 weekly record would have restricted diversions more in low flow years like 2001. For example, using the 1996–2006 period of record with weekly data would have resulted in an increase in the volume diverted for both Vaseux and Whiteman Creeks in 1999 (a high flow year) by 11% and 1%, respectively, compared to using the 1970/71-2006 record with daily data. In contrast, the volume of water diverted in 2001 (a low flow year) would have decreased in Vaseux and Whiteman Creeks by 23% and 57%, respectively. An overall comparison (see **Figure 2.8** and **Figure 2.9**) of the minimum instream flow thresholds from 1970/71–2006 daily data vs. 1996–2006 weekly data shows that using the shorter and less frequent 1996–2006 weekly records would have resulted in higher thresholds during high flow periods but similar thresholds during low flow periods compared to the more complete record (1970/71–2006 daily).

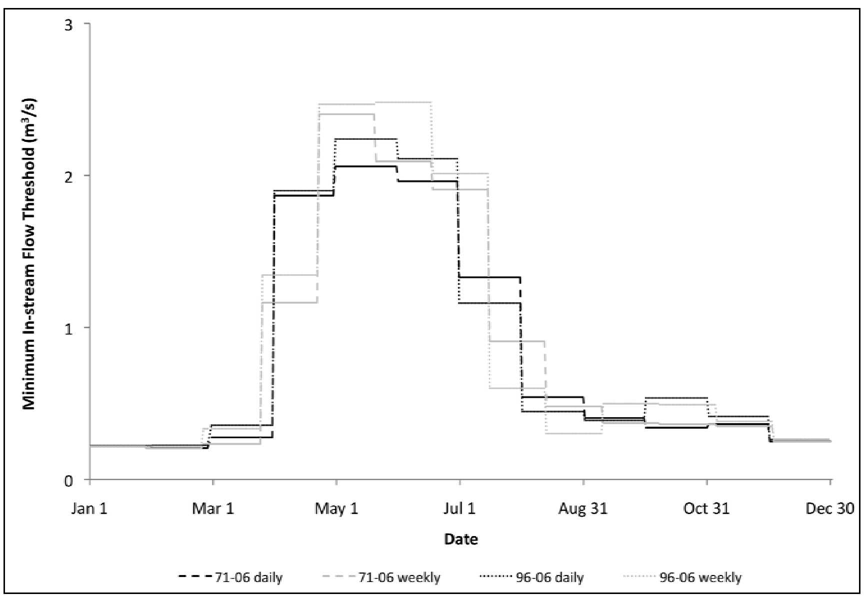


Figure 2.8. Vaseux Creek above Solco Creek (WSC #08NM171). Minimum instream flow thresholds for the 1971–2006 vs. 1996–2006 periods of record and for daily vs. weekly discharge data.

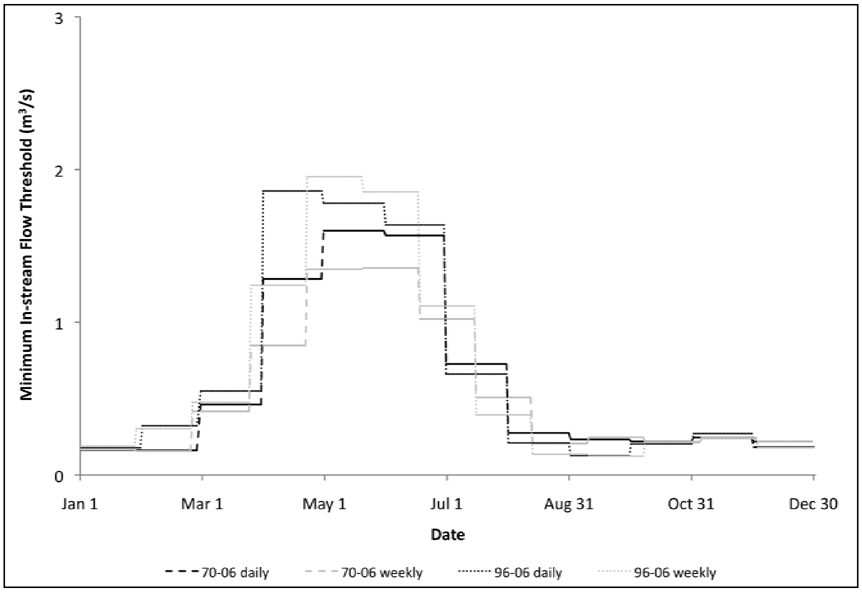


Figure 2.9. Whiteman Creek above Bouleau Creek (WSC #08NM174). Minimum instream flow thresholds for the 1971–2006 vs. 1996–2006 periods of record and for daily vs. weekly discharge data.

2.6 Method 3: Flow guidelines from site specific studies

IFNs to meet fisheries objectives in main-stem river and lake segments in the Okanagan Valley bottom have been specified in several previous reports (Anonymous 1973, Okanagan Basin Agreement (OBA) 1974, Bull 1999) and are reflected in an advanced decision support system (Alexander *et al.* 2008) that resource managers now use to satisfy competing objectives of managing water supplies to balance objectives such as ensuring fish friendly flows, adequate levels of flood protection and adequate water to meet dry-period irrigation needs. IFNs and "ecosystem integrity" indicators for some Okanagan tributary streams have also been explored (NHC 2001). Finally, considerable work has been completed on Trout Creek and is currently underway on Mission Creek to identify flow requirements and Water Use Plans (WUP) that address fish conservation and production goals. Rainbow trout, kokanee or sockeye salmon have been used as the indicator species for assessing flow/habitat impacts and benefits for these studies based on their high level of sensitivity to water quality, water quantity and physical habitat conditions (from OBWB 2008).

2.6.1 Okanagan River mainstem – Fish/Water Management Tools guidelines

Because Okanagan Lake Dam at Penticton controls the flow in the mainstem Okanagan River, both socio-economic and fish flow requirements have been the subject of a number of intensive investigations (see Canada-British Columbia Okanagan Basin Agreement 1974a,b,c; Alexander and Hyatt 2008; Alexander et al. 2008). In the case of Okanagan Lake and River, water levels and flows are managed to provide a balance between flooding, agriculture, fisheries, urban water supply and other interests. However, natural variation in seasonal inflows, scientific uncertainty, competing objectives and multi-agency communication barriers (often related to staff turnover) have historically been significant challenges faced by resource managers responsible for deciding how to allocate limited and variable water supplies in the basin. As with most water management decisions, value differences often come into play, with wide variations in weight placed on flood control vs. other considerations such as water for ecological needs.

To move beyond the sometimes outdated and suboptimal fixed rules in the 1974 Okanagan Basin Agreement, field studies and quantitative models were designed and developed for the Okanagan Fish/Water Management Tool (OKFWM or FWMT) by the COBTWG between 1999 and 2002. Using the same external monthly inflow forecasts provided to the Okanagan basin water managers by the provincial Government's River Forecast Centre, water release decisions are passed to OKFWM's five state-of-the-science biophysical models (hydrology, socioeconomic water management rules, water temperature, kokanee and sockeye) that address lake and down-river considerations at a variety of sites (e.g., Okanagan River at Okanagan Falls, Okanagan River near Oliver). These submodels leverage web service automation for daily real-time updates on lake elevations, water temperatures and discharge in addition to manual information updates obtained from ongoing field monitoring programs (see Alexander and Hyatt 2008 for details). This real-time information feeds into the hydrology and water temperature components of the model to "self-correct" inflow forecasts and adjust forecasts for accumulated thermal units (ATUs) which determine the windows of vulnerability for developing sockeye and kokanee eggs.

OKFWM packages submodel results inside an internet-accessible (www.ok.fwmt.net) tool to guide real-time water release decisions for Okanagan Lake Dam. Specifically designed for day-to-day water and fisheries managers, the web user interface and output reporting features of OKFWM provide an intuitive "traffic light" decision-making framework for choosing weekly water releases at Okanagan Lake dam. The OKFWM software has undergone over 5 years of in-season use (2002-2008), and is now an embedded part of routine water operation decision-making by the Province and Fisheries and Oceans Canada. OKFWM has been recognized as a cutting-edge and innovative computer model that allows all levels of government to participate and agree on trade-offs to best meet socio-economic and environmental goals associated with water management at Okanagan Lake Dam. Jim Mattison, Assistant Deputy Minister of the Water Stewardship Division noted, "*The tool has really helped, not only improving our operation of the [Okanagan] River, but also greatly improving stakeholder and public understanding of the decisions that we make*." In recognition of this achievement, the team and the tool received a 2007/2008 Premier's Innovation and Excellence Award.

Okanagan River sockeye salmon

Legally speaking, Canada and the United States share responsibility for conservation and management of Okanagan River sockeye under the terms of the Pacific Salmon Treaty (1985). In addition, Canadian resource management agencies are constitutionally obligated to conserve and restore First Nations' access to food, social and ceremonial fisheries for salmon. Given their biological, economic and cultural significance, Okanagan River sockeye salmon are the subjects of several significant stock and habitat restoration initiatives, including the Okanagan Fish/Water Management program, and Skaha Lake experimental sockeye reintroduction project.

Fish population restoration in the Okanagan has taken on a higher profile in recent years owing to efforts by First Nations and greater awareness by regulatory agencies about the significant declines in fish abundance. In spite of curtailment of both marine and freshwater harvest, Okanagan sockeye abundance has generally declined (**Figure 2.10**). This poses a major concern as Okanagan River sockeye salmon are the only significant remnant stock of salmon returning to Canada through the Columbia River system in the U.S.

(a)

(b)

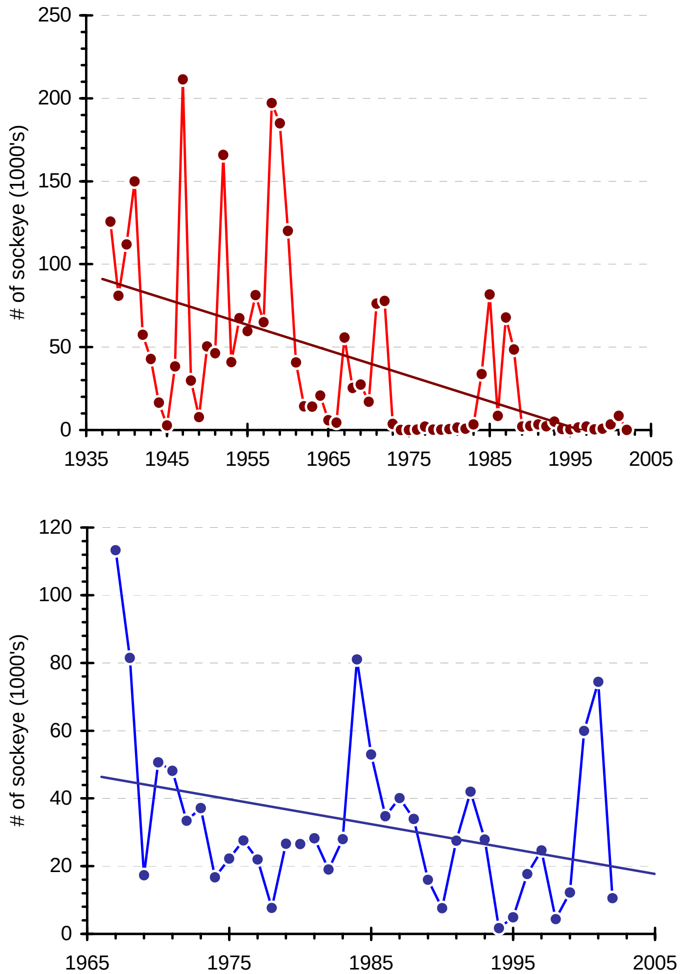


Figure 2.10. (a) Columbia River sockeye salmon catch and (b) Okanagan River sockeye salmon abundance as indexed by passage at Wells Dam, Columbia River (Hyatt and Rankin 1999).

Sockeye goal 1: minimize scour mortality on incubating sockeye eggs

If the water manager fails to lower Okanagan Lake's elevation over the winter, two things are likely to happen. First, lakeshore properties will be flooded. Second, the water manager will likely have to resort to "panic" releases during one or more of April, May and June. These months overlap with the time when sockeye eggs are incubating in Okanagan River. April and May panic flows at Okanagan Lake dam are doubly bad for sockeye eggs because they combine with often sizeable unregulated downstream tributary inflows (which always enter the River and cannot be controlled). Together, panic releases and downstream tributary inflows result in unacceptably high rates of mortality to sockeye eggs through gravel scour (movement of spawning gravel particles, grinding and crushing eggs, and premature flushing of eggs downstream). Field studies suggest that if flows exceed 50 $m^3.sec^{-1}$ in the Oliver area during the incubation period, over 60% of eggs die (Summit 2002a as cited in Alexander and Hyatt 2008).

Sockeye goal 2: maximize survival of rearing sockeye fry (flow mitigation for Osoyoos Lake temperature-oxygen squeeze)

High water temperatures and low oxygen levels, which can establish in Osoyoos Lake in particularly warm summers, are detrimental to rearing sockeye fry and limit their potential to survive. Pulse releases of water in September or August that yield an average monthly inflow to Osoyoos Lake greater than 10 $m^3.sec^{-1}$ are hypothesised to alleviate these rearing limitations (Hyatt et al. 2008). To be effective, a summer pulse release should be of sufficient magnitude and continue for as long as is required to inject an average inflow of no less than 10 $m^3.sec^{-1}$ of water into Osoyoos Lake in the month of September or August. Higher average inflows in either of these months will alleviate the risk even further. The exact time weighted distribution of the inflow required within this summer/early fall period is the subject of ongoing adaptive management investigations.

Tactically, these releases are only possible in certain classes of inflow years (not possible in very dry years), and are only **plausible in average, below-average water years when the water manager has considered the potential need for these pulse releases early enough in the spring, and hedged enough water in reserve**. In other words, during the spring fill period the water manager would need to err on the *higher* side of full pool to realize enough water in storage to permit release of this volume during the summer months without excessively drawing down Okanagan Lake. In practice therefore, a change in risk attitudes related to the balance of flood protection vs. fish population survival needs may be required.

In review, there are four key objectives for the water manager to consider when regulating Okanagan Lake and River:

1. minimising flooding damage around Okanagan Lake and along the Okanagan River downstream of Okanagan Lake;
2. satisfying domestic and irrigation water supply demands;
3. protecting fisheries values, especially Okanagan Lake shore-spawning kokanee eggs and Okanagan River sockeye eggs, alevin and fry; and
4. supporting recreation, navigation and tourism (maintaining acceptable water levels for boat docks and ramps and for river float tourist businesses).

It is difficult for the water manager to make decisions about how much water to release and when to release it from Okanagan Lake dam because the amount and timing of inflow to the system vary significantly each year. The water manager must draw down or lower lake elevation (water level) during winter months (November to February) because Okanagan Lake dam doesn’t have the capacity to handle high inflows during peak snow-melt from March to June. This requires the water manager to understand predictions of inflow to Okanagan Lake based on early winter snowpack and long-term weather forecasts. **Figure 2.11** provides the geographic context and summary of the fish/water objectives and trade-offs addressed within the Okanagan Fish/Water Management Tool. Details associated with balancing these different objectives are described in Alexander et al. (2008).

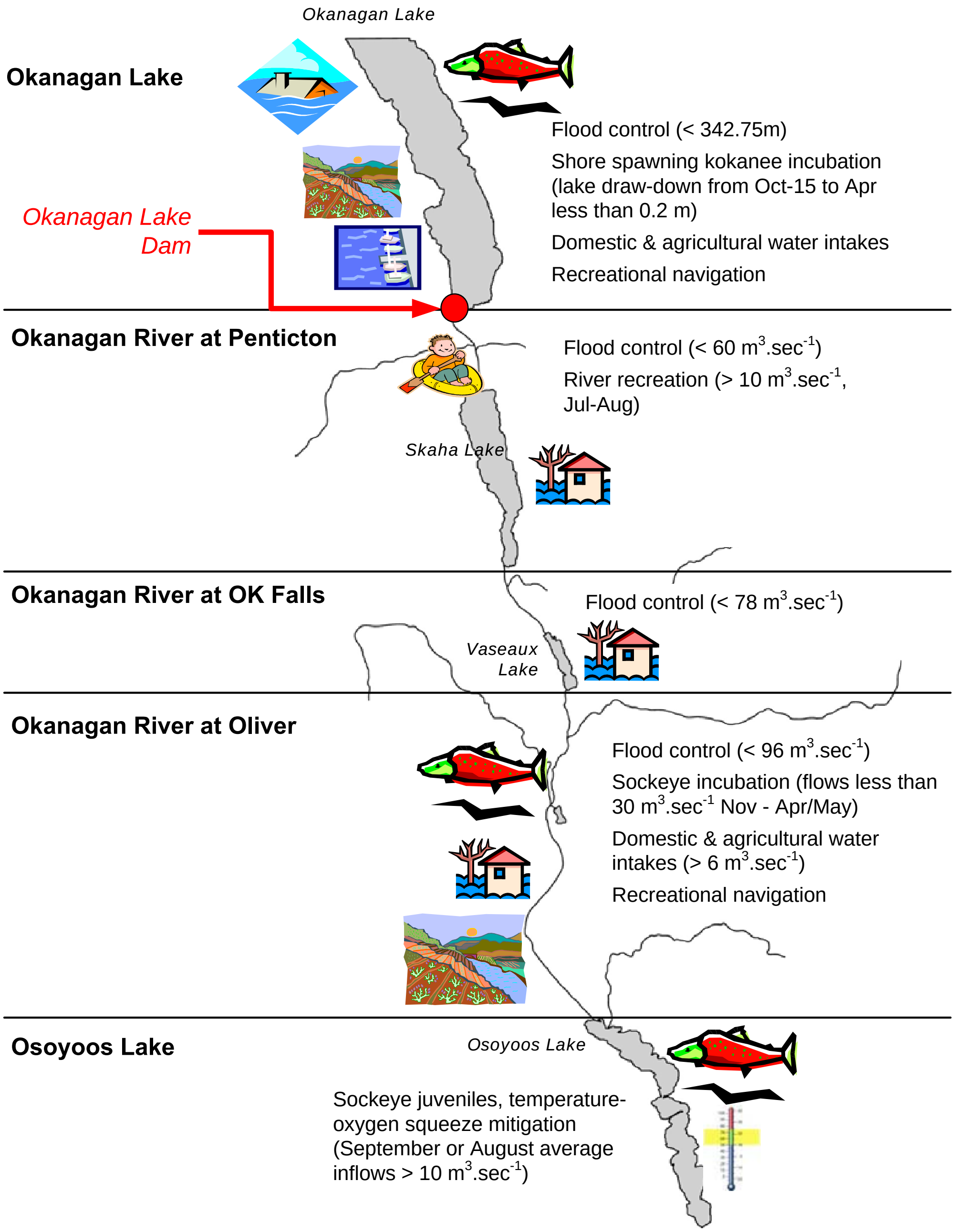


Figure 2.11. The five sections of Okanagan basin that are included in OKFWM. The bullet points summarize the key fish/water management objectives that must be considered within each section.

Okanagan River sockeye salmon instream flow needs loaded to the Okanagan Water Database

For the present instream flow needs study, we uploaded the minimum *and* maximum flow envelope known to avoid and/or improve sockeye egg and juvenile fry incubation and rearing success. Because the optimal solution depends on many factors (water year type, peak sockeye spawning time, winter water temperatures, etc.), no attempt was made to *optimize* this target flow envelop across other flood/water supply objectives. The weekly flows used are within the bounds of flows that have occurred historically. **It is important to note that the *maximum* flows supplied June –September represent the**

approximate flooding limits of flows at the sites used and are *not* target flows for fish. On the other hand, **our minimum flows for the whole year and our maximum flows between October and May do represent minimum and maximum target flows for Okanagan River sockeye.**

FWMT instream flow guidelines were provided for the following three locations: (1) Okanagan River at Penticton (the dam); (2) Okanagan River at Okanagan Falls; and (3) Okanagan River near Oliver. Oliver is the most significant node in FWMT when addressing sockeye salmon flows. It also serves as a surrogate for flows entering Osoyoos Lake. The flow guidelines we supply *upstream* of Oliver take into account average rates of accretion (surrounding tributary and groundwater inflows) and water extractions in the summer-time. That is, differences in flow guidelines upstream of Oliver at Okanagan Falls and Penticton incorporate the flows that would be needed at these sites in average and dry years (wet years were excluded from the calculation of average weekly tributary accretions) in order to, on average, realize the flow guidelines at the more biologically significant *downstream* location—Oliver. These average flow envelopes (see **Figure 3.17**) therefore apply to all years, but in-season would be managed according to flood, water supply, fish trade-offs embedded in FWMT.

2.6.2 Trout Creek and Mission Creek – surrogate stream approach

Site specific instream flow recommendations were determined for Trout Creek and Mission Creek (nodes 42 and 22 respectively) by following BC Ministry of Environment biologist's suggested multipliers on historic flows for Camp Creek (1965-2007) and Pearson Creek (1970-1987 and 2004-2008) negotiated inside of water use agreements. Camp Creek is an unregulated tributary stream in the Trout Creek sub-basin; Pearson Creek an unregulated tributary stream in the Mission Creek sub-basin. These multiplier values were identified inside of water use planning trade-off negotiations including consideration of PHABSIM modelling. Unlike the other instream flow guidelines in this report (including Okanagan River mainstem sockeye flow guidelines from FWMT), these Trout Creek and Mission Creek instream flows embed value trade-off decisions between fish and other human water needs.

Trout Creek

In the case of Trout Creek, we associated the reservoir stage levels identified in the Trout Creek Water Use Plan (Operating Agreement B) with the concept of a water year. The Trout Creek Water Use Plan defines fish flow multipliers to be applied to (unregulated) Camp Creek flows based on reductions in stage of Thirsk Reservoir. According to discussions with Phil Epp (pers. comm., 2009) Stage 1 multipliers represent reservoir levels that would be expected in wet and average years. Stage 2 and 3 multipliers represent reservoir levels that would be expected in (different intensities of) dry years (see **Table 2.5**). Reduction stages 4 and 5 were viewed as very extreme scenarios ("sky is falling") and were therefore not used in our approximations.

Table 2.5. Trout Creek Water Use Plan (Operating Agreement B) – reduction stage multipliers vs. Camp Creek flows by month.

	Reduction Stage					
	1	2	3	4	5	
June	10	8	6	4	0	Fish flow x Camp
	90	85	80	70	0	Community target factor %
July	10	10	9	4	0	Fish flow x Camp
	90	85	80	70	0	Community target factor %
Aug	10	10	10	4	0	Fish flow x Camp
	90	85	80	70	0	Community target factor %
Sept	10	10	10	4	0	Fish flow x Camp
	90	85	80	70	0	Community target factor %
Oct	10	10	10	4	0	Fish flow x Camp
	50	50	50	50	0	Community target factor %

In order to back-calculate weekly average minimum instream flow requirements from the information in **Table 2.5**, we first made a distinction between dry water years and average/wet waters. Dry water years were defined as years when February 1 through July 31 net inflows to Okanagan Lake were less than 350,000,000 m^3. Average/wet years were defined within our analyses as years when inflows were greater than 350,000,000 m^3. (Wet years were defined as years when inflows were greater than 650,000,000 m^3). Historic Camp Creek flows for the period 1965-2007 were then grouped into these two water year type bins. The historic daily gauged flows were then averaged to Okanagan Water Database weekly flows for these appropriate water year classes. We then applied 4 different Camp Creek multiplier schedules to these dry year and wet/average year historic weekly average flows to arrive at weekly average Trout Creek minimum instream flow needs:

- *Case1a/Default (dry yrs)*: In dry years, we used a multiplier of 8.5x Camp for the month of June, when in a dry year. For the remaining months, a multiplier of 10x Camp was used.
- *Case1b/Default (avg/wet yrs)*: In average/wet years we used a multiplier of 10x Camp for all months.
- *Case2a/Drier conditions (dry yrs)*: In dry years, we used a multiplier of 6.5x Camp for the month of June, when in a dry year. For the remaining months, a multiplier of 9x Camp was used.
- *Case 2b/Drier conditions (avg/wet yrs)*: In average/wet years we used a multiplier of 9x Camp for all months.

Current climate conditions (and its effect on Trout Creek reservoir stages) would likely match most closely with the Case 1 multiplier schedules. Potentially, future climate change conditions may increase the frequency that Trout Creek reservoirs are under stage 2/3 conditions, in which case recommended instream flows under the Trout Creek Agreement would be reduced. This situation may be better represented by flows associated with the multiplier schedules defined for Case 2.

The Camp Creek flow multipliers used are consistent with the Trout Creek Water Use Plan Operating Agreement reduction stage schedules, but precise mapping of stages to water years involves subjectivity. The 4 cases we provide should however bracket the range of water supply conditions well enough that these average Trout Creek instream flows ought to compare well with calculated in-season flows under the appropriate reservoir stage condition. Some residual error will remain, as fundamentally, the approach we used is retrospective and is based on applying multipliers to historic average weekly flows rather than real-time in-season daily flows.

Unlike the other default instream flow guidelines we provided (BCIFN, meta-analysis optimal flows), Trout Creek agreement fish flows embed fish-water-human value trade-off decisions. Furthermore, these Trout Creek instream flows will award lower and lower fish flows should Camp Creek flows systematically decline through time. Hence, we caution that over the long-run these flows may not be optimal for fish from a resilience and recovery standpoint.

Mission Creek

For Mission Creek, a constant multiplier of 6x Pearson Creek flows was applied for all years. At the time of writing, this surrogate stream approach and 6x multiplier were in preliminary stages, and not finalized inside of any formal agreement (Phil Epp, pers. comm., 2009). The period of record used in applying this multiplier was 1970–1987 and 2004–2008. The 1970–1987 period represents a Water Survey of Canada gauge, while the 2004–2008 period represents spot measurements taken by Phil Epp, BC Ministry of Environment.

Unlike the other default instream flow guidelines we provided (BCIFN, meta-analysis optimal flows), Mission Creek fish flows arrived at in this manner may embed fish-water-human value trade-off decisions. Furthermore, these Mission Creek instream flows will award lower and lower fish flows should Pearson Creek flows systematically decline through time. Hence, we caution that over the long-run these flows may not be optimal for fish from a resilience and recovery standpoint.

2.7 Lower reference flows

An off-stated desire among water managers is the identification of a base or minimum required flow that represents the water required to maintain a sufficiently healthy stream; one which allows some type of persistence (below the optimal level) of dependent aquatic fauna and flora (Poff et al. 1997). The aim of identifying this level of flow is administrative simplicity and certainty: finding the minimum flows needed so that water available to meet human needs is clear. (Readers should review section 2.2 for the wider context surrounding this matter). In general there is a desire to avoid repeated extreme low-flow events in this regard, because they often serve as ecological “bottlenecks” that present critical stresses for a wide array of riverine species (Poff and Ward 1989). The intent in maintaining this base flow is not to provide availability of optimal levels of aquatic habitat for different species in a stream. Rather such a flow would represent a base level of aquatic habitat protection sufficient to ensure species persistence (i.e., fish and other taxa may be seriously impacted in the short term, but manage to persist in the long term) (Dilts et al. 2005). While identifying such critical base flows would obviously be useful for water managers who are attempting to balance a suite of water demands, actually determining the precise magnitude, frequency, duration, timing, and variability of base flows necessary to maintain some level of ecosystem functioning (particularly in low flow periods) and allow the persistence of associated biotic populations is highly problematic.

Identification of a general rule for short term base flows has been attempted in work by Tennant (1976), and in summaries of similar data from British Columbia (Ptolemy and Lewis 2002). From a variety of cross-sectional measurements, the relationship between wetted width and %MAD sometimes indicates an abrupt change at approximately 10% MAD (Hatfield et al 2002). 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. Such a criterion is not necessarily “wrong.” Instead, it should be seen as a hypothesis in need of empirical testing (Hatfield et al. 2002). In our view, the blanket adoption of such simple rules for purposes of entrenching water allocation decisions in the absence of site-specific research, stakeholder input, and consideration of the broader basin-wide spatial ecological management framework is both dubious and dangerous.

Alternatively patterning identification of base flows to a seasonally variable natural flow regime is a means of realizing flows with greater ecological value than static approaches that ignore system state and natural hydrological patterns and variability. Mimicking components of natural flows as an approach for setting required flows is employed not only within the Okanagan Fish/Water Management Tool (Alexander et al. 2008) but also the Water Use agreements for the Okanagan's regulated Trout and Mission Creeks (see section 2.6.2 for greater detail). Water use plans for Trout and Mission Creek use multipliers of flows in nearby tributaries (Camp and Pearson Creeks respectively) to specify intake bypass flows. The tributaries are unregulated (although not fully 'natural' because they have activities like forest harvesting in them), and are (based on comparisons of historical and current monitoring results), deemed to be reasonable surrogates for what would be the natural flow variation in Trout and Mission Creeks (P. Epp, MOE, pers. comm.). While relationships vary somewhat over the course of the annual hydrograph, it is considered that by multiplying Camp Creek flows by a factor of 10, and Pearson Creek flows by a factor of 6 the plans will approximate what would be the natural flows in Trout and Mission Creeks respectively during the post freshet low flow period from July through October. These defined "natural flows" in Trout and Mission are thereafter considered in the water use plans to represent the required weekly "maintenance" flows for these creeks during the low flow period from the beginning of July through October for each year (P. Epp, MOE, pers. comm. 2009).

The real-time approach used in these Water Use Plans is intended to move beyond specified targets like base or minimum flows and rely on the assumption that replicating a more natural flow regime over the course of the year should provide the necessary ecological benefits and allow better-than-adequate life-cycle support for stream biota. The real-time conversions developed within the Mission and Trout Creek Water Use Plans using surrogate streams is a worthwhile approach but has not yet been developed for other streams across the wider Okanagan Basin nor tested through follow-up monitoring in Trout and Mission Creek. Whether the "maintenance" flows obtained from this approach are truly sufficient over low-flow periods to ensure biotic integrity and the long term persistence of fish populations will need to be monitored and evaluated over time. This should be an area of continuing research in the Okanagan.

In the interim, there is not an accepted, peer reviewed approach using modeled naturalized flows that we can employ to develop a set of recommended weekly base/minimum flows deemed sufficient to maintain 'adequate' ecosystem function and ensure population persistence across the suite of Okanagan subbasins. However, consistent with the idea that replicating a natural hydrograph is most likely to promote retention of ecosystem functions and persistence of dependent populations we provide (in addition to IFN recommendations for optimal flows, watershed conservation flows, and BCIFN minimal risk flows) we provide a lower reference flow. This lower reference flow is represented by the weekly 25th percentile (approximately: 3rd lowest of 11 weekly flow points) of the naturalized flow at each node. This 25% percentile (statistical) flow for each node is used for comparison with BCIFN flow thresholds in the figures provided in Appendix B of this report.

The weekly 25th percentile flows give an arbitrary lower reference line <u>not</u> to be confused with or interpreted as a recommended minimum flow level for any of the nodes. The 25th percentile simply represents a flow that has been exceeded approximately 3 years out of 4 in the stream for each week. For certain, we can say that the 0th percentile (naturalized) flow would be very bad for aquatic/riparian organisms – a virtual death sentence. For certain we can say that the 99.99th percentile (naturalized) flows would be very nearly optimal. Where in-between these two extremes we should be is a *complex* function of site-specific hydrology, focal species and life-stage, state (both physical and biological), and the overriding biophysical linkages that govern flow-biota survival and productivity. It is also a function of spatial meta-population dynamics – how many protected pristine refuge areas do we have elsewhere in the basin that focal species *x* in node *i* could access during low flow periods? None? Some? The answers to these central questions – in addition to one's value system – dictate the appropriate risk range to aim for between these extremes.

Thus, having absorbed the reality of these complexities, there should at least be *some* ecosystem value in striving to ensure that weekly flows during the traditionally low flow periods in a stream are **at least** consistent with the natural level of flows possible in most years. We stress that the 25th percentile flow lines are merely an arbitrary reference against which to compare other types of targets used in this study.

2.8 Additional sensitive species and ecological functions

A fundamental assumption in traditional IFN analyses is that the aquatic ecosystem is adequately protected if the flow-related habitat requirements of salmonid fishes are addressed (i.e., salmonids as sentinel-species indicators of aquatic ecosystem integrity). Canada's new Species at Risk Act (SARA), however, creates a requirement to consider status and trend information for a broad range of sensitive or threatened species (and not only salmonids). Accordingly, it was deemed important in this project to determine how our recommended IFN flows would address instream flow needs of other sensitive stream, lake or wetland species present in the Okanagan Basin. A basic principle for IFN assessment should be to ensure that the recommended flows are sufficient to cover the needs of all sensitive species and valued ecosystem components, though not necessarily in every year (e.g., a fringing wetland may not need to be flooded every year to maintain viable amphibian populations, etc.).

Assessing a suite of focal species or ecosystem components with potentially complimentary (or in some cases competitive) flow needs requires a rigorous delineation of ecological flow requirements. For example, in a recent large project on California's Sacramento River (Stillwater Sciences 2007) ESSA led a formal process for selecting a set of focal species for which IFN were determined using quantitative functional relationships (**Figure 2.12**). However, this process represented a long-term 3 year project. For our work in the Okanagan, we did not have the resources, time, or scientific understanding of Okanagan species to go through such a rigorous process. Nevertheless, we used the basic principles and criteria outlined in **Figure 2.12** to identify additional focal species in the Okanagan Basin beyond those which are already incorporated (either explicitly or implicitly) in our recommended IFN methods (i.e., optimal fish flows for salmonids and BCIFN flows).

In general, we identified additional "sensitive" species in the Okanagan Basin that have dependencies or associations with aquatic habitats, have significant regulatory relevance (e.g., federal SARA listing; provincially blue or red listed), and have perceived population sensitivity that could be affected by changes to instream flows. Our literature review with respect to sensitive species selection was therefore focused on answering the following questions:

- Based on the criteria described above for selecting focal species, what species in the Okanagan could be impacted by ecosystem disruption to lake, river, wetland and riparian habitats (e.g., fish, invertebrates, plants)?
- Does the literature contain life history periodicity charts and flow needs for candidate focal species, or can flow needs be inferred from species distributions?
- To what extent are these species already considered (implicitly or explicitly) in the IFN methods described under Task 3?

Once sensitive species were identified, we worked systematically to document information on species-specific ecological needs of each life stage (i.e., *how would flows affect them?)*. To the extent qualitative information / quantitative data were available we also sought to assess their sensitivity based on (i) a description of the timing of use of these habitats (i.e., *what are the critical periods*?), and/or (ii) a determination of the abundance and location of these habitats. Such elements are important as they represent core factors affecting habitat sensitivity (**Figure 2.13**).

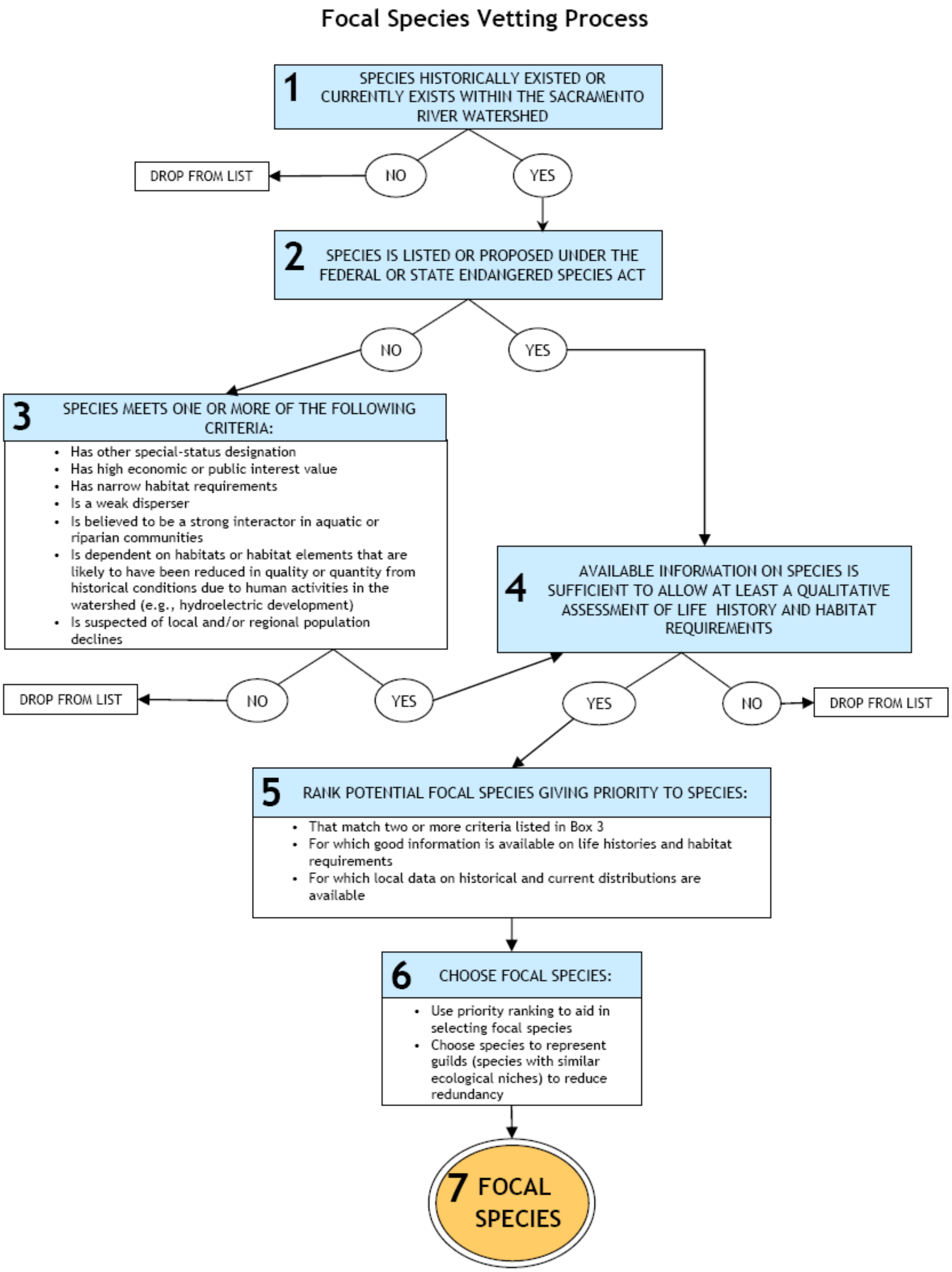


Figure 2.12. Process for selecting focal species as described in the Sacramento Ecological Flows Study. Source: Stillwater Sciences 2007; and TNC, ESSA and Stillwater Sciences 2008. We utilized general elements of this approach for identifying aquatic dependent sensitive species in the Okanagan Basin.

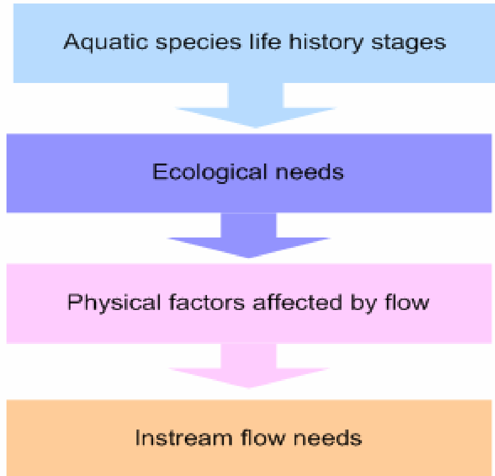


Figure 2.13. Overview of approach for assessing instream flow needs for sensitive species. Starting with the top box we identified sensitive species in the Okanagan Basin and the necessary ecological conditions (e.g., aquatic habitat use, flow) required by species' life stages. We then related these to the necessary geomorphic and hydrologic process that must take place in order to maintain suitable ecological conditions (e.g., critical life stage flows, channel maintenance, wetland linkage) to maintain populations. This also helped us to identify what instream flow method(s) seem most suitable for determining IFN for the suite of sensitive species (e.g., watershed conservation flows, optimal flows for fish during critical periods).

2.9 Treatment of uncertainty and risk

There are a number of uncertainties inherent in instream flow analysis data, methods and indicators. The first source of error is uncertainty in naturalized flow records – the backbone of most of the instream flow guidelines in this report. Naturalized flow datasets often have to be assembled from reconstruction methods, which include data and assumptions that often involve large or unknown errors (see Summit 2009). Our walkthrough of our instream flow guideline plots provide an overview of the magnitude of these errors (section 3.1.1 below, based on Summit's work).

With the meta-analysis optimal fish flows, there is both formulation and statistical uncertainty. By formulation uncertainty, we mean there is ongoing debate about the ability of the PHABSIM approach to adequately describe and measure the needs of fish. There is a wide array of opinion on this, from those who think the approach is bordering on ludicrous to those who accept it unquestioningly. There are also many in the middle who think that it has real limitations but nevertheless works fairly well and the alternatives are unworkable, unrealistic, or outright unavailable—in short, the best we can do under the circumstances. By statistical uncertainty, we mean the meta-analysis is built on a relationship between optimal flow (i.e., peak on the WUA curve) and stream size (i.e., MAD), but there is much scatter around the line even on a **logarithmic** scale. Practically-speaking, this means there is good confidence in the relation, but the predictions fall along a broad band rather than a tight line. This can be seen as the cloud of points in the graphs, e.g., **Figure 2.14**.

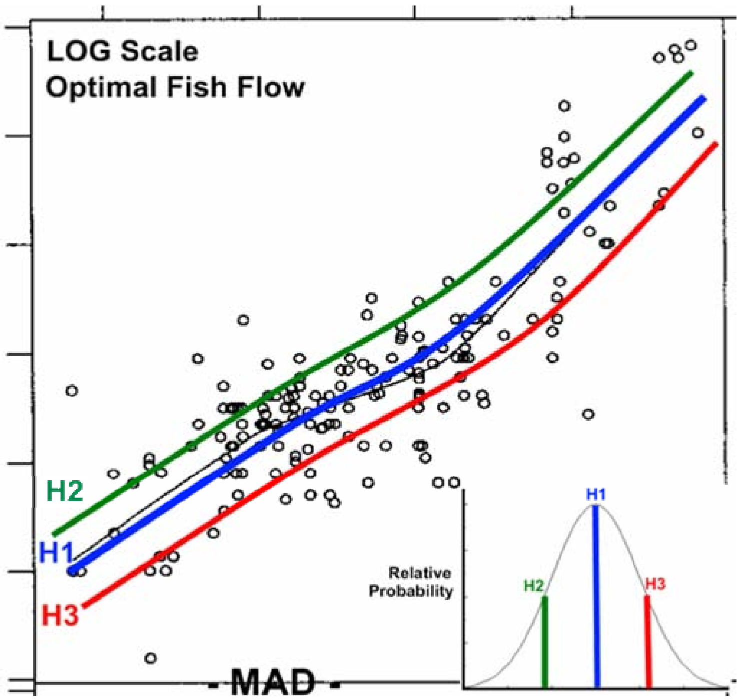


Figure 2.14. Meta-analysis based calculation of optimal fish flows for salmonid species/lifestages (Hatfield and Bruce 2000).

The meta-analysis predicts the flow that maximizes habitat for a particular life stage and species based on MAD and location. The prediction mean is a regression line through a cloud of PHABSIM study points, such that 50% of the points are above the line and 50% are below. By following that regression prediction, one is tacitly accepting the hypothesis that on average you will be correct, but that 50% of the time you will be under-representing the amount of water needed for that species in a particular stream. Essentially, you accept the ecological risk that half the time you will be allocating too much water to other users to the detriment of fish needs. Ecological risk would be decreased or increased by shifting the regression line (prediction intervals), so that fewer or more points fall above the line respectively. To address this uncertainty, our analysis results provide the 50% prediction interval around the mean.

Furthermore, section 2.4.3 documents our successful efforts to corroborate other meta-analysis assumptions for use in the Okanagan basin (e.g., comparing results with data and PHABSIM calculations conducted by Phil Epp of the Ministry of Environment).

The BCIFN method calculates the median of all daily flows for each calendar month (grouping all years together) and the monthly medians are then ordered from lowest to highest. The minimum instream flow threshold for the lowest median flow month is set to the 90th percentile of the mean daily flows for that month. Conversely, the minimum flow threshold for the highest median flow month is set to the 20th percentile of the mean daily flows for that month. The flow threshold for each of the other 10 months are calculated as a sliding percentile of mean daily flows each month between the 20th and 90th percentiles. Thus, the only statistical uncertainty in this method owes to the quality of the naturalized flow data used. The only other "uncertainty" in the BCIFN method—the monthly percentiles used—are not structural or statistical but value and risk-attitude statements. Reviewers of the BCIFN standard agreed with the percentiles used given it's intent of setting a high first-filter on water extraction activities, although others may prefer a different set of percentiles. Maintaining BCIFN recommended minimum risk flows and allowable diversions is expected to result in very low risk to fish, fish habitat, and overall productive capacity. Below these thresholds flow-related constraints on aquatic productivity for certain species and classes of organisms will start to occur.

As documented earlier, we had to modify the BCIFN approach to use weekly (instead of daily) flow data over only an 11 year base period (1996–2006). This temporal resolution and time-frame will have reduced the precision of the statistical results relative to the standard BCIFN approach (e.g., determination of the 90th percentile flow for the lowest flow period using only 44 instead of 560+ data points). There would not be any expected bias toward higher or lower thresholds, but results would be less precise simply due to calculations of summary statistics from a smaller sample size.

We evaluated the potential sample size related bias in section 2.5.1 (and see **Table 2.4**) and concluded that there were no systematic consequences. Further, we have plotted moving average trend-lines for those readers that prefer to think in finer time increments, noting however that the approved and peer reviewed method operates at a seasonal, monthly resolution.

Another form of uncertainty in our analysis relates to interannual variability in flows. There is no such thing as an “average” water year, and therefore, in any one year at any particular moment a stream may be either above or below a calculated instream flow guideline. To address this, in section 3.5 we provide an initial hydrologic risk assessment that calculates the probability that different instream flow guidelines will be exceeded within the following critical periods: 1) freshet flood period (May/June), 2) late summer/fall dry period (Aug/Oct) and 3) mid-winter dry period (Jan/Feb). This is achieved using naturalized flow time series to calculate these seasonal and guideline specific exceedance probabilities. As the inputs for our analysis are naturalized flows, exceedance levels should be relatively high as compared to regulated flows after human extraction activities. Nevertheless, this exceedance probability approach based on naturalized flows quantifies the frequency one expects to realize a particular seasonal instream flow guideline, and provides an important reference point. Comparing a sub-basin node’s inherent ability to meet instream flow guidelines provides an indication of subbasin to subbasin sensitivity, and also a baseline of comparison with anthropogenic risk once time series for net water availability after all extractions are available.

This exceedance technique boils down week over week and year over year information to one number that can then be used to generate simple maps and to risk categorize subbasins for future studies identifying fish protection priorities. The general approach to developing exceedance plots and associated hazard maps for use in the Okanagan Water Supply and Demand Study has been described in a previous ESSA report (Alexander and Robson 2007). This is a promising avenue for simplifying communication of risks to the achievement of instream flow targets.

3 Results

In total we generated a total of 38 independent IFN scenarios, representing different mixes of IFN method, species, life-stage and risk tolerance. These IFN scenarios were uploaded to the Okanagan Water Database, as shown for the example in **Figure 3.1**.

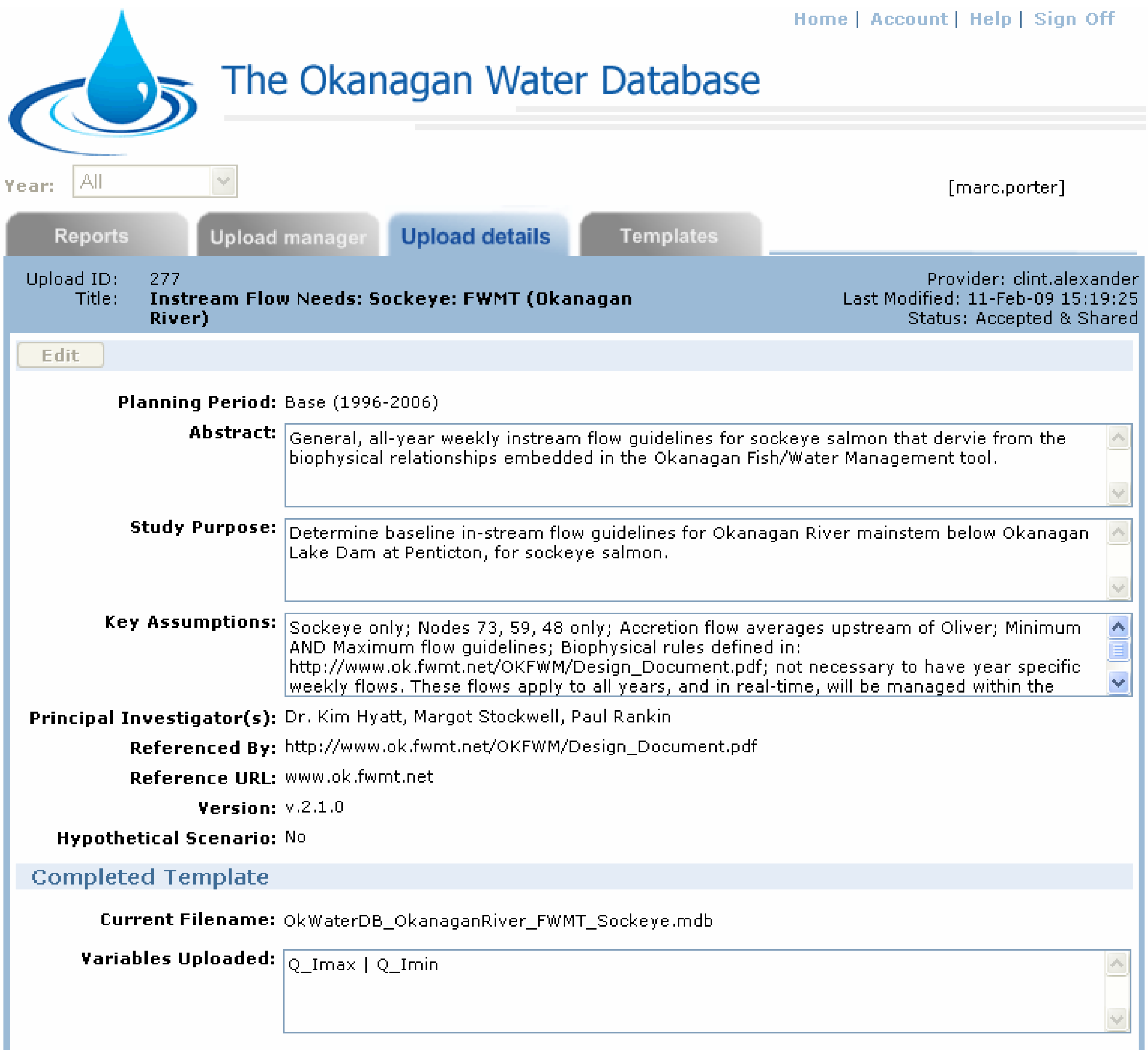


Figure 3.1. An example screen capture of the database template used for uploading IFN recommendations into the Okanagan Water Database for each instream flow scenario we developed.

3.1 Understanding instream flow guideline plots: a walk-through

3.1.1 Natural variation and measurement error in naturalized flows

BCIFN and meta-analysis based thresholds have been calculated based on the historical 1996-2006 time series of naturalized flows (i.e., mean weekly flows used for BCIFN thresholds and mean annual flow for the meta-analysis based optimal fish flow targets). There is natural variation in the flows captured over the 11 years of the averaging (also referred to as process error or 1st stage error). **Figure 3.2** presents an example of this natural variation in flows for Trout Creek (Node 42). A broad scatter of individual weekly naturalized flows exists over the 11 year period, with often wide 95% confidence intervals around the average.

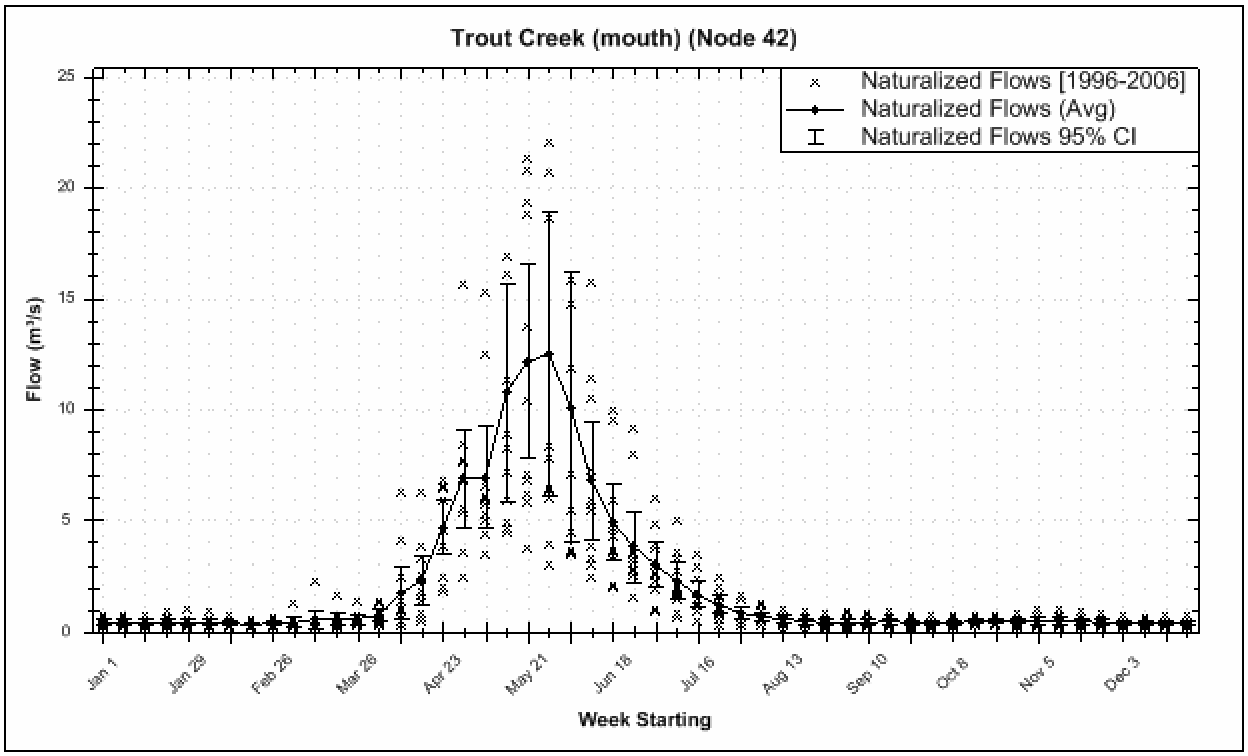


Figure 3.2. Naturalized hydrograph for Trout Creek over the 1996-2006 time period showing individual weekly flows for each year (represented by x's) and the mean weekly flow bounded by 95% CIs ($\alpha = 0.05$) based upon a T-distribution with 10 degrees of freedom (N – 1).

Additional error in calculation of mean naturalized flows is also present in the way data has been assembled and manipulated in the modeling exercise itself (Summit 2009). This type of error is termed measurement error or 2nd stage error. Approximate ranges for measurement error required by the OkWaterDB (binned error categories i.e., >10%-25% error, 25%-50% error, etc.) have been assigned for the naturalized flows calculated at each node, and these error ranges will vary by node depending on the quality of data available for modeling the naturalized flow. An example of the potential error (high end estimate for this node) in calculating the weekly naturalized flow is presented for a single year (1996) for (Trout Creek - Node 42) in **Figure 3.3**.

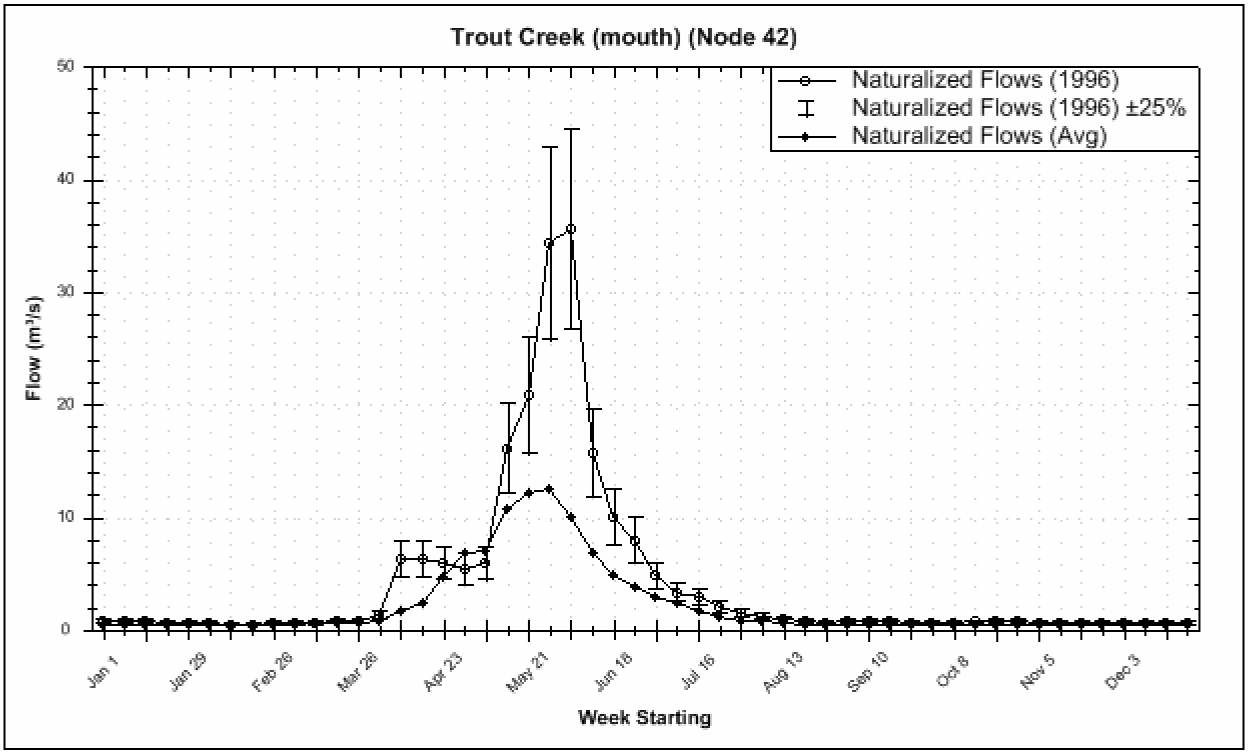


Figure 3.3. Naturalized hydrograph for a particular year (1996) in Trout Creek (Node 42) illustrating measurement error range bars (± 25%) around the calculated mean weekly flows. The average weekly flow across all 11 years of the time series is also provided for reference.

Both natural variation in annual flows and measurement error will affect the bias and precision with which mean weekly naturalized flows can be calculated for use with our IFN methods. These two sources of error components will be compounding, a calculation we did not attempt to undertake. However, a cursory assessment of potential error in estimated naturalized flows across a number of nodes indicated that measurement error appeared negligible relative to natural flow variation, particularly in high flow months. We note that we translated the measurement error in the calculation of mean weekly naturalized flows through to our calculated IFN thresholds at each of the nodes through our varied methods. However, to quantify how uncertainty in the naturalized flows could shift the potential IFN threshold values would require more statistical information than is presently available. We have instead focused our quantification of uncertainty around elements inherent in our IFN methods (e.g., prediction intervals around OFF targets, adjusted time series for our BCIFN calculations). However it must be recognized that uncertainty caused by natural variation in flows and, to a lesser extent, measurement error with the flow naturalization process represents an unquantified source of error in the IFN threshold values which may be important for some types of guidelines and at particular subbasin nodes. Additional insights on these risks can be assessed by review of the naturalized flow study report (Summit 2009).

3.1.2 Lower reference flows

In addition to individual naturalized flow points each we have also provided a lower reference flow depicting the approximate lower 25th percentile flow each week for each node (as described in 2.7). Figures incorporating this lower reference flow line for each Okanagan node are presented in Appendix B in conjunction with figures for BCIFN minimum risk flows and BCIFN-derived watershed conservation flows. **Figure 3.4** and **Figure 3.5** (zoom) provide an illustration of this approximate 25% percentile line (lowest 3rd of 11 flow points) in relation to the range of naturalized flow points from the 11 years of the time series for an example tributary (Trout Creek).

Caveats relating to uncertainty in modelling naturalized flows may perhaps be compounded in the estimates for this 25% percentile reference flow, particularly for smaller tributaries during the lowest flow periods. Recent assessment of a number of spatial hydrologic models to estimate stream discharge (Stanfield et al. 2009) suggested that such models were generally unable to accurately predict flows in streams during low-flow periods when upstream catchments were smaller than about 178 km^2, a size above many of the Okanagan tributaries modeled. If this is a factor in the naturalization process used for the Okanagan nodes then some modelled flows, particularly during drier weeks, may be an underestimate of the historic flows that actually occurred in some streams.

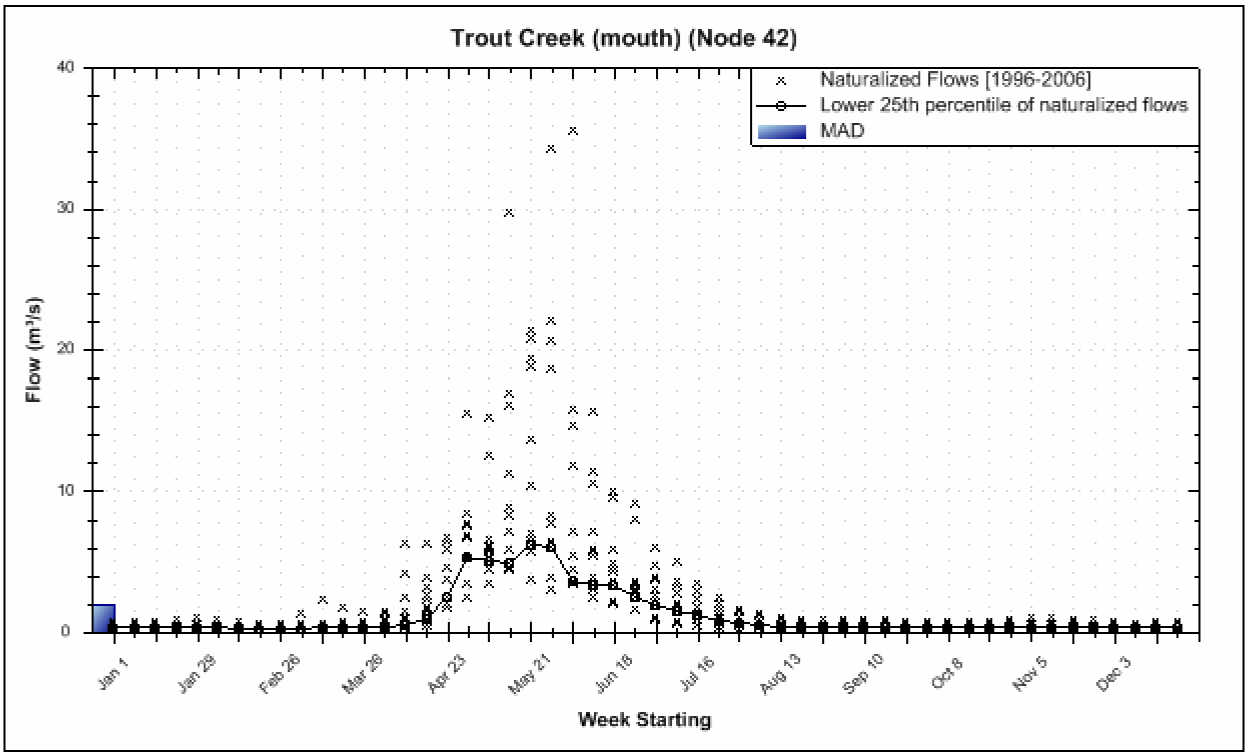


Figure 3.4. Individual weekly naturalized flows and the lower 25% percentile of naturalized flow (lower reference flow line) for Trout Creek (a zoom for greater resolution is provided in **Figure 3.5**).

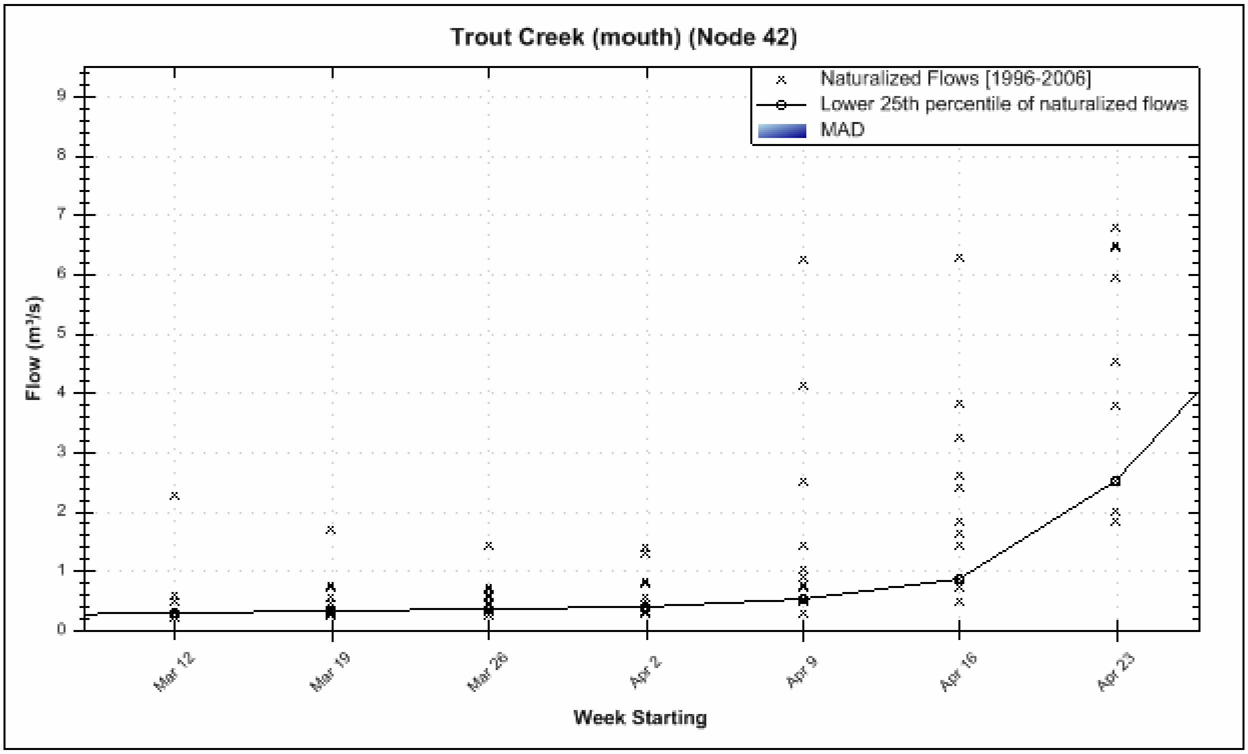


Figure 3.5. Zoomed view of a section of **Figure 3.4** for Trout Creek showing individual weekly naturalized flows relative to the approximate 25% percentile of naturalized flow (lower reference flow line).

3.1.3 BCIFN minimum risk flows

As described in section 2.5 the BCFIN methods work on a monthly time-step. For our study the BCIFN thresholds have been aggregated into thirteen 4 week periods, with minimum risk flow thresholds and recommended maximum diversion rates the same for each week within each 4 weeks of the distinct thirteen periods. The BCFIN-derived conservation flow thresholds developed for this project can be expressed either on a weekly basis or aggregated to a monthly period for direct comparison with the minimum risk flow thresholds. **Figure 3.6** provides an example of BCIFN minimum risk flow thresholds and monthly aggregated BCIFN-derived conservation flow thresholds for Trout Creek (Node 42), overlaid with the 143 scatter points (11 years * 13 periods). Each scatter point 'x' is the average of the four naturalized flows—1 for each week in the 4-week period. The average of these averages is then shown with a 95% confidence interval. **Figure 3.7** provides a zoom-in to the same example for a subset of the year so that flow values can be seen more easily. The figures illustrate (for the Trout Creek example) that naturalized flows generally exceed threshold values for BCIFN minimum risk flows and conservation flows. As indicated by these figures it is sometimes difficult to reach the BCIFN minimum risk flow thresholds in the drier months (e.g. Jul 16 – Sep 9) (which under the BCIFN guidelines use higher percentiles than the spring freshet period).

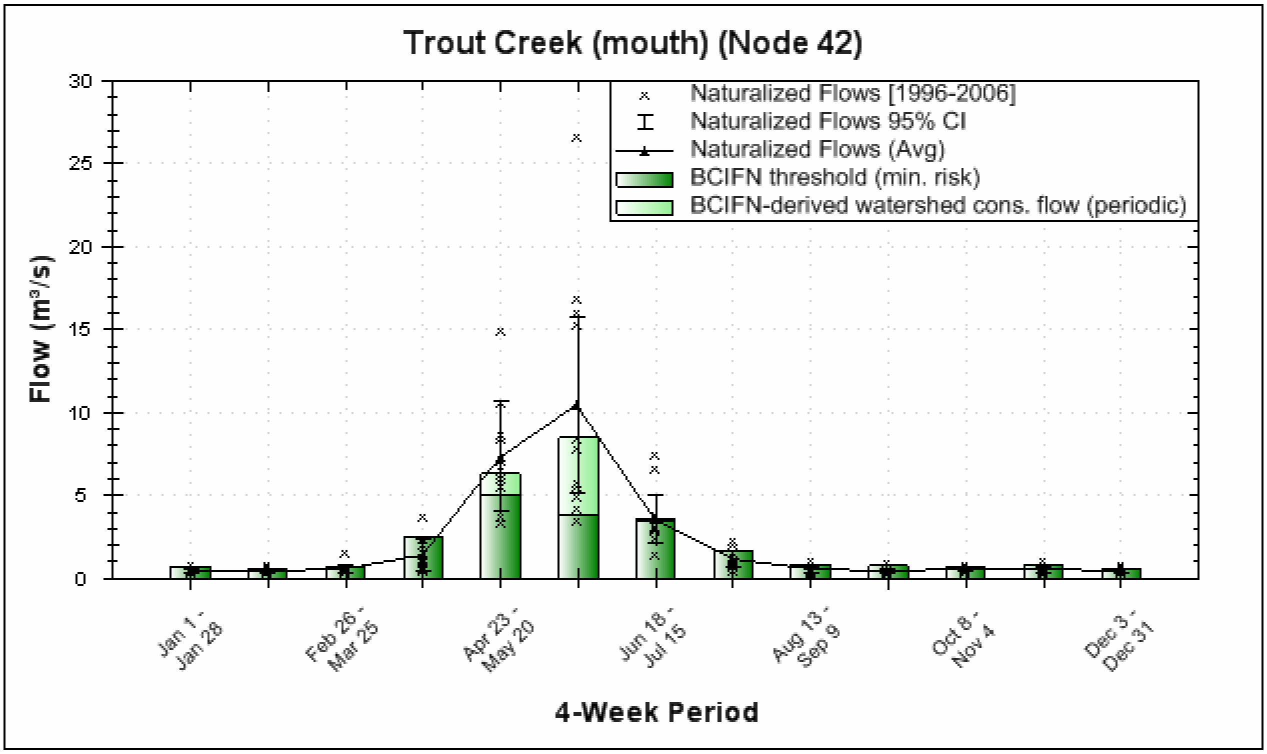


Figure 3.6. Monthly BCIFN minimum risk flow thresholds and BCIFN-derived watershed conservation flows for Trout Creek (Node 42) overlaid with aggregated monthly naturalized flows for the 1996-2006 period. For a given year and 4-week period, the 4 naturalized flows were averaged. These 11 values were then averaged. A 95% confidence interval (alpha 0.05), based upon a T-distribution with 10 degrees of freedom (N – 1).

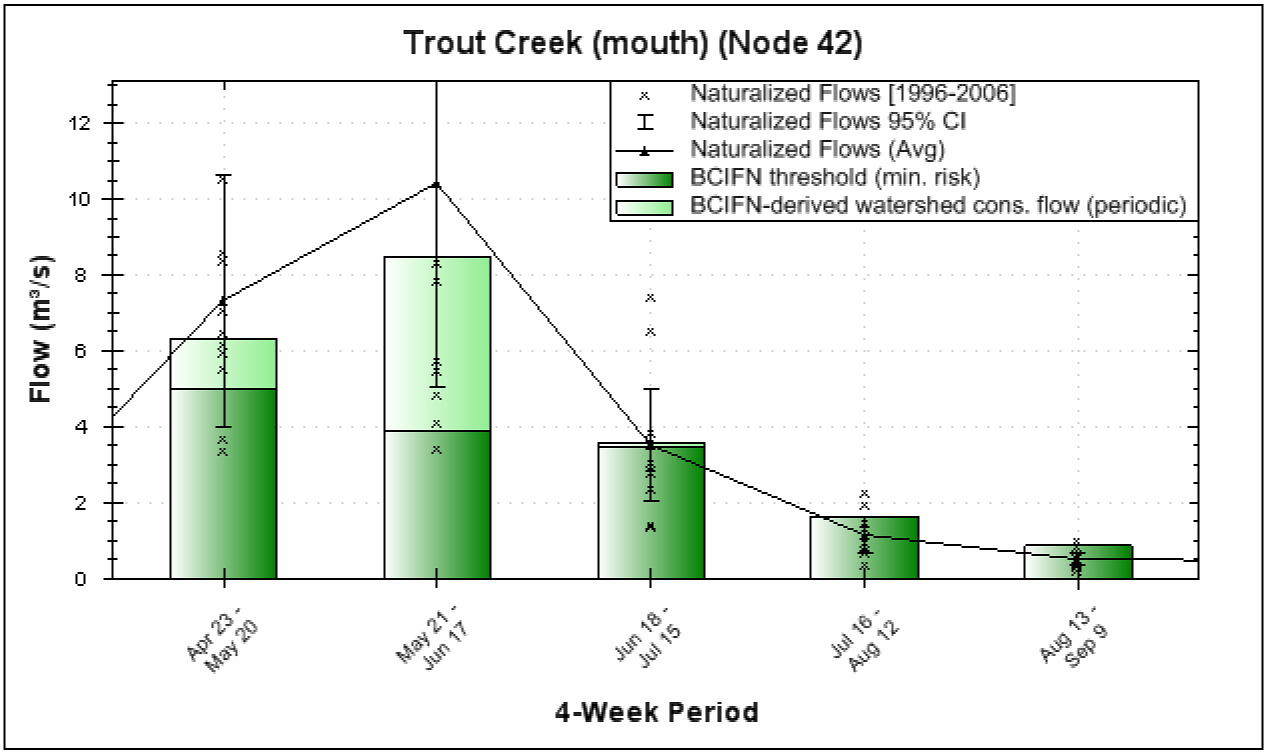


Figure 3.7. A zoomed-in view of a subset of **Figure 3.6** showing monthly BCIFN minimum risk flow thresholds and BCIFN-derived watershed conservation flows for Trout Creek (Node 42) overlaid with aggregated monthly naturalized flows for the 1996-2006 period. For a given year and 4-week period, the 4 naturalized flows were averaged. These 11 values were then averaged. A 95% confidence interval (alpha 0.05), based upon a T-distribution with 10 degrees of freedom (N – 1).

Figure 3.8 shows an example of BCIFN minimum risk flow and BCIFN-derived conservation flow thresholds conforming to the 52 week time step used by the Okanagan Water Supply and Demand Study. The light green vertical lines represent the boundaries of the thirteen bins (shown as bars above), where those scatter point 'x' values were used to derive the BCIFN threshold for the given 4-week period. As the BCIFN method will, by definition, generate abrupt, monthly stepped shifts in flow thresholds we have supplemented our representation of the BCIFN minimum risk flow thresholds with a smoothed 4-week moving average (**Figure 3.9**). This trend-line is strictly for aiding communication of the BCIFN threshold concept. The underlying methodology spans thirteen 4-week periods; the moving average is therefore not a replacement for the weekly thresholds. BCIFN-derived conservative flow thresholds are captured on a weekly time step so no moving average was used. To provide better visualization of naturalized flow conditions in comparison with the BCIFN recommended minimal risk flows an additional flow metric is also depicted within **Figure 3.8** and **Figure 3.9**, the lower 25th percentile of weekly naturalized flow (as discussed in section 3.1.2).

The BCIFN minimum risk flow thresholds (with moving averages), the BCIFN-derived conservation flow thresholds, and the lower 25th percentile naturalized flows were calculated for 36 Okanagan tributary stream nodes and are presented fully in **Appendix B.**

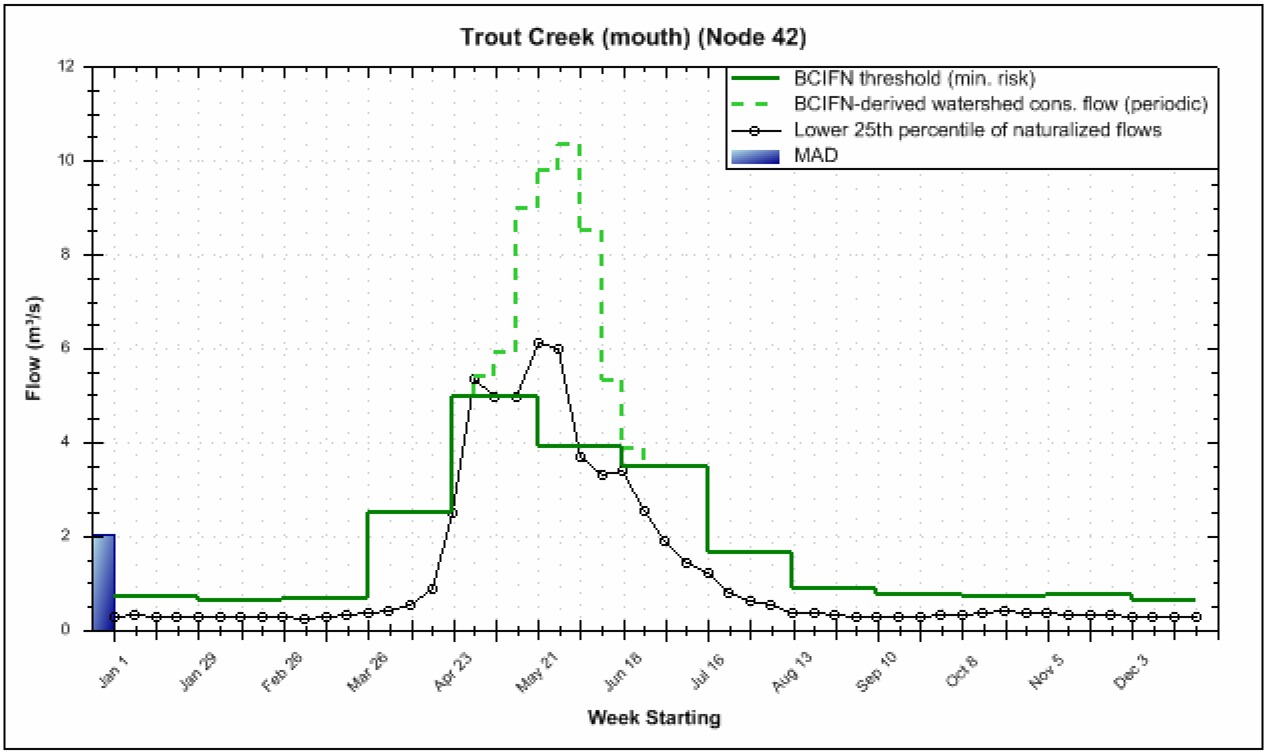


Figure 3.8. Weekly BCIFN minimum risk flow (solid green) and BCIFN-derived conservation flow (dashed green) thresholds for an example stream node (Trout Creek – Node 42). A line (black) depicting the lower 25th percentile of naturalized flows across all 11 years (a base reference value) and the mean annual discharge (MAD) (blue bar at left) are also provided to illustrate how these BCIFN thresholds relate to the range of naturalized flows at the node.

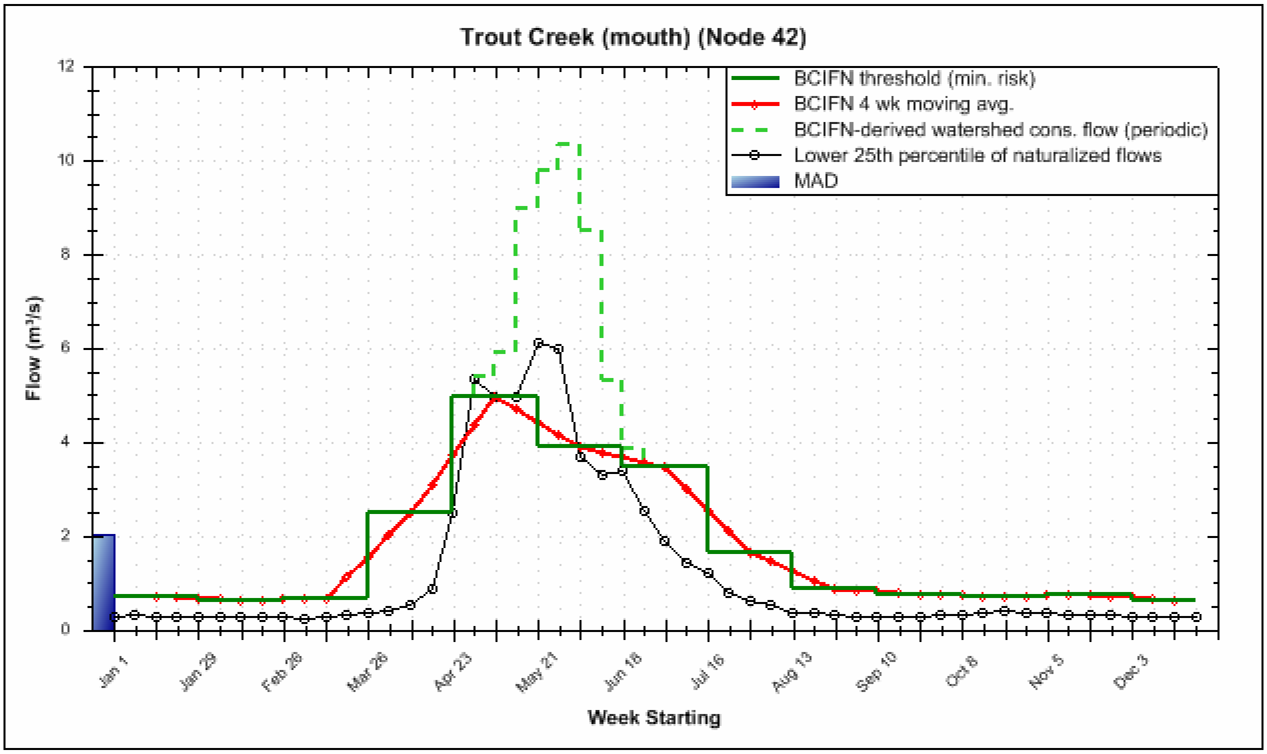


Figure 3.9. The same representation of BCIFN minimum risk flow and BCIFN-derived conservation flow thresholds as depicted in **Figure 3.8** but overlaid with a smoothing routine based on a 4-week moving average calculation of the BCIFN to better illustrate how thresholds would be more gradually shifting if fully interpretable on a weekly time step.

3.1.4 Meta-analysis optimal fish flows

The Hatfield and Bruce (2000) meta-analysis based regressions we have used allow predictions of optimal flow needs for salmonid spawning and rearing based on watershed location and mean annual discharge (MAD) as described in section 2.4. The examples in Figures 3.8 to 3.10 for Mission Creek (Node 22) show the predicted optimal flows for spawning and rearing of salmonid species present in the creek at different times of the year. **Figure 3.10** shows optimal flows for rainbow trout, **Figure 3.11** shows optimal flows for kokanee, while **Figure 3.12** provides an illustration of the overlapping optimal flow needs for rainbow trout and kokanee together. Within the figures different coloured lines represent optimal flows for different species, where solid lines represent target spawning flows and dashed lines represent target rearing flows. The threshold lines represent the mean predicted optimal flow for that species/life-stage combination. **Figure 3.13** replicates the combined Mission Creek example from **Figure 3.12** but introduces a measure of quantified risk tolerance around the optimal flows, displaying the upper and lower 50% prediction intervals around each predicted mean optimal flow. As described in section 2.4 the upper bound of the 50% prediction interval means that 75% of streams can be expected to have an optimum flow of this value or less, whereas only 25% of the streams can be expected to have optimal flows at or below the lower bounding value of the 50% prediction interval. **Figure 3.14** provides a zoom-in to a selected area of this example, better showing the staggered and/or overlapping salmonid species flow needs and the variation in the range of possible optimal flows.

Figures depicting our meta-analysis based predictions of optimal flows for salmonid spawning and rearing within 36 Okanagan tributary stream nodes are presented fully in **Appendix B.** Some figures in the appendix also depict optimal flows for Chinook and coho salmon. Although Chinook and coho are not currently present in the Okanagan Basin depictions of recommended flows for optimal spawning and rearing are provided to assist possible future recovery efforts for these species in key tributary streams.

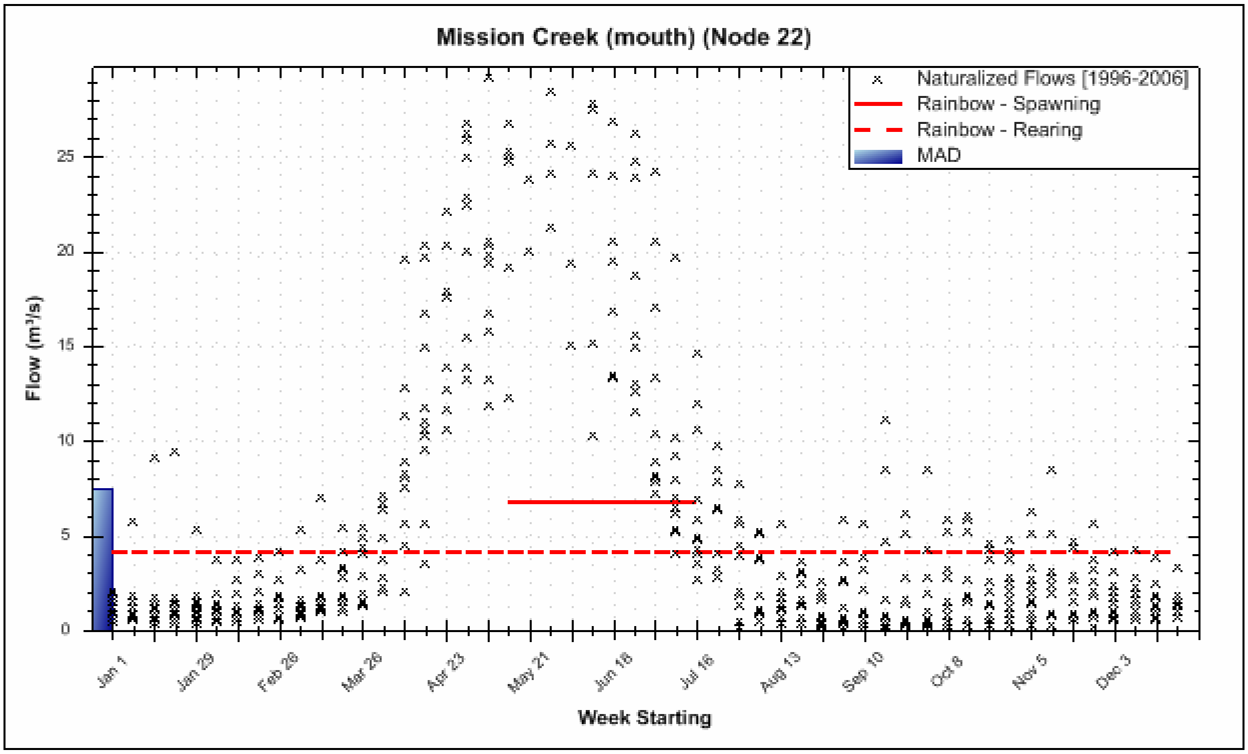


Figure 3.10. Predicted optimal flows for spawning (solid red line) and rearing (dashed red line) of rainbow trout present in Mission Creek (Node 22). Representations of the weekly naturalized flow values across all 11 years (x's), and mean annual discharge (MAD) (blue bar) are provided to illustrate how the optimal fish flows relate to the range of naturalized flows at the node. The Y-axis has been truncated here for better illustration of threshold flows, but the full range of individual naturalized flow points is shown in the Appendix B figures.

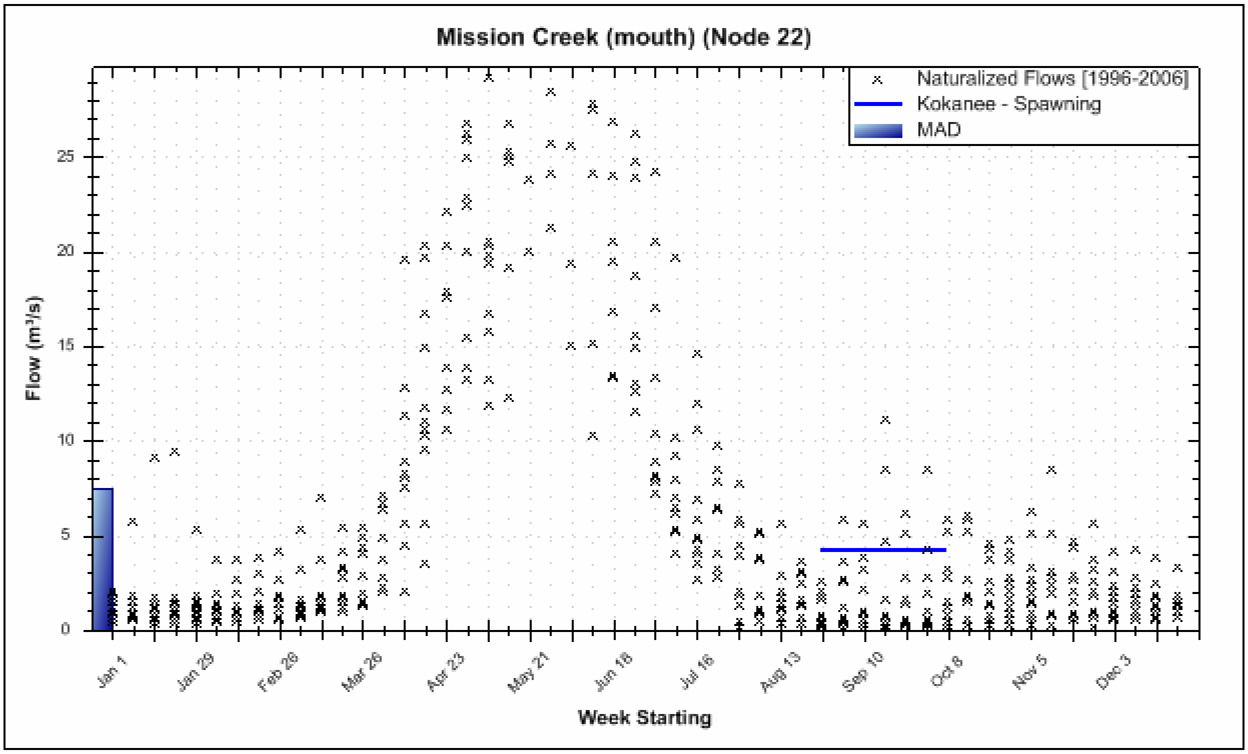


Figure 3.11. Predicted optimal flows for spawning (solid blue line) of kokanee present in Mission Creek (Node 22). Representations of the weekly naturalized flow values across all 11 years (x's), and mean annual discharge (MAD) (blue bar) are provided to illustrate how the optimal fish flows relate to the range of naturalized flows at the node. The Y-axis has been truncated here for better illustration of threshold flows, but the full range of individual naturalized flow points is shown in the Appendix B figures.

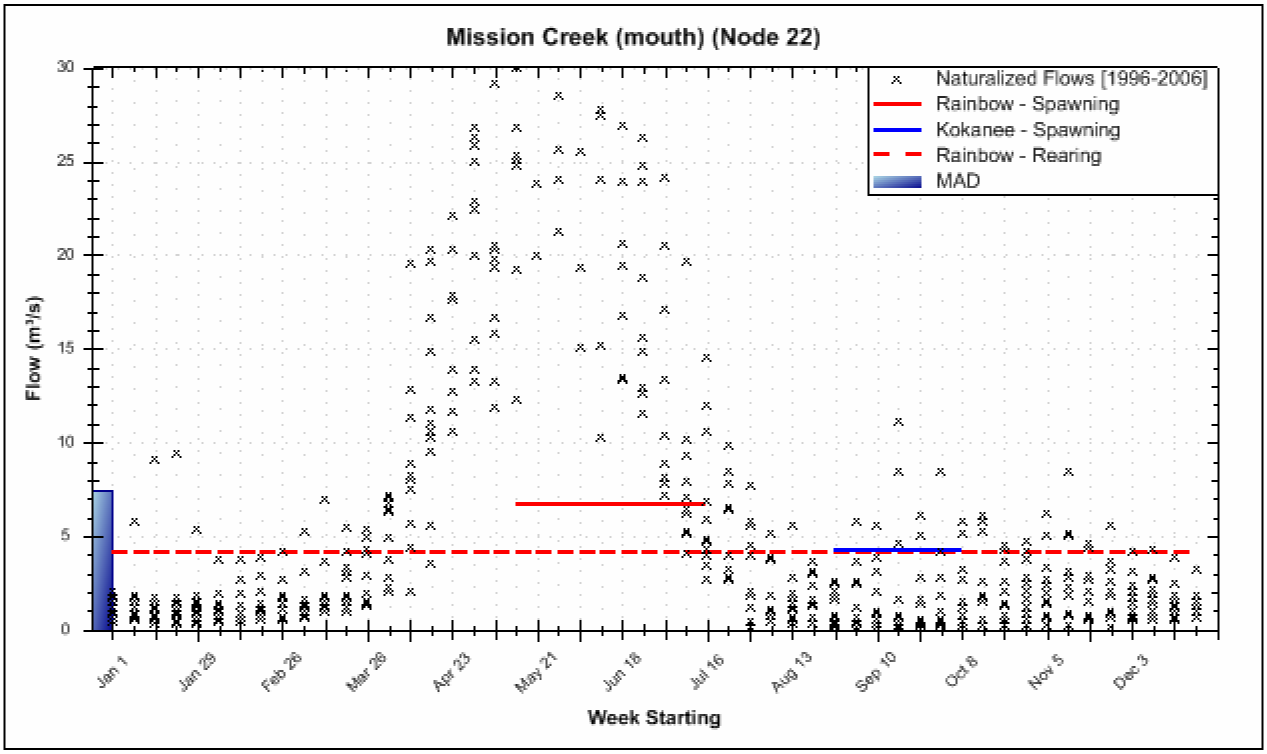


Figure 3.12. Predicted optimal flows for spawning (solid line) and rearing (dashed line) of both rainbow trout (red) and kokanee (blue) present in Mission Creek (Node 22). Representations of the weekly naturalized flow values across all 11 years (x's), and mean annual discharge (MAD) (blue bar) are provided to illustrate how the optimal fish flows relate to the range of naturalized flows at the node. The Y-axis has been truncated here for better illustration of threshold flows, but the full range of individual naturalized flow points is shown in the Appendix B figures.

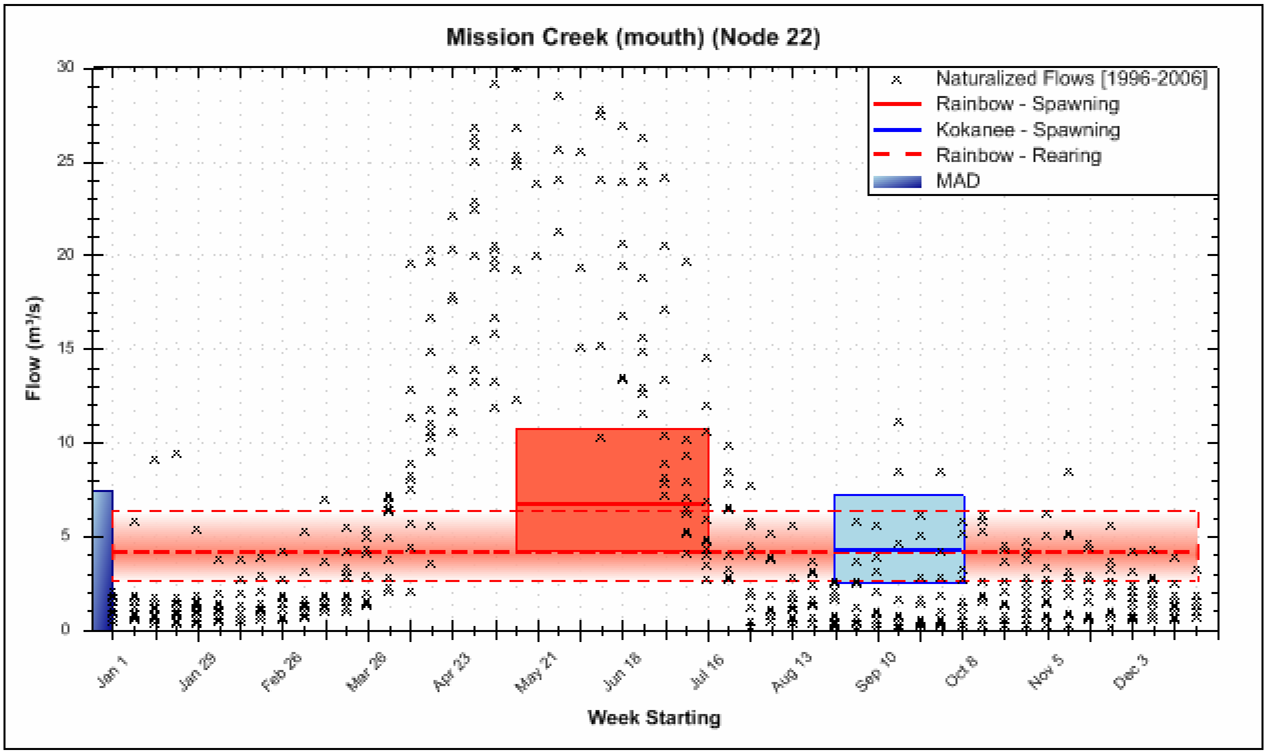


Figure 3.13. Predicted optimal flows for spawning (solid lines) and rearing (dashed lines) of rainbow trout (red) and kokanee (red) present in Mission Creek (Node 22). Solid/gradated colour bands represent the upper and lower 50% prediction intervals (PIs) around the mean optimal flow prediction for spawning/rearing respectively. Representations of the weekly naturalized flow values across all 11 years (x's), and mean annual discharge (MAD) (blue bar) are provided to illustrate how the optimal fish flows relate to the range of naturalized flows at the node. The Y-axis has been truncated here for better illustration of threshold flows, but the full range of individual naturalized flow points is shown in the **Appendix B** figures.

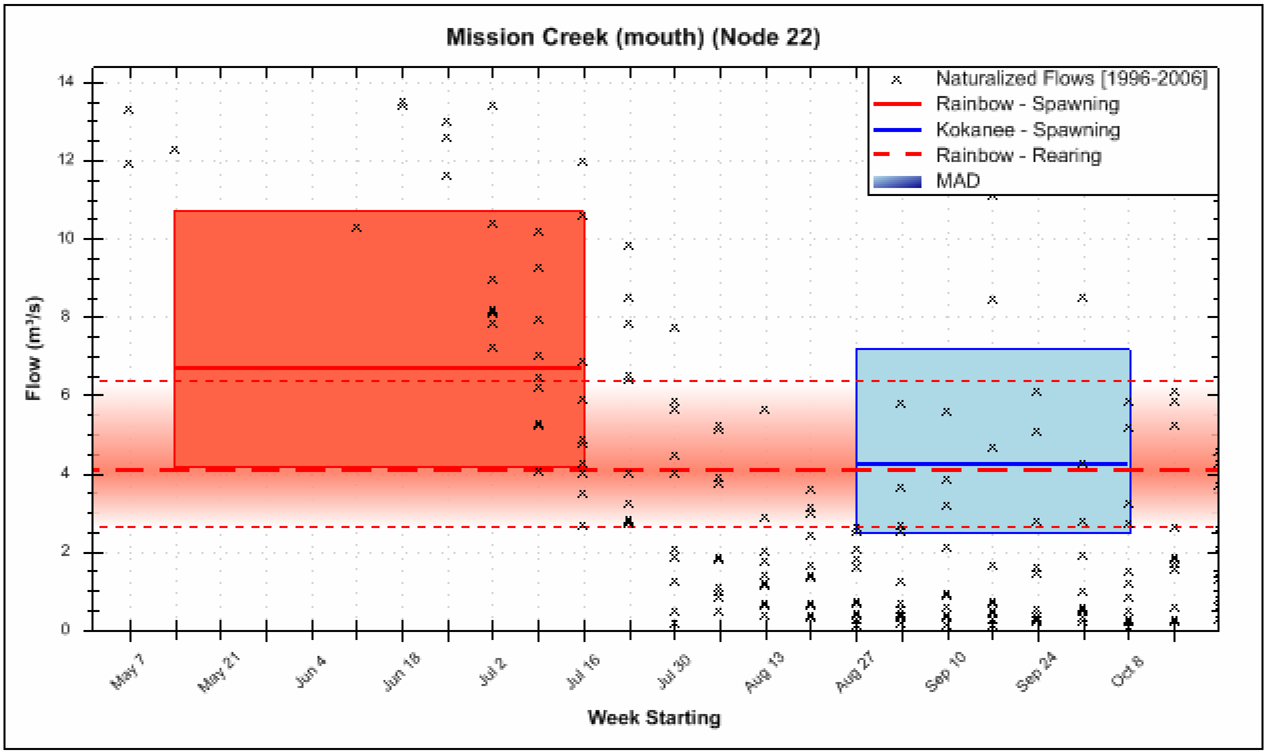


Figure 3.14. A zoom-in of the example presented in **Figure 3.13** showing optimal flows for spawning (solid lines) and rearing (dashed lines) of rainbow trout (red) and kokanee (red) present in Mission Creek (Node 22). Solid/gradated colour bands represent the upper and lower 50% prediction intervals (PIs) around the mean optimal flow prediction for spawning/rearing respectively. Representations of the weekly naturalized flow values across all 11 years (x's), and mean annual discharge (MAD) (blue bar) are provided to illustrate how the optimal fish flows relate to the range of naturalized flows at the node. The Y-axis has been truncated here for better illustration of threshold flows, but the full range of individual naturalized flow points is shown in the Appendix B figures.

3.2 Instream flow recommendations by subbasin node

Figures depicting instream flow requirements for minimum risk flows and watershed conservation flows based on the BCIFN guidelines (Hatfield et al. 2003) as well as optimal fish flows (by salmonid species and life-stage) based on the Hatfield and Bruce (2000) meta-analysis based approach are presented for each of 36 tributary stream nodes in **Appendix B.**

Naturalized flows generally achieved recommended weekly *BCIFN minimum risk flows* during the freshet period across all nodes, but often failed to reach BCIFN minimum risk flow thresholds in the late summer to mid winter time periods.

Weekly *BCIFN-derived watershed conservation flows* were achieved frequently at most nodes during the freshet. BCIFN-derived watershed conservation flow thresholds were consistently reached better than 20% of the time across all nodes over the 11-yr time series of weekly naturalized flow values.

Naturalized flows varied in their ability to achieve optimal flows for different salmonid species during critical life-stage periods. In general, naturalized flows were sufficient in most years to achieve *optimal spawning flows* for spring spawning salmonids (i.e., rainbow trout and steelhead) but often failed to provide recommended optimal flows for fall spawning species (i.e., kokanee and sockeye) at Okanagan tributary nodes. Seasonal naturalized flows at nodes were also generally insufficient to attain optimal spawning flows for fall spawning Chinook and coho salmon (to be noted if populations of these species were to return to the Basin).

Achievement of *optimal rearing flows* for rainbow trout and steelhead at Okanagan nodes varied considerably throughout their year-long residence in the streams (as would also be the case for coho (hypothetically) in the key streams evaluated)). While naturalized flows would achieve recommended optimal rearing flow criteria for these resident salmonids throughout much of the year at most Okanagan nodes, optimal rearing conditions would not be maintained in the late summer to mid-winter time period. Naturalized flows however appeared able to provide recommended optimal rearing flows for Chinook salmon during their shorter period of stream residency (as evaluate hypothetically at key streams).

3.3 Site specific studies

In addition to our default IFN guidelines, separate plots are presented for Trout Creek and Mission Creek (Node 42 and 22 respectively) that depict weekly flow recommendations based on water use agreements currently in place for Trout Creek and in development (draft) for Mission Creek. These water use agreement-based flows are shown in comparison to our default BCIFN minimum risk flow and meta-analysis-based optimum fish flow recommendations. Recommended flows within the Trout Creek Water Use Plan (**Figure 3.15**) during average/wet years are near the BCIFN minimum risk flow thresholds in most months and exceed them during higher flow periods. Trout Creek Water Use Plan flows are also close to recommended BCIFN-derived watershed conservation flows during the freshet. During dry years the recommended flows are often quite far below BCIFN minimum risk flow thresholds, even in high flow months, and BCIFN-derived watershed conservation flows are not achieved at any time during such years. During average/wet years recommended flows would appear generally to provide optimal flows for rainbow trout spawning, and also provide (during some periods of the year) optimal rearing flows for rainbow trout. Optimal flows would not be achieved for fall spawning kokanee in average/wet years. In dry years the recommended flows could provide optimal flows for part of the rainbow trout spring spawning period and for limited intervals during the year for rainbow trout rearing. As for average/wet years optimal flows for kokanee spawning would not be achieved in dry years, with the degree of divergence from recommended optimal flows even greater.

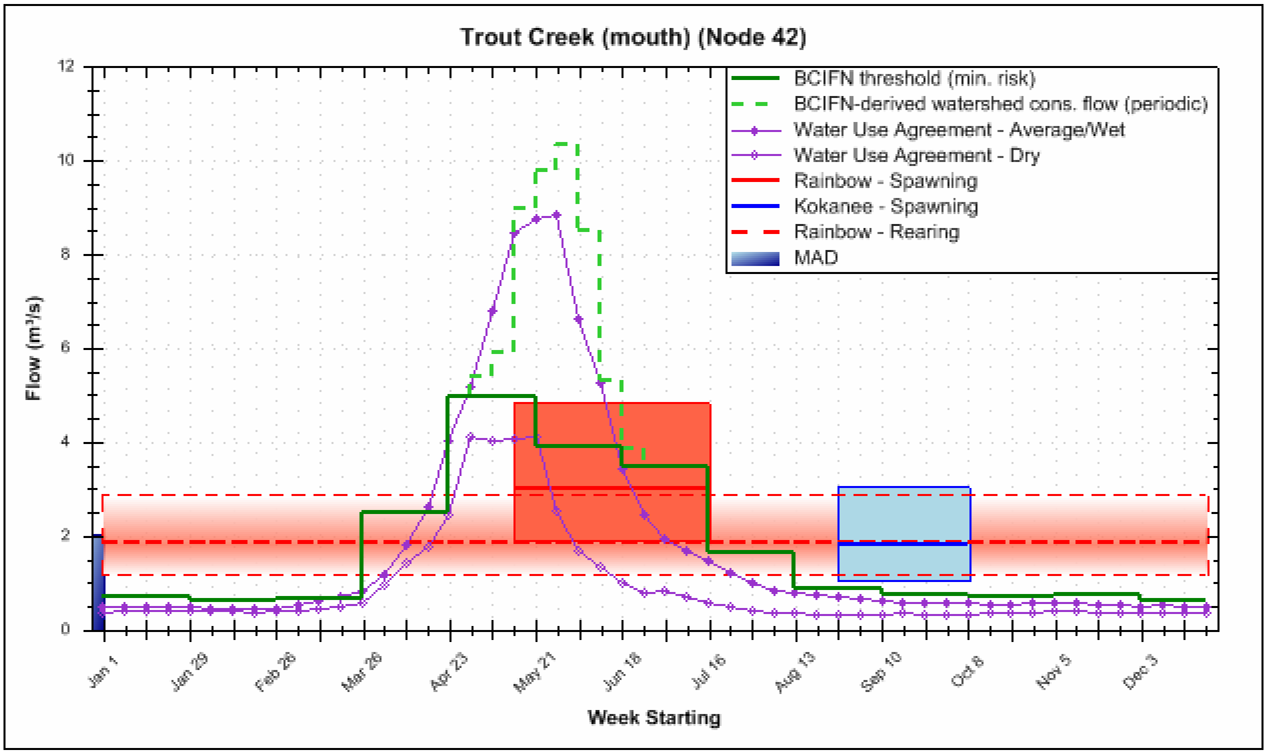


Figure 3.15. Recommended weekly flows for Trout Creek (average/wet and dry years) based on the Trout Creek Water Use Plan presented in relation to our default IFN recommendations.

Recommended flows within the draft Water Use Plan for Mission Creek (**Figure 3.16**) generally fall below the BCIFN minimum risk flow thresholds except during the highest flow weeks. In those high flow months they also achieve BCIFN-derived watershed conservation flow thresholds. Water Use Plan flows would provide sufficient water to achieve mean optimal flows for rainbow trout spawning and for rainbow trout rearing in most months. Flows would not be sufficient to provide optimal flows for kokanee spawning (as represented by the mean optimal flow value). Water volume at this time, however, would be sufficient to provide flows equivalent to the lower 50% PI value bounding for optimal kokanee spawning flows.

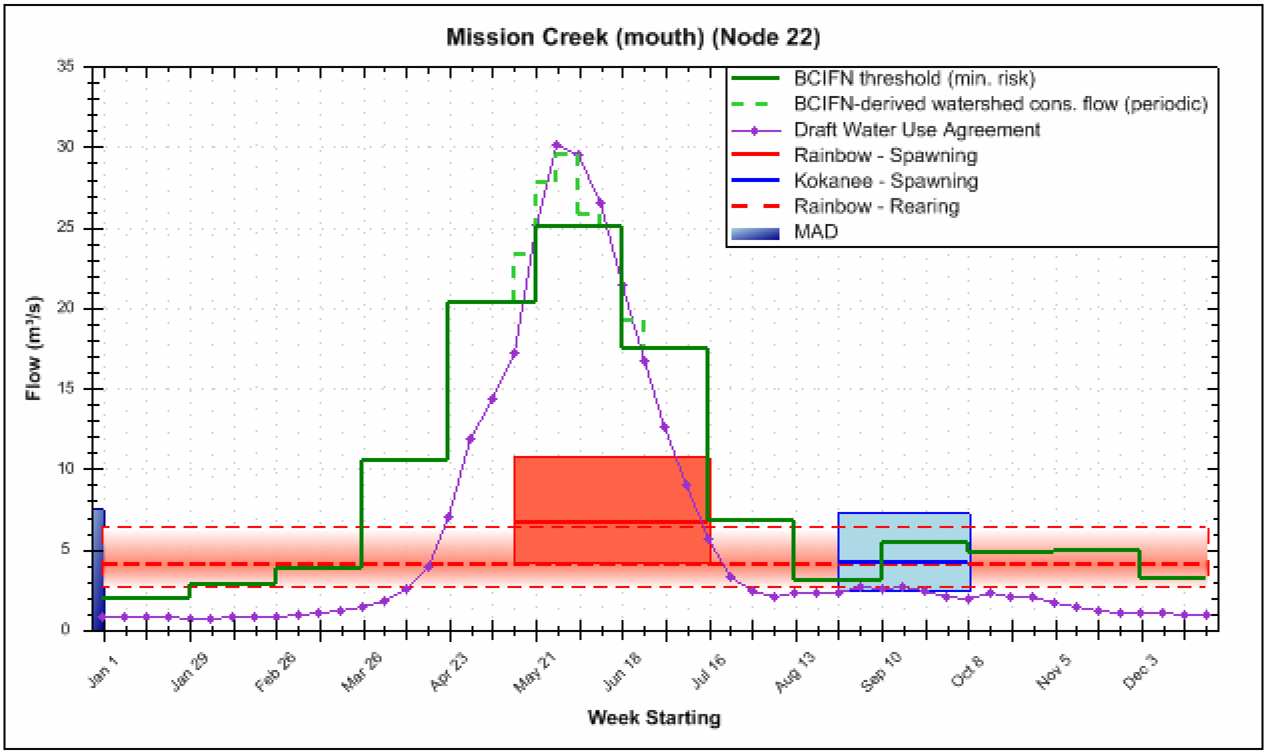


Figure 3.16. Recommended weekly flows for Mission Creek based on the draft Mission Creek Water Use Plan presented in relation to our default IFN recommendations.

Okanagan River mainstem: juvenile sockeye salmon flow envelopes

FWMT instream flow guidelines for Okanagan River at Penticton (the dam); Okanagan River at Okanagan Falls; and Okanagan River near Oliver are shown in **Figure 3.17**. Oliver is the most significant node in FWMT when addressing sockeye salmon flows. It also serves as a surrogate for flows entering Osoyoos Lake. These average flow envelopes therefore apply to all years, but in-season would be managed according to flood, water supply, fish trade-offs embedded in FWMT. Background and methods are discussed above in section 2.6.1.

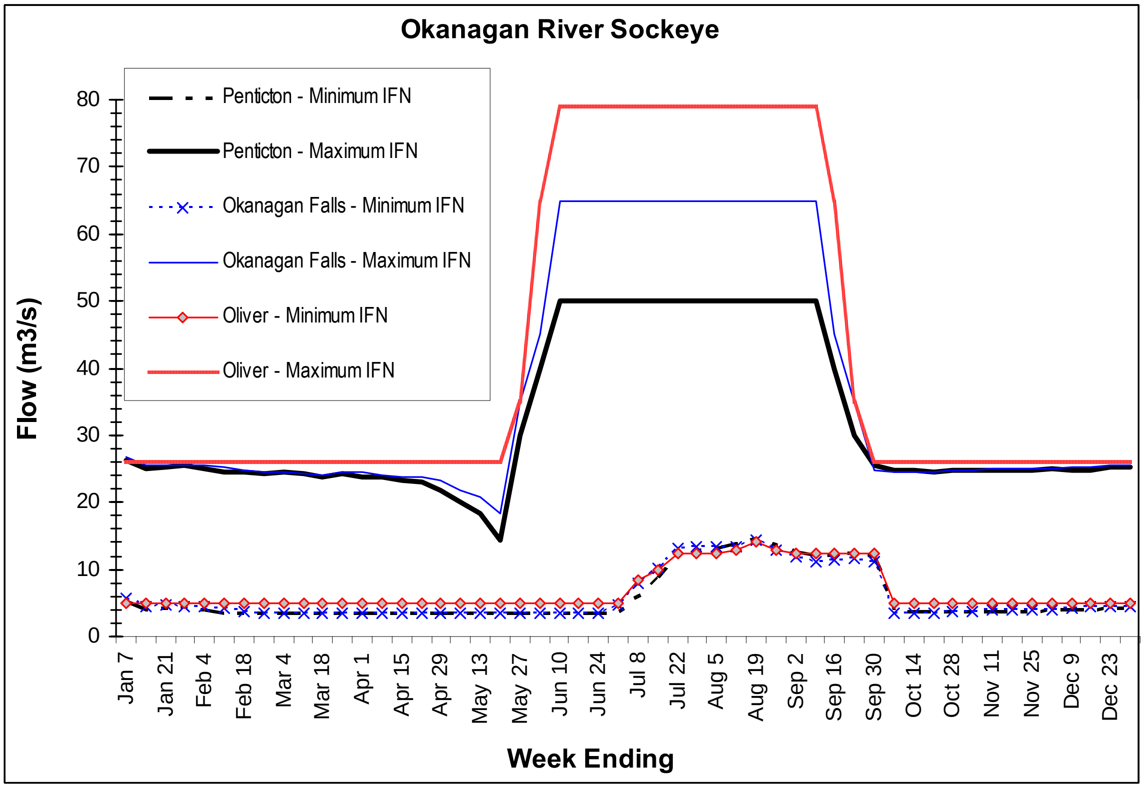


Figure 3.17. Okanagan River mainstem minimum and maximum instream flow guidelines for juvenile sockeye salmon derived from the sockeye submodel of the Okanagan Fish/Water Management Tool.

It is important to note that the *maximum* flows June - September represent the approximate flooding limits of flows at the sites used and are *not* target flows for fish. On the other hand, **our minimum flows for the whole year and our maximum flows between October and May *do* represent minimum and maximum target flows for Okanagan River sockeye.**

3.4 Additional sensitive species and ecological functions

Employing the filtering process described in section 2.8 we identified eight additional aquatic-dependent sensitive species present within the Okanagan Basin (**Figure 3.18**) that could potentially be affected by instream flows. Final consultation with MOE and CDC biologists confirmed these as threatened aquatic species of key management concern. Brief summaries of distinguishing characteristics, distribution, conservation status, use of aquatic habitats, perceived threats and perceived linkage to instream flow needs are provided for each of these sensitive species. **Table 3.2** represents an overview synthesis of this information.

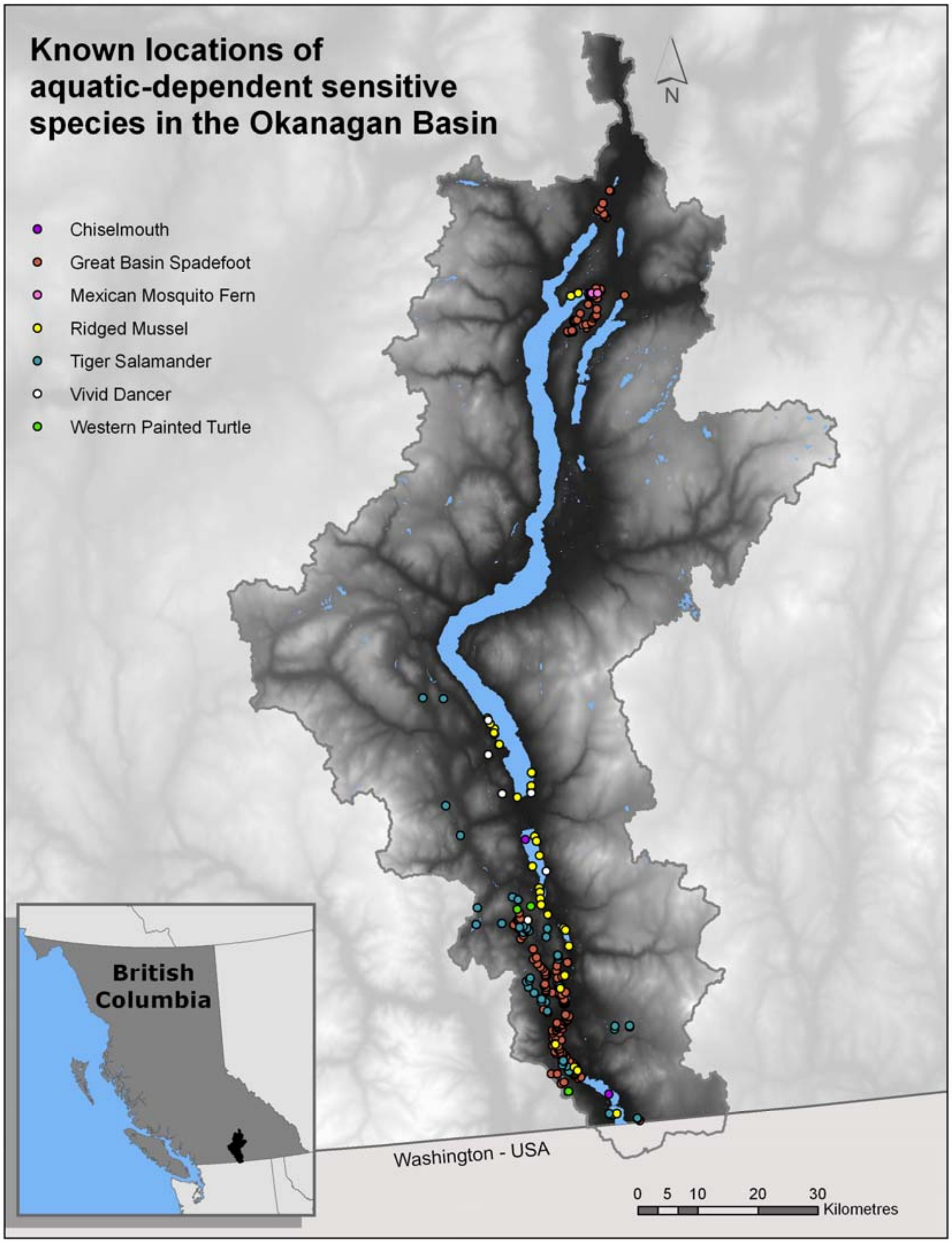


Figure 3.18. Known locations of sensitive species in the Okanagan Basin that are dependent on aquatic habitats at some point in their life cycle (records from BC Conservation Data Centre, March 2009).

3.4.1 Mexican Mosquito Fern (*Azolla mexicana*)

Description, distribution and status: The Mexican mosquito fern is a floating aquatic fern that can form thick extensive mats in lakes, ponds, ditches, and quiet areas of streams. While primarily a still-water species it has also occasionally been found in faster-flowing waters both in B.C. and elsewhere (Martin 2008). The Mexican mosquito fern is found globally in North, Central, and South America. In Canada it is found only in B.C. where it reaches the northern limit of its range. This COSEWIC-threatened and BC red-listed species is known from only three locales in south-central B.C.: the North Thompson River area, the Shuswap Lake area, and Vernon. In these areas, a total of 11 populations have been reported in the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report (Brunton 1984), of which three are now assumed to be extirpated (SIRPRT 2008). Population trends for each of the remaining eight B.C. populations are difficult to assess for this species as observations indicate that this species' "presence" at a site fluctuates from year to year.

Aquatic habitat use: Mexican mosquito fern prefers cool, slightly acidic, partially shaded, phosphorus-rich, nutrient poor, still waters with low salinity (Brunton 1984). Excessive localized water movements (turbulent flow, wind, waves) will eventually fragment and kill Mexican mosquito ferns (Lumpkin and Plunknett 1980). Populations in streams within the Okanagan have been found only in 'oxbows' that experience little flow (B. Klinkenberg, UBC, pers. comm.). The species has relatively narrow growing requirements and is susceptible to changes in water levels and composition. Mexican mosquito fern grows well when the water depth is only a few centimeters and the roots can touch the substrate (Wagner 1997). This may correspond to summer drawdown in areas of deeper water. However, the species is also considered sensitive to desiccation (B. Klinkenberg, UBC, pers. observation 2007). Periodic annual flooding is considered to aid population dispersal (Martin 2008). Detailed ecological knowledge of the full suite of habitat conditions required for persistence of this species is not considered to exist currently (SIRPRT 2008).

Threats: The most significant threat to Mexican mosquito fern in B.C. is considered to be potential habitat loss due to site development and in-filling/conversion of existing habitat on private land and transportation rights-of-way. Populations may also be threatened by transportation corridor maintenance activities and/or construction such as road salting, run-off, herbicide drift, as well as road and track maintenance and development. Events such as water chemistry changes, water level, turbidity, or watercourse alteration may also impact populations (SIRPRT 2008).

Instream flow need: ***wetland linkage***—should be addressed by regular achievement of BCIFN-derived watershed conservation flows.

3.4.2 Tiger Salamander (*Ambystoma tigrinum*)

Description, distribution and status: The Tiger Salamanders is a large (up to 20 cm long), pond-breeding amphibian with aquatic larvae and terrestrial adults. They have a complex life cycle with eggs being laid in aquatic habitats shortly after the first, early spring rains. Larvae hatch from eggs within 10–21 days, and continue to occupy aquatic habitats until August when gills become reduced and they begin to breathe air, during metamorphosis. Juvenile Tiger Salamanders migrate to terrestrial habitats including grassland, shrub-steppe and open forest during late summer or early fall rains and generally live underground (COSEWIC 2001). Tiger Salamanders are widely distributed in North America, ranging from southwest Canada, to central and western United States. A disjunct distribution of the Tiger Salamander occurs in Washington State, Oregon, Idaho, and south-central British Columbia (COSEWIC 2001). The COSEWIC-endangered and provincially red-listed Southern Mountain population of Tiger Salamander occupies the northern portion of this distribution in BC, where it is restricted to the South Okanagan, Lower Similkameen, and Kettle River watersheds (SIRART 2008a). Both the extent of occurrence and area of occupancy of the Southern Mountain population are thought to be declining (COSEWIC 2001), but detailed data on population and distribution trends are lacking. A decline in the area of occupancy over the past 30 years is inferred from apparent extirpations at historical breeding sites, combined with extensive habitat loss within the area of occurrence

Aquatic habitat use: The Southern Mountain population occupies arid habitats at low- and mid-elevations (up to about 1250 m above sea level) within the dry interior region of British Columbia (COSEWIC 2001). Courtship, mating, egg-laying, and development of eggs and larvae take place in either vernal pools (seasonal and temporary wetlands, generally rainfall or groundwater generated) or permanent ponds. Individual breeding sites in vernal pools may disappear either permanently or for many years due to ecological succession, severe droughts, or other factors. Therefore, populations require a mosaic of breeding sites of different water depths distributed across the landscape to ensure persistence (Richardson *et al.* 2000). Important features of breeding sites include persistence of water until larval development is complete (from mid-March to mid-August), shallow (generally <1 m) water depths along at least portions of the water body, soft bottom substrate, abundant emergent vegetation, suitable cover for metamorphs along the shoreline, and absence of introduced fish (COSEWIC 2001).

Threats: Loss, fragmentation, and degradation of terrestrial and aquatic habitat by housing and agricultural developments are the most serious and widespread threats to Tiger Salamanders in B.C. Specific threats to aquatic habitats include conversion, by draining and infilling of wetlands and ponds, and degradation by water level reduction related to irrigation (SIRART 2008a). Other threats to Tiger Salamanders in the Okanagan include predation from exotic species (e.g., perch, trout, bass, bull frogs), pollution of breeding ponds from agricultural and household compounds, road mortality, infectious fungal diseases, and extreme summer drought events that can dry out breeding ponds (potential climate change impacts to Tiger Salamanders in regards to this last threat may be widespread and severe) (SIRART 2008a).

Instream flow need: ***wetland linkage*** - should be addressed by regular achievement of BCIFN-derived watershed conservation flows. However, spring/summer vernal pools required as critical Tiger Salamander breeding habitat are not directly linkable to instream flows.

3.4.3 Great Basin Spadefoot (*Spea intermontana*)

Description, distribution and status: The Great Basin Spadefoot, is a small toad-like amphibian with a sharp-edged dark ridge (“spade”) on the inner side of each hind foot, used for burrowing. During the breeding season in the spring and early summer Spadefoots migrate to wetlands where their eggs are laid in small, loose clusters attached to vegetation or on the bottom substrate. Their tadpoles develop rapidly, metamorphose into juveniles, and migrate from the wetlands (within 1–2 months from egg-laying) to nearby terrestrial habitats (Jones *et al.* 2005). Juveniles and adults spend the remainder of the year on land, sometimes on the surface during rainy nights but generally buried underground in sandy or loamy soils. Great Basin Spadefoot is widely distributed within arid regions of western North America. In Canada, the species is restricted to low to mid-elevations in dry valleys of the Southern Interior and plateau areas of the Central Interior of British Columbia (COSEWIC 2007). In B.C. this COSEWIC-threatened and provincially blue-listed species occurs in the Okanagan, Similkameen, Kettle-Granby, Fraser, Thompson and Nicola River valleys and the South Cariboo Region (SIRART 2008b). There are no population trend data, but the species is thought to be in decline in B.C. based on widespread loss and fragmentation of arid grassland habitats (COSEWIC 2007).

Aquatic habitat use: The availability of a suitable water source for breeding is considered critically important for Great Basin Spadefoot (COSEWIC 2007). Spadefoots breed in a wide variety of temporary and permanent water bodies, including human-made sites such as irrigated depressions, ponds, pools, or ditches, but seem to prefer small vernal pools that fill in and dry up each year (COSEWIC 2007). Seasonally wetted margins of wetlands and larger bodies also provide high-quality breeding habitat. Important features of breeding sites include retention of water until tadpoles have metamorphosed (from April to at least until end of May in B.C.) and warm shallow areas for egg-laying and larval development (COSEWIC 2007). The absence of predatory fish dramatically increases the survival of eggs and tadpoles (Sarell 2004).

Threats: Conversions of terrestrial and wetland habitat to housing development and crop production, and associated activities such as road construction and lawn establishment, are considered the greatest threat to Spadefoots. Temporary wetlands used for breeding, in particular, have been lost at a dramatic rate throughout populated areas through infilling, changes in drainage patterns, and decrease of water tables (Adams 1999, 2000, COSEWIC 2007). Although Spadefoot eggs and tadpoles develop quickly, shorter breeding periods due to drying up of ponds likely reduce breeding success, and may prevent it altogether in dry years (Sarell 2004). Other threats to Spadefoot in the Okanagan include predation from exotic species (e.g., bass, carp, perch, bull frogs), impaired reproduction and abnormal development as a result of exposure to pesticides, road mortality and off-highway vehicle recreation in breeding wetlands (SIRART 2008b). Spadefoot may also be highly vulnerable to potential climate change warming effects that could cause premature or increase complete drying of ephemeral ponds used for breeding (Cohen *et al.* 2004).

Instream flow need: ***wetland linkage*** **-** should be addressed by regular achievement of BCIFN-derived watershed conservation flows. However, spring vernal pools required as critical Spadefoot breeding habitat are not directly linkable to instream flows.

3.4.4 Vivid Dancer (*Argia vivida*)

Description, distribution and status: The Vivid Dancer is a large blue damselfly of the mountains of western North America with a very specialized life history. In Canada it occurs only in southern British Columbia where this provincially red-listed species is found near hot and cool springs from the southern Coast Range east to the Rocky Mountains (Cannings 2002). In the Okanagan the only known sites for Vivid Dancer are a cool spring near Madeline Lake west of Penticton and a spring-fed stream near Okanagan Falls (BC Conservation Data Centre 2009).

Aquatic habitat use: Vivid Dancer are dependent on cool/warm/hot springs, with adults perching nearby and egg laying occurring in underwater vegetation at or near the springs. Their larvae live in streams and pools draining the springs (Cannings 2002).

Threats: Development, diversion or other modifications to springs represent the main threat to the small number of existing Vivid Dancer populations in B.C. (Cannings 2002).

Instream flow need: ***N/A*** – Vivid Dancer are dependent on hot spring water sources, which cannot be directly linked to instream flow needs.

3.4.5 Chiselmouth (Acrocheilus alutaceus)

Description, distribution and status: The chiselmouth is a large minnow with hard cartilaginous plates in its upper and lower jaws. The cartilage in the lower lip has a straight-cutting edge that looks like a chisel which these herbivorous fish use to scrape algae from rocks or other substrates (BC Fish Facts 1999). Chiselmouth is the only fish species in B.C. that is an obligate algivore (specialized algae feeder). Chiselmouth have a fairly limited distribution in B.C., being confined to the Columbia and Fraser River systems. In the Okanagan Basin this provincially blue-listed species occurs in the Okanagan River and south Okanagan lakes (Cannings and Ptolemy 1998). Chiselmouth are considered vulnerable because of its spotty distribution, with many populations being quite small. It is known from only 20 locations in the province and appears to have disappeared from some of these places in recent years (Cannings and Ptolemy 1998).

Aquatic habitat use: In British Columbia, chiselmouth are found in a variety of relatively warm water bodies: small creeks to backwaters of larger rivers and small kettle lakes to large lakes, although they seem to occur more often in lakes than rivers (Cannings and Ptolemy 1998). In rivers chiselmouth prefer deeper, warmer sections with moderately fast to fast water. Spawning occurs in late June and early July, with lake populations spawning in tributary streams (Cannings and Ptolemy 1998). Although spawning has not been observed, eggs have been found both on the open bottom and buried among boulders (Scott and Crossman 1973). Very little is known about the full life cycle of the species and critical habitat requirements are unknown (Cannings and Ptolemy 1998; BC Fish Facts 1999).

Threats: Perceived threats to chiselmouth include disruption to natural stream flow, toxins from agricultural runoff, and riparian removal (Haas 1998).

Instream flow need: ***minimum flows for spawning (and possibly rearing) in tributary streams*** – should be addressed by maintaining BCIFN minimum risk flow thresholds. Spawning needs possibly addressed further by maintenance of optimal fish flows for rainbow trout spawning, as spawning times for the two species in the Okanagan appear to overlap (J. Mitchell pers. comm.). Whether recommended spawning flows for rainbow trout are also appropriate for chiselmouth would be a matter for further investigation, as would the actual distribution of chiselmouth in Okanagan streams.

3.4.6 Western Painted Turtle (*Chrysemys picta*) – Intermountain-Rocky Mountain population

Description, distribution and status: The Western Painted Turtle is a small, freshwater turtle with a smooth dark carapace, distinctive for the red and yellow patterns on its limbs and upper shell. It is widely distributed across western and Central North America, extending in Canada from southwest Ontario to southwest B.C. Western Pond Turtle is, however, one of only two extant, native freshwater turtle species west of Ontario, which makes it a significant element in the overall biodiversity of the western provinces (COSEWIC 2006b). The COSEWIC-special concern and provincially blue-listed Intermountain-Rocky Mountain population of Western Pond Turtle is found in pockets throughout the southern interior of B.C., mostly in the Okanagan. There are no population trends known for the Western Pond Turtle but based on perceived habitat trends it is considered that the species has likely suffered serious declines in the Okanagan Basin (COSEWIC 2006b).

Aquatic habitat use: Painted Turtles are semi-aquatic and can be found in the shallow waters of ponds, lakes, oxbows and marshes, in slow-moving stream reaches, or the quiet backwater sloughs of rivers (COSEWIC 2006b). They forage, mate and hibernate in water, and will undertake overland migrations in the spring and fall to find different ponds for breeding or hibernation (Gregory and Campbell 1987). Shallow wetland areas provide important habitat for feeding, basking, shelter from predators, and winter hibernation. Suitable wetlands have muddy substrates, an abundance of emergent vegetation, and numerous basking sites. Painted Turtle habitat also includes riparian zones bordering wetlands as females nest up to 150 m away from water, in loose, warm, well-drained soils (COSEWIC 2006b).

Threats: Western Pond Turtle are considered vulnerable to habitat loss, and susceptible to human and natural disturbances. The primary threats to Painted Turtles are conversion of small wetlands to more “usable” land for human activities including agriculture, raising of livestock and urban development.

Additional threats include water pollution, road mortality, riparian vegetation loss, water extraction and altered wetland hydrology.

Instream flow need: ***Wetland linkage—***should be addressed by regular achievement of BCIFN-derived watershed conservation flows

3.4.7 Rocky Mountain Ridged Mussel (*Gonidea angulata*)

Description, distribution and status: The Rocky Mountain Ridged Mussel is a trapezoidal shaped, bluish-black freshwater mussel up to 125 mm long with a complex life cycle that includes a short parasitic stage attached to a fish host. This species is the only known living taxon in the Gonidea genus. Ridged Mussel is found in the Columbia River system in southern British Columbia (Okanagan and possibly the Kootenay) (Clarke 1981) and is known in Canada only from the main, valley-bottom water bodies from Penticton south to the border (COSEWIC 2003). Historically, this species occurred from southern British Columbia to south-central California; however, the current range is believed to be considerably smaller. In the Okanagan Basin this COSEWIC-special concern and provincially red-listed species has been found in Okanagan Lake, Okanagan River, Vaseux Lake, Park Rill Creek, Skaha Lake and Osoyoos Lake (COSEWIC 2003, CDC 2008). Population status in B.C. has not been determined. However, Ridged Mussels are believed to be declining, as inferred from the relatively few live specimens collected and general declines in habitat water quality. There appear to be two distinct, severely fragmented populations of Ridged Mussels in the Okanagan River system (COSEWIC 2003).

Aquatic habitat use: Habitat occupied by Ridged Mussels is generally characterized as substrates of lakes, streams, and rivers that range in size from gravel to firm mud with the presence of at least some fine material (e.g. sand, silt or clay). Preferred sites generally have constant flow, rather shallow water (typically < 3 m in depth), and well-oxygenated substrates, especially when occurring in finer sediments. Ridged mussels appear to avoid areas with shifting substrates, periodic dewatering or extreme water level fluctuations, continually turbid conditions, or with seasonal hypoxia or anoxia. Ridged mussels are dispersed primarily during their glochidial stage, first by currents and then by fish; hence, distribution and ecology are limited by current and fish host(s). After leaving the fish host the transformed glochidia, now called juveniles, typically drop to the substrate. There is thought to be little or no seasonal or life stage movement of post-glochidial forms (COSEWIC 2003). Adults are thought to be effectively sessile unless disturbed, in some reported cases not moving even as lakes are dewatered, effectively dying in place. Juveniles are more active with displaced individuals being observed to reorient and rebury themselves when disturbed. Ridged Mussel do not appear to migrate seasonally or during the breeding season, either in river, lakes or streams though definitive data are lacking (COSEWIC 2003).

Threats: The greatest threat to Ridged Mussels is considered to be the loss or degradation of suitable habitat (COSEWIC 2003). Past channelization and the creation of dams and vertical drop structures (concrete weirs) within the Okanagan River have likely been and are the greatest threats to this species due to direct, physical disturbance and by creating barriers to potential fish host movement. Rapid human population growth throughout the Okanagan Basin has resulted in alteration of shoreline and littoral zones and has added pollutants into the watershed. Introduced species including fish, Eurasian water milfoil and exotic mussel species also pose threats to Ridged Mussel (COSEWIC 2003; CDC 2008). As Ridged Mussels are also reliant upon a host fish (currently unidentified but suspected to be some form of salmonid) for dispersal, this also increases its vulnerability if salmonid numbers decline (CDC 2008). Other threats to this species are eutrophication, heavy metals, and transition elements. In the short-term, a proposed re-alignment of the Okanagan River could negatively impact existing ridged mussel populations, at least in the short term (CDC 2008).

Instream flow need: ***Minimum flows for maintaining aquatic life*** – should be addressed by maintenance of BCIFN minimum risk flow thresholds in streams where Ridged Mussel are thought to occur (i.e., Park Rill Creek); **lake elevations to maintain shallow wetted lake margins** – should be addressed by operating rules for lake drawdowns in Okanagan Lake under the OKFWM tool. Vaseaux, Skaha and Osoyoos lakes are much smaller, with different bathymetry and operational guidelines for lake elevations that will need to be evaluated.

To further assess (qualitatively) whether dessication due to lake drawdowns might represent a serious problem for Rocky Mountain Ridged Mussels we examined the expected lake drawdown elevations (**Table 3.1**) under Okanagan Lake operating rules for normal or extreme drought conditions (Anonymous 1974). We then compared these lake elevations in relation to the known locations of Ridged Mussel within Okanagan Lake (**Figure 3.19**). Essentially all Ridged Mussel specimens (CDC/MOE occurrence records) were collected near the lake margins, essentially at what would be the normal high water elevation level for Okanagan Lake. No mussels appear to have been collected at lower depths in the bathymetry profile. Note, however, that the historical ridged mussel records have been collected opportunistically and there has not been a systematic survey undertaken to date to evaluate mussel distributions across different depths – COSEWIC 2003; Phil Epp, pers. comm. Regardless, this inventory data would seem to indicate that *any* drawdown of lake levels (normal or extreme drought) could be problematic for adult mussels at the lake margins if they lack sufficient ability to resist desiccation, or else cannot move quickly enough through or along the substrate to track descending water levels. This problem could be compounded in steeper areas of the lake where the depth profile changes more radically and reduced lake levels could force motile mussels into areas deeper than their preferred <3m depth zone. We examined this issue by further assessing the bathymetry profile at different areas of the lake (see **Figure 3.19** and **Figure 3.20**), and evaluating the bathymetry profile in areas in which mussels had been found historically. Although no clear pattern is evident, it does appear that mussels are commonly found in areas of the lake with fairly gradual slopes, which would presumably make it easier to adjust to changing lake levels without being forced to enter rapidly deepening water. The steeper sloped areas of the lake (where some mussel surveys have also occurred) do not seem to support mussels (at least as indicated by the surveys to date).

Table 3.1. Okanagan Lake operation rules affecting lake elevations in normal and extreme drought years as mandated by the Okanagan Basin Implementation Agreement (Anonymous 1974).

	Okanagan Lake Elevations		
	Normal high	Normal minimum	Prolonged drought: allowed minimum
(ft)	1,123.80	1,118.80	1,116.80
(m)	342.53	341.00	340.40

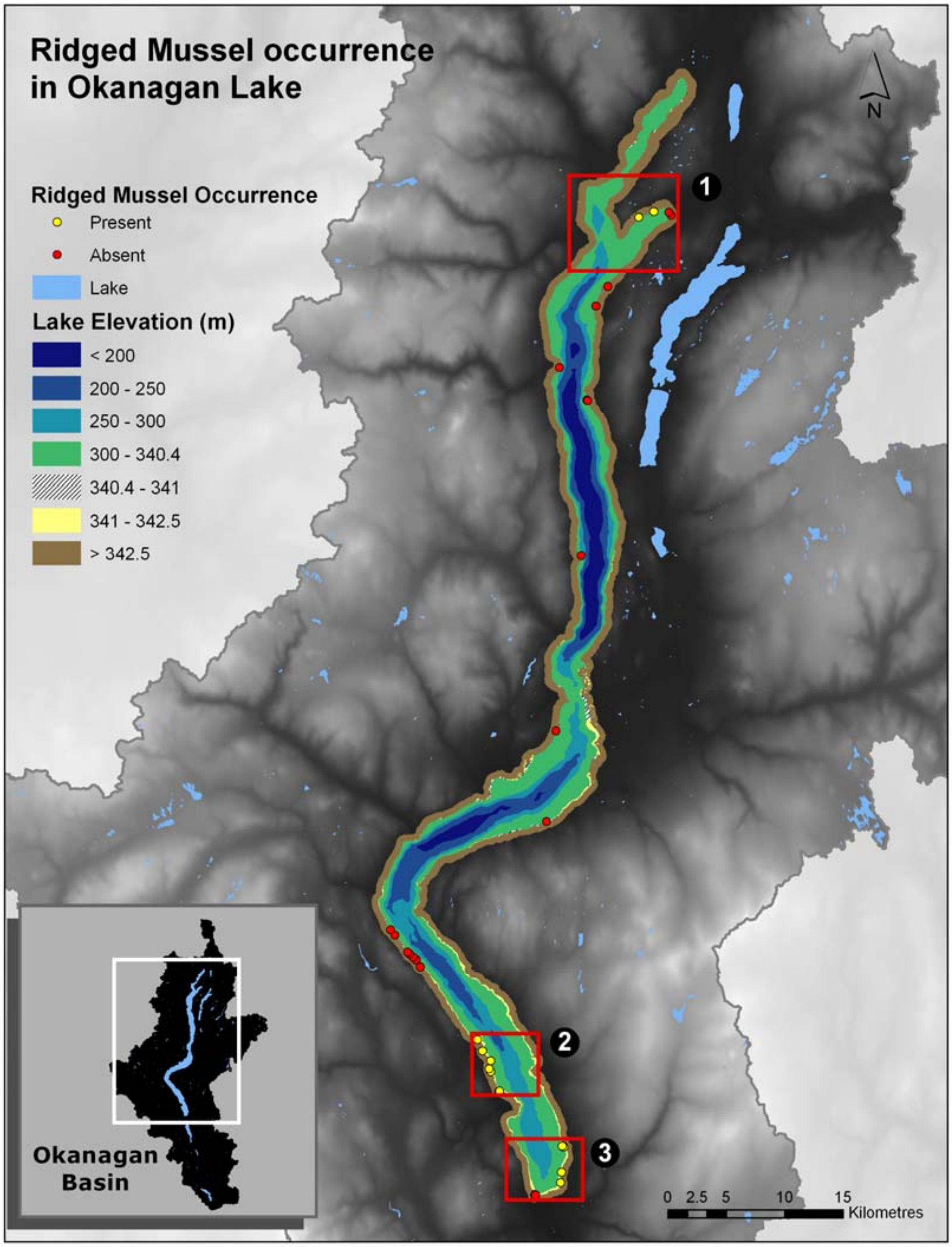


Figure 3.19. Locations of historical Rocky Mountain Ridged Mussel surveys in Okanagan Lake. Yellow points indicate where mussels were detected, red points indicate where surveys were undertaken but mussels not detected. Lake elevations between 341–342.5m indicate lake height during normal lake operating conditions, 340.4–341m indicate lake elevation drawdowns under extreme drought conditions. Other lake elevations are used to indicate the general depth profile of the lake. Numbered cells indicate location of zooms in **Figure 3.20**.

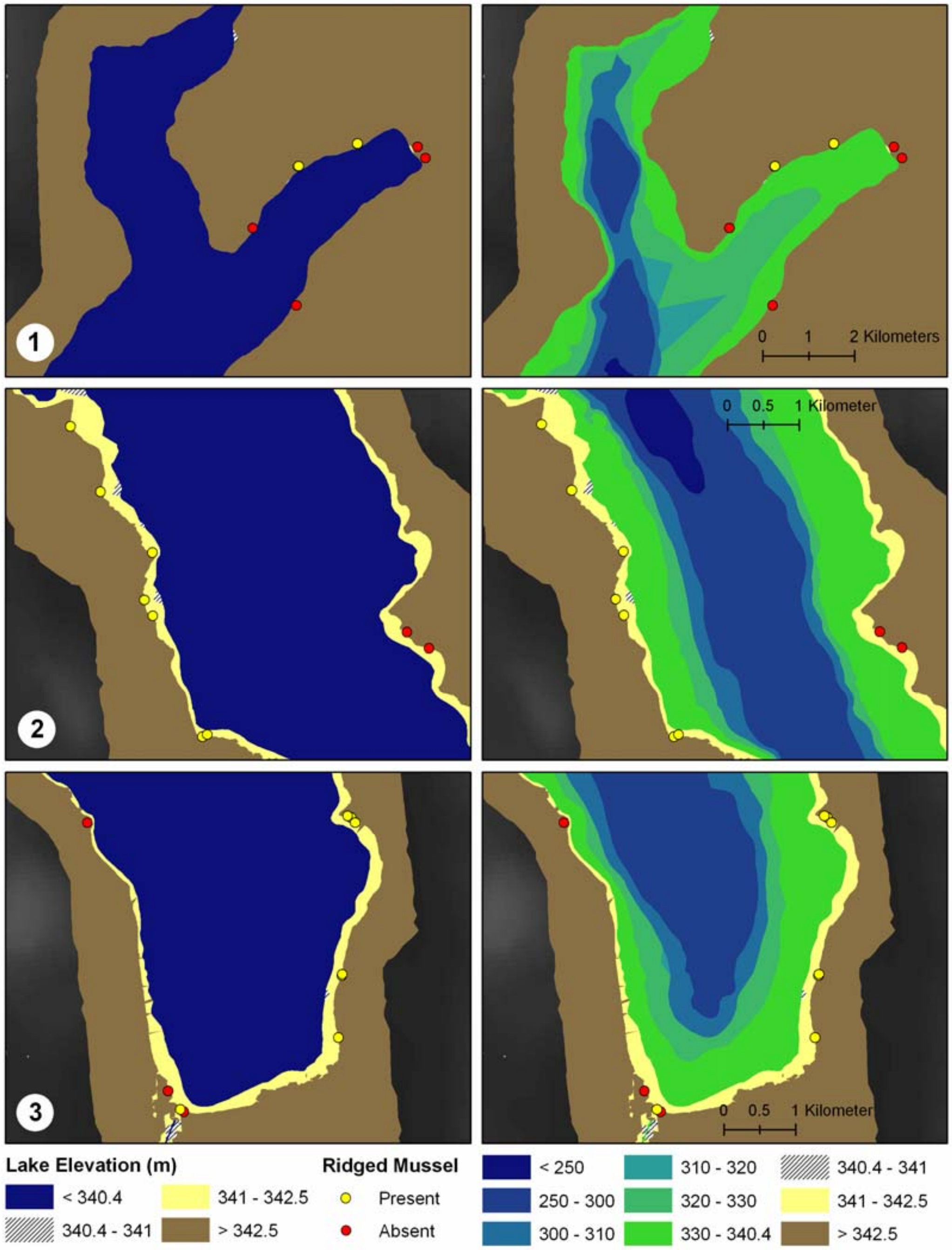


Figure 3.20. Zoomed views of areas of Okanagan Lake where Rocky Mountain Ridged Mussel have been observed. Yellow points indicate where mussels were detected, red points indicate where surveys were undertaken but mussels not detected. Lake elevations between 341–342.5m indicate lake height during normal lake operating conditions, 340.4–341m indicate lake elevation drawdowns under extreme drought conditions. Other lake elevations are used to indicate the general depth profile of the lake. Numbered views indicate location of zooms in **Figure 3.19**.

Table 3.2. Summary of aquatic habitat use by identified sensitive species in the Okanagan and proposed linkage to IFN thresholds.

Species	Conservation Status (Federal/Provincial)	Use of Aquatic Habitats	Linkage to IFN flow recommendations
Mexican mosquito fern (*Azolla mexicana*)	COSEWIC status - Threatened BC status - red listed	Found in quiet backwaters, still waters of ponds and oxbow lakes. Has relatively narrow growing requirements and is susceptible to changes in water levels and composition	Wetland linkage flows - achievement of BCFIN-derived watershed conservation flows
Tiger salamander (*Ambystoma tigrinum*)	COSEWIC status - Endangered BC status - red listed	Breeding and larval development is dependent on seasonal vernal ponds and wetlands that retain water from egg-laying in mid-March to larval emergence by mid-August.	Wetland linkage flows - achievement of BCFIN-derived watershed conservation flows. However seasonal vernal pools are more critical breeding habitat
Great Basin Spadefoot (*Spea intermontana*)	COSEWIC status - Threatened BC status - blue listed	Breeding and tadpole development predominantly dependent on seasonal vernal pools, ponds or ditches that must retain water until tadpoles have metamorphosized (April to the end of May).	Wetland linkage flows - achievement of BCFIN-derived watershed conservation flows. However seasonal vernal pools are more critical breeding habitat
Vivid Dancer damselfly (*Argia vivida*)	COSEWIC status - not addressed BC status - red listed	Found in direct association with springs (mainly hot springs but also some cool springs) where larvae live in creeks and ponds surrounding the springs.	N/A – hot/cool springs dependent, not directly linkable to IFN
Chiselmouth (*Acrocheilus alutaceus)*	COSEWIC status - Not at risk BC status - blue listed	Present in small kettle lakes, margins of larger lakes, streams and in small to medium sized rivers, where it tends to be found in deeper backwaters.	minimum flows for spawning (and possibly rearing) in tributary streams – maintenance of BCIFN minimum risk flows, possibly supplemented by maintenance of optimal spawning and rearing flows for rainbow trout
Western Painted Turtle (*Chrysemys picta bellii*)	COSEWIC status - Special concern BC status - blue listed	Found in shallow waters of ponds, lakes, oxbows and marshes, in slow-moving stream reaches, or the quiet backwater sloughs of rivers	Wetland linkage flows - achievement of BCFIN-derived watershed conservation flows
Rocky Mountain Ridged Mussel (*Gonidea angulata*)	COSEWIC status - Special concern BC status - red listed	Found in well-oxygenated waters with stable habitat conditions. Appears to avoid areas with shifting substrates, periodic dewatering or extreme water level fluctuations, continually turbid conditions, or with seasonal hypoxia or anoxia. Generally found in shallow waters < 3 m deep	minimum flows for maintaining aquatic life – maintenance of BCIFN minimum risk flow thresholds; lake elevations to maintain shallow wetted lake margins – operating rules within the OKFWM tool.

3.5 Inherent hydrologic risk assessment (using naturalized flows)

The *inherent* ability of tributary streams (i.e., without water extraction activities) to achieve recommended flows for IFN during critical periods can be determined by calculating exceedance probabilities. Exceedance plots sort time series data in ascending order, then normalize the data such that the probability of exceeding the smallest value observed in the time series is 1, and the probability of exceeding the highest value ever observed is ~ 0. The resultant cumulative empirical probability distribution is meaningful if there are enough observations, generally >> 100. Since there is no such thing as an average water year or an average flow, this is the recommended technique for determining how often a particular target flow will be exceeded when considering a defined time period and/or seasonal period within a time series of interest.

Results of our exceedance probability analyses are presented in a series of matrices and a selection of example hazard maps that display one of three categories of exceedance probabilities (see Alexander and Robson 2007). Display of exceedances is sometimes based (where it seems appropriate) on a "traffic light" (red/yellow/green) approach relative to potential thresholds of concern across tributary nodes in the Okanagan Basin. We **emphasize** that these analyses are preliminary, intended to communicate the approach only. As the exceedance analysis herein is (1) primarily based on comparisons of IFN flow targets with naturalized flows, and (2) our hazard threshold criteria (which define red/yellow/green) were arbitrary for example purposes, refinement of this analysis are required before it can be used to reach conclusions around geographic fish protection priorities. **Improvements needed are to first use net water availability time series from water balance modelling study** (comparing these exceedance probabilities with those found using naturalized flows). Second, managers must decide on threshold criteria for mapping exceedance probabilities as either red, yellow or green.

A value-neutral way to depict relative risk across the tributary nodes is to define red/yellow/green cut-offs using terciles. Terciles divide an ordered distribution of exceedance probability calculations into three equal groups, each containing a third of the nodes. However, this provides only a relative scalar of what subbasins are, relative to one another, more or less sensitive. It does not indicate that green ("good") nodes are insensitive to flows from an instream flow perspective – nodes rated best using terciles may be flow sensitive. To "start the dialogue", we have therefore also selected some initial absolute risk thresholds based on tentative criteria of 1) > 75% exceedance = good (green), 25-75% = acceptable (yellow) and < 25% = unacceptable (red) or 2) > 50% exceedance = good (green), 25-50% = acceptable (yellow) and < 25% = unacceptable (red). **Figure 3.21** and **Figure 3.22** illustrate example exceedance plots for optimal flows for rainbow trout and kokanee spawning and rearing within Trout Creek and Mission Creek respectively, and the colour assignment between red/yellow/green was split based upon $P(x) < 25\%$, $25\% \leq P(x) < 75\%$, and $P(x) \geq 75\%$.

Another consideration in preparing these plots is whether the exceedance probabilities should be calculated for the entire year or for seasons or windows within any given year. Per advice received by the IFN Committee, exceedance probabilities for minimum BCIFN risk flow targets were assessed for each of three critical time periods: spring freshet, winter dry and summer dry, while watershed conservation flows were assessed for the spring freshet period.

Relative risk (based on terciles) for optimal fish flow exceedances are only depicted across nodes for rainbow trout and kokanee as other salmonid species were too sparsely distributed across the Okanagan to warrant a basin-wide exceedance risk analysis (i.e., limited number of nodes with the particular species present). Instead, for these species we used only the absolute threshold criteria (as described above for minimum BCIFN risk flow thresholds) within the relevant nodes. Optimal fish flow threshold exceedance probabilities were assessed within each salmonid species' critical rearing and/or spawning periods.

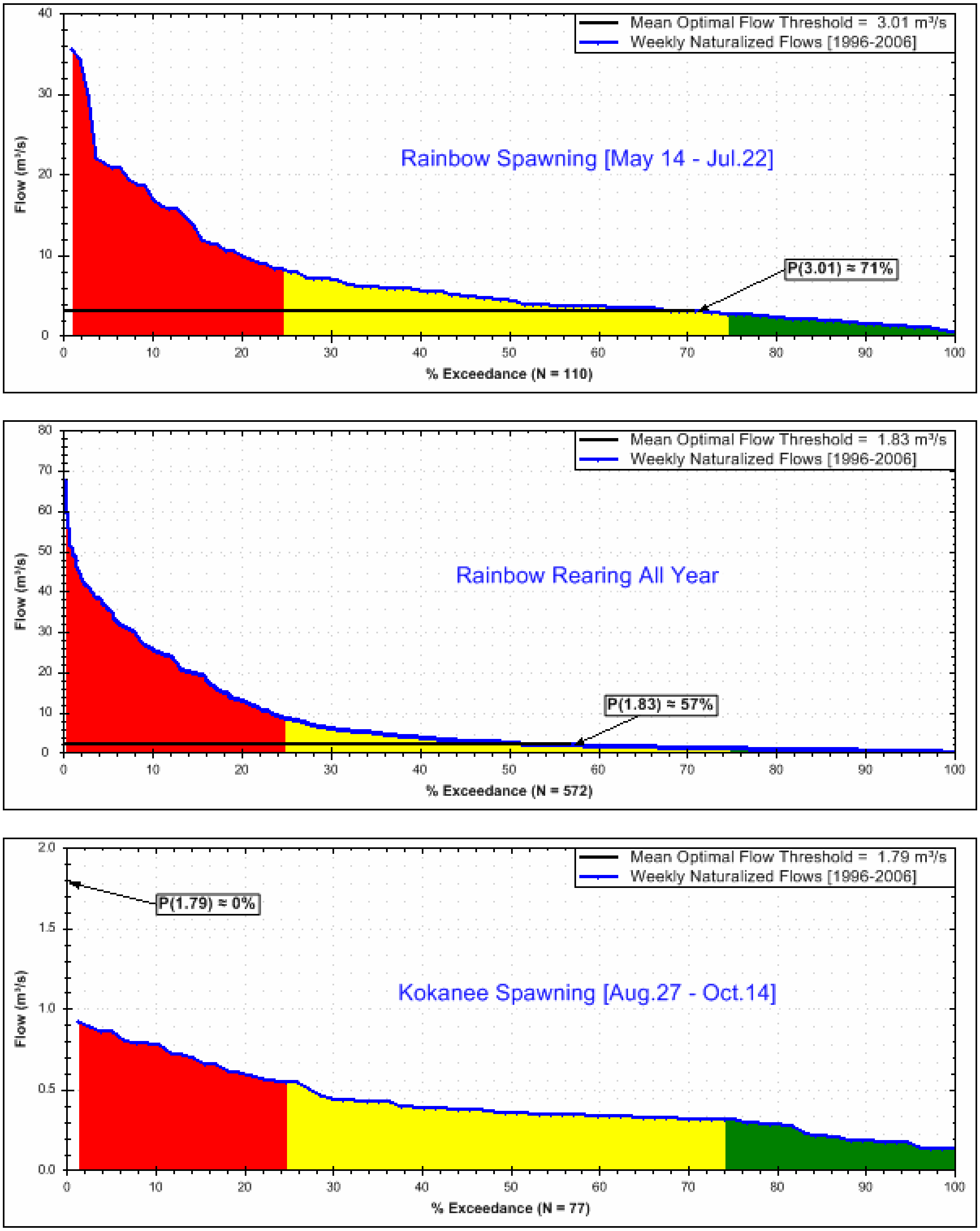
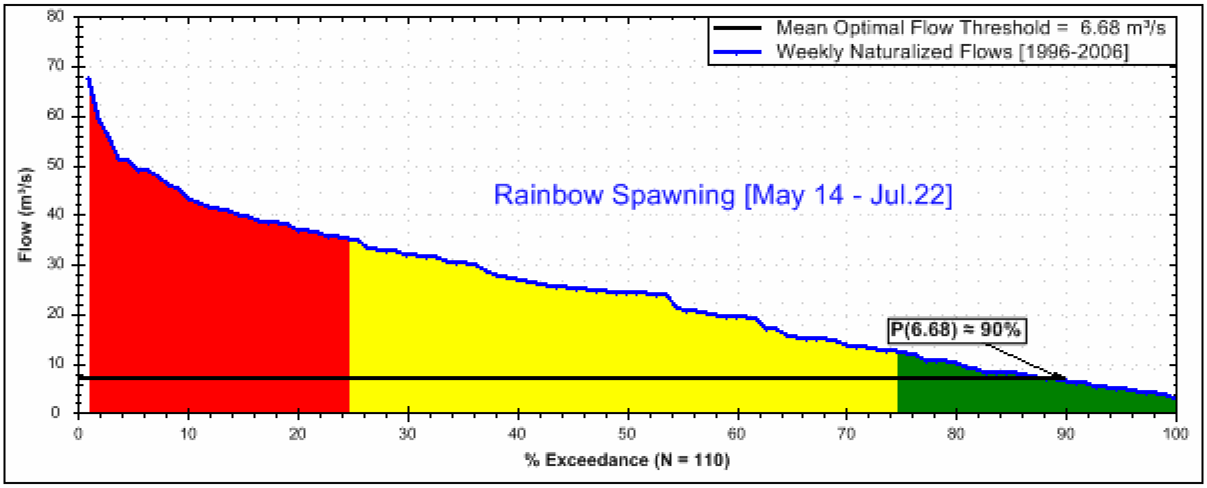
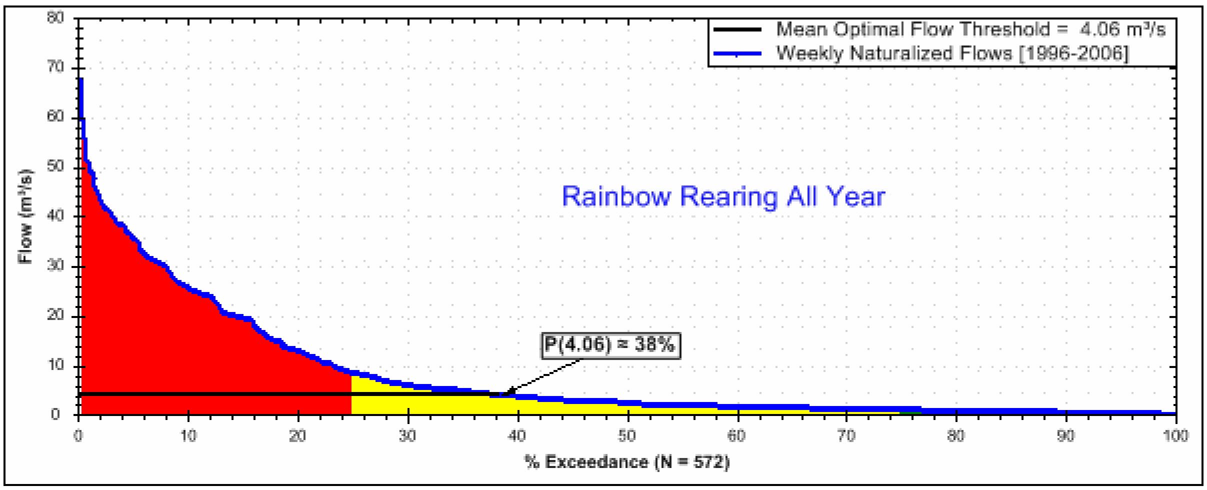


Figure 3.21 Trout Creek exceedance plots for rainbow spawning and rearing, and kokanee spawning based upon their associated meta-analysis mean optimal flow threshold. Example red/yellow/green split based upon P(x) = 25%/75%.





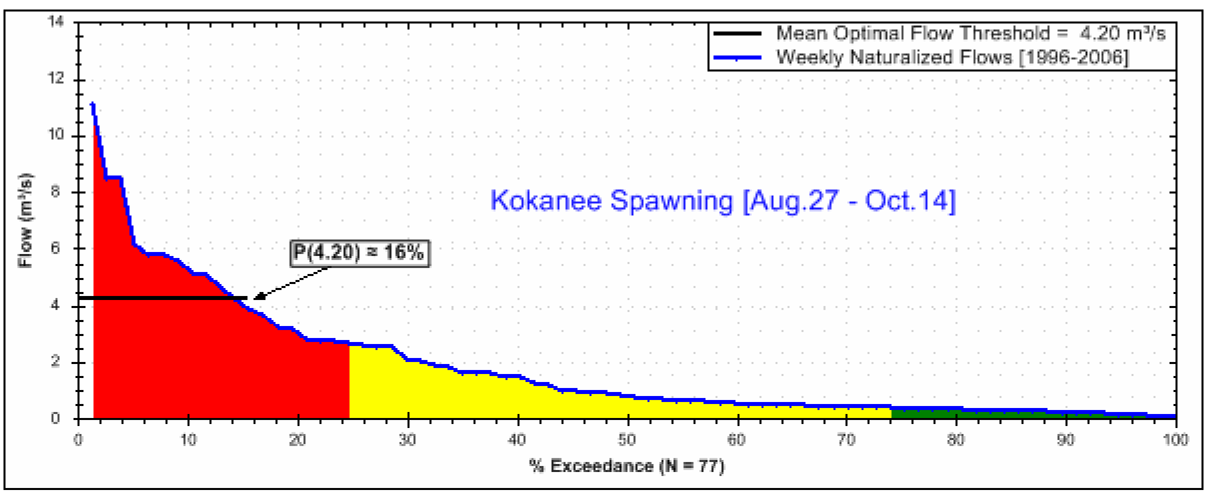


Figure 3.22 Mission Creek exceedance plots for rainbow spawning and rearing, and kokanee spawning based upon their associated meta-analysis mean optimal flow threshold. Example red/yellow/green split based upon P(x) = 25%/75%.

Examples of exceedance probabilities matrices at different critical time periods that we developed for our calculated IFN thresholds are presented in

Table 3.3 (and repeated in **Table C.1)** with BCIF minimum thresholds and BCIFN-derived watershed conservation flows for comparison with regulated flows (where possible).

Table 3.4 provides an exceedance matrix example for optimal flows for rainbow trout and kokanee spawning, with risk levels assigned through green/yellow/red colour coding. The full suite (including the examples below) of exceedance matrices developed for different salmonid species, exploring different threshold criteria and different risk tolerances are presented within additional tables in **Appendix C**.

Optimal flows for rainbow spawning appear to be achieved fairly consistently across most nodes by naturalized flows, although optimal rainbow trout spawning flows are achieved less than 25% of the time in some streams (**Table 3.4** and **Table C.2**). Regularly achieving optimal flows for kokanee spawning with naturalized flows appears to be problematic across the nodes, with most nodes achieving weekly optimals for kokanee less than 25% of the time, and some nodes never achieving their target flows (**Table 3.4** and **Table C.6**). Optimal flow needs for rainbow rearing were consistently met throughout the freshet period with generally a "good" categorization (i.e., threshold achieved greater than 50% of the time), but very rarely during other critical time periods (**Tables C.3 to C.5**).

Although steelhead and sockeye have known presence in only two tributary nodes, optimal spawning flows for steelhead are generally achieved with naturalized flows at these nodes (i.e., greater than 75% of the time), while optimal spawning flow targets for sockeye were not (i.e., less than 25% of the time) (**Table C.7**). Optimal steelhead rearing flows were achieved consistently during the freshet but not at other critical time periods (i.e., generally less than 25 or 50% of the time, depending on the degree of risk tolerance acceptable). Optimal flows for Chinook and coho spawning were rarely met in the four tributary streams in which they were evaluated (**Table C.8 and C.9** respectively). Optimal flows for Chinook rearing were, however, much more consistently achieved, nodes generally being categorized as yellow or green risk depending on the potential degree of risk tolerance acceptable (**Table C.9**). Optimal flows for coho rearing in the four streams were fairly good considered on an all-year basis (i.e., generally achieved greater than 25% of the time) and were almost universally achieved across the nodes during the freshet period (**Tables C.10 and C.11**). However, during the mid winter and late summer dry periods rearing flows were much lower, with optimal flow threshold exceedances ranging from 0% to 64%, dependent on the degree of risk tolerance evaluated.

Again, we emphasize that these risk categorizations—meant for illustrative purposes – use naturalized flow time series rather than the more relevant net water availability data that are soon to emerge from the water balance modelling project.

Table 3.3. BCIFN minimum risk flow threshold and BCIFN-derived conservation flow threshold exceedance analysis, compared to nodes with regulated historical flows. An upward pointing green arrow indicates that the probability of exceeding the flow threshold for the period of interest has increased with regulated flows, whereas a red arrow pointing down indicates the probability of exceeding the flow threshold has decreased.

Node		BCIFN Minimum Flow Threshold									Conservation Flow			
ID	Name	Freshet			Late Summer			Mid-winter			Freshet			ID
1	Vernon Creek at outlet of Kalamalka Lake	72	49	▼	36	13	▼	12	32	▲	57	37	▼	1
3	Deep Creek (mouth)	53			13			31			53			3
5	Irish Creek (mouth)	51			4			9			36			5
8	Equesis Creek (mouth)	55			9			10			38			8
10	Nashwhito Creek (mouth)	56			9			10			39			10
12	Vernon Creek (mouth); includes Zone A & B	73	65	▼	29	20	▼	12	14	▲	62	53	▼	12
14	Whiteman Creek (mouth)	59			8			9			40			14
16	Shorts Creek (mouth)	59	52	▼	8	15	▲	9	0	▼	40	43	▲	16
18	Lambly Creek (mouth)	59			8			9			40			18
20	Kelowna (Mill) Creek (mouth)	51	35	▼	13	21	▲	13	2	▼	39	28	▼	20
22	Mission Creek (mouth)	68	51	▼	12	9	▼	11	4	▼	66	46	▼	22
24	Bellevue Creek (mouth)	67			11			6			40			24
25	Residual area E-5	67			11			5			40			25
26	McDougall Creek (mouth)	45			10			0			28			26
27	Residual area W-8	73			18			14			64			27
28	Powers Creek (mouth)	60	49	▼	9	23	▲	8	5	▼	40	41	▲	28
30	Trepanier Creek (mouth)	61	60	▼	10	3	▼	9	0	▼	44	41	▼	30
32	Peachland Creek (mouth)	69	45	▼	12	14	▲	11	14	▲	37	24	▼	32
34	Chute Creek (mouth)	67			11			5			40			34
36	Eneas Creek (mouth)	58			10			6			40			36
37	Residual area W-12	73			29			14			64			37
38	Robinson Creek (mouth)	66			7			0			38			38
40	Naramata Creek (mouth)	67			10			5			40			40
42	Trout Creek (mouth)	73	62	▼	8	14	▲	11	2	▼	40	50	▲	42
44	Turnbull Creek	67			7			1			38			44
46	Penticton Creek (mouth)	67			10			6			40			46
51	Shingle Creek (mouth)	58			10			10			42			51
52	Ellis Creek (mouth)	69			11			9			43			52
54	Residual area E-11	70			12			9			44			54
55	Marron River	62			10			8			33			55
60	Shuttleworth Creek (mouth)	70			11			9			44			60
66	Vaseux Creek (mouth)	72			12			9			48			66
69	Park Rill (mouth)	62			10			8			32			69
71	Wolfcub Creek (mouth)	66			10			9			44			71
73	Testalinden Creek (mouth)	60			8			6			31			73
78	Inkaneep Creek (mouth)	68			12			9			48			78

Table 3.4. Rainbow and kokanee optimal spawning flow threshold exceedance analysis - terciles (relative risk) and P() = 50/75% (absolute risk), compared to selected nodes with regulated historical flows. An upward pointing arrow indicates that the probability of exceeding the flow threshold for the period of interest has increased with regulated flows, whereas a grey cell with no arrow indicates the probability of exceeding the flow threshold has decreased.

Rainbow Spawning

Node ID	Node Name	P() red/yellow/green using terciles: Mean Optimal		Lower 50% PI		P() < 25% / P() < 75% / P() ≥ 75%: Mean Optimal		Lower 50% PI		P() < 25% / P() < 50% / P() ≥ 50%: Mean Optimal		Lower 50% PI	
1	Vernon Creek at outlet of Kalamalka Lake	58	35	79	44	58	35	79	44	58	35	79	44
3	Deep Creek (mouth)	12		33		12		33		12		33	
5	Irish Creek (mouth)												
8	Equesis Creek (mouth)	38		49		38		49		38		49	
10	Nashwhito Creek (mouth)	26		45		26		45		26		45	
12	Vernon Creek (mouth); includes Zone A &	62	53	84	69	62	53	84	69	62	53	84	69
14	Whiteman Creek (mouth)	45		57		45		57		45		57	
16	Shorts Creek (mouth)	48	43	62	55	48	43	62	55	48	43	62	55
18	Lambly Creek (mouth)	49		63		49		63		49		63	
20	Kelowna (Mill) Creek (mouth)	22	17	41	28	22	17	41	28	22	17	41	28
22	Mission Creek (mouth)	89	78	96	85	89	78	96	85	89	78	96	85
24	Bellevue Creek (mouth)	43		60		43		60		43		60	
25	Residual area E-5												
26	McDougall Creek (mouth)	9		15		9		15		9		15	
27	Residual area W-8												
28	Powers Creek (mouth)	44	33	58	45	44	33	58	45	44	33	58	45
30	Trepanier Creek (mouth)	51	44	72	55	51	44	72	55	51	44	72	55
32	Peachland Creek (mouth)	27	20	45	29	27	20	45	29	27	20	45	29
34	Chute Creek (mouth)	40		59		40		59		40		59	
36	Eneas Creek (mouth)	11		17		11		17		11		17	
37	Residual area W-12	0		0		0		0		0		0	
38	Robinson Creek (mouth)	5		17		5		17		5		17	
40	Naramata Creek (mouth)	28		48		28		48		28		48	
42	Trout Creek (mouth)	70	60	85	68	70	60	85	68	70	60	85	68
44	Turnbull Creek												
46	Penticton Creek (mouth)	49		66		49		66		49		66	
51	Shingle Creek (mouth)	55		76		55		76		55		76	
52	Ellis Creek (mouth)	52		66		52		66		52		66	
54	Residual area E-11	31		50		31		50		31		50	
55	Marron River	6		13		6		13		6		13	
60	Shuttleworth Creek (mouth)	40		58		40		58		40		58	
66	Vaseux Creek (mouth)	62		73		62		73		62		73	
69	Park Rill (mouth)												
71	Wolfcub Creek (mouth)	13		23		13		23		13		23	
73	Testalinden Creek (mouth)												
78	Inkaneep Creek (mouth)	35		57		35		57		35		57	

Kokanee Spawning

P() red/yellow/green using terciles: Mean Optimal			Lower 50% PI			P() < 25% / P() < 75% / P() ≥ 75%: Mean Optimal			Lower 50% PI			P() < 25% / P() < 50% / P() ≥ 50%: Mean Optimal			Lower 50% PI			ID
26	11		66	18		26	11		66	18		26	11		66	18		1
0			16			0			16			0			16			3
																		5
0			0			0			0			0			0			8
0			0			0			0			0			0			10
21	16		70	29		21	16		70	29		21	16		70	29		12
0			0			0			0			0			0			14
0	1	▲	0	5	▲	0	1	▲	0	5	▲	0	1	▲	0	5	▲	16
0			0			0			0			0			0			18
0	5	▲	14	28	▲	0	5	▲	14	28	▲	0	5	▲	14	28	▲	20
14	14		29	32	▲	14	14		29	32	▲	14	14		29	32	▲	22
																		24
																		25
																		26
0			0			0			0			0			0			27
0	1	▲	0	2	▲	0	1	▲	0	2	▲	0	1	▲	0	2	▲	28
0	0		3	1		0	0		3	1		0	0		3	1		30
0	0		9	13	▲	0	0		9	13	▲	0	0		9	13	▲	32
0			0			0			0			0			0			34
0			0			0			0			0			0			36
0			0			0			0			0			0			37
0			0			0			0			0			0			38
0			0			0			0			0			0			40
0	4	▲	0	9	▲	0	4	▲	0	9	▲	0	4	▲	0	9	▲	42
0			0			0			0			0			0			44
0			0			0			0			0			0			46
0			0			0			0			0			0			51
0			1			0			1			0			1			52
0			1			0			1			0			1			54
																		55
																		60
																		66
																		69
																		71
																		73
																		78

Hazard maps based on exceedance probability bins provide a way to assess spatial patterns of flow risk across the Basin (i.e., are there discernible differences in natural flow risk based on location). An example of a hazard map based on exceedances for a particular threshold of concern (flows during the rainbow trout spawning period) is presented in **Figure 3.23**. A larger suite of example hazard maps for salmonid species optimal spawning/rearing flows for kokanee and rainbow trout are presented in **Appendix D** as further examples.

These hazard maps are based on the hypothetical thresholds of acceptability (consistent with the exceedance plots) described above. For the species optimal flows we also display risk maps derived using IFN thresholds for both the mean optimal flows and the lower 50% prediction interval.

Given the limitations of this preliminary exceedance analysis, a node-by-node assessment of inherent hydrologic risk was not undertaken for this report. However, in general, tributary nodes in the northeast section of the Basin seemed to display a better inherent ability to achieve IFN flows defined for different species and during different time periods of the year, whereas the opposite seemed to be the case for tributary nodes in the northwest section of the Basin.

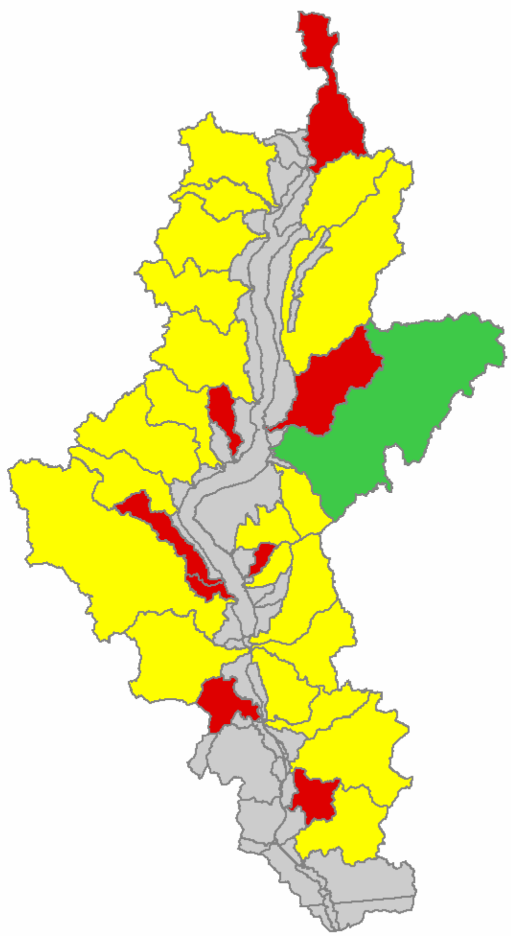


Figure 3.23. Example hazard map showing optimal flow threshold exceedance probabilities across tributary nodes for rainbow trout spawning. In this example green nodes can exceed minimum flow thresholds more than 75% of the time yellow nodes exceed thresholds 25–75% of the time, and red nodes exceed thresholds less than 25% of the time (based on historical weekly naturalized flows for 1996-2006). Default IFN analyses were not undertaken for the gray coloured nodes which represent either residual areas without permanent flowing streams, lakes or the mainstem Okanagan River.

3.5.1 Comparison with select regulated flows

To assess the extent to which recent regulated flow regimes for Okanagan tributaries associated with seasonal water storage and withdrawals may impact IFN flow threshold exceedances we evaluated weekly regulated flows at gauged tributaries (where possible). The regulated flow data used in our study includes some gross assumptions (generally associated with matching flows at the mouths of tributaries vs. where gauges are located upstream), so our analysis in this regard is preliminary. We were able to extract daily regulated flow data (which we converted to weekly averages) for 9 tributary stream nodes with at least 10 years of relatively consistent data collection (only some of which overlapped with our 1996–2006 naturalized data time series) in the period of interest (e.g. freshet/late summer/mid-winter). Regulated flow data came from upstream gauge locations variably distant from the downstream nodes (i.e., stream mouth), so we attempted to adjust for this by a simple correction factor. For stream gauge locations upstream of the node of interest, the regulated flow was scaled by taking the area of the watershed for the node divided by the area of the watershed at the gauge location. This correction is crude and more complex modeling will need to be taken at some point to more accurately adjust for this spatial discrepancy between node and gauging stations and allow more valid flow comparisons.

Exceedance probabilities calculated using regulated flows in relation to BCFIN minimum flow thresholds, BCIFN-derived conservation flow thresholds and optimal flows for kokanee are represented within tables in **Appendix C.** Readers can compare these exceedance results with those for the naturalized flows ("no regulation") for the 9 locations in question. Interestingly, these comparisons indicate that for 5 of the 9 regulated subbasins, IFN exceedance probabilities were greater than those found for the naturalized flows in the late summer dry period. This is likely a result of increased water storage during the freshet in these nodes, with subsequent release of this stored water later in the summer when consumptive water demand is high (Russell Smith, pers. comm. 2009). However, these nodes generally show *reduced* probabilities of exceeding minimum flow thresholds during other critical time periods. The other nodes evaluated show a mix of differences in exceedance probabilities between regulated and naturalized flows at different times of the year, likely reflecting different water management priorities that may be in play at these nodes such as flood control (e.g., Vernon Creek) or heavy year- round human consumption (e.g., Mission Creek) (Russell Smith, pers. comm. 2009). This comparison should be updated with results of water balance scenario modelling results, using net water availability time series.

4 Discussion

The Okanagan Sustainable Water Strategy seeks to "*ensure our limited water resources are coordinated and well managed – working towards a future for the Okanagan where water does not compromise human health and well-being, the environment, or the economy*" (OWSC 2008). While a notable goal, this will not be achieved easily as successfully managing water supplies to balance human and ecosystem needs represents a long standing challenge in resource management (e.g., Richter et al. 2003; Arthington et al. 2006; King and Brown 2006). Conflicts emerge when water managers are faced with water scarcity—either limited supply or high demand – leading to situations where insufficient water is available for both out-of-stream (human) and instream (ecosystem) uses. The Okanagan Water Supply and Demand Project seeks to assist water managers by providing the best estimates of past, present and future water need and availability, ultimately taking into account present water use, population growth, climate change, land use change, preservation of the environment, and other factors (OWSC 2008). IFN recommendations developed in this report for the Okanagan Water Supply and Demand Project are intended to provide guidance as to the instream flows required to protect fish and other aquatic biota, optimize fish production and ensure overall functioning of stream ecosystems. Although the use of instream flow standards can not directly reduce conflicts between instream and out-of-stream water users, they can describe basic water needs for fish and provider consistency in approaches for identifying those needs (Nelitz et al. 2009).

Instream flow has direct effects on aquatic environments through its influence on hydraulic parameters such as current and depth. It also indirectly affects aquatic ecosystem integrity through its influence on physical habitat, connectivity of riparian areas, nutrient dynamics and the ability of aquatic species to access habitat (Bradford 2008). There is, however, no universal instream flow value that is certain to protect all components of fish habitat in all streams. For example the meta-analysis regressions of Hatfield and Bruce (2000) predict how optimal 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 an IFN threshold flow it implies that on average it should perform well, but that on some streams the threshold would be too rigid and on others too lax. An IFN value is in essence a probabilistic statement regarding the protection of fish habitat (Hatfield *et al.* 2002). Uncertainty in the characterisation of IFN and the variable response of aquatic biota and fish populations to those flows (i.e., uncertainty in the indicators) are two of the principle sources of uncertainty in determining IFN (Bradford and Heinonen 2008). The current state of knowledge about the effects of low flows on fish can be summarised by **Figure 4.1**, where risk to aquatic biota increases as residual flow decreases and vice versa. Between the two endpoints there is considerable uncertainty as a consequence of i) our inability to predict hydrological and biological responses with models and ii) the effect that unpredictable future events (e.g., climate change) will have on hydrographs and aquatic species (Whitfield *et al*. 2002; Bradford and Heinonen 2008).

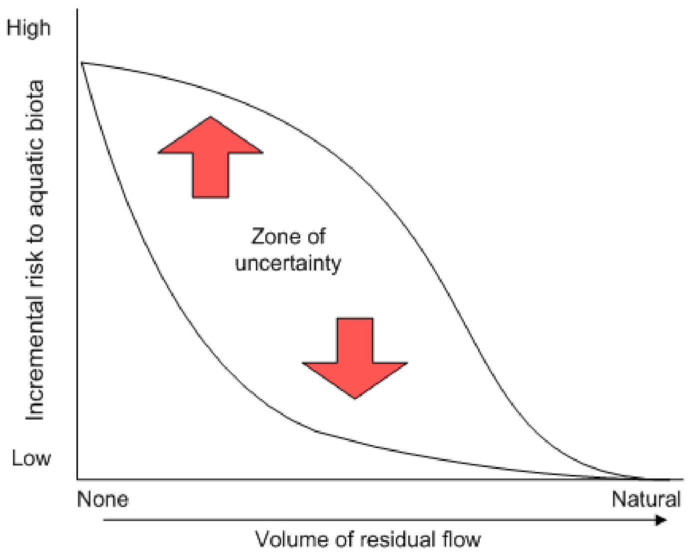


Figure 4.1. Conceptual relationship between the risk to aquatic biota and residual flow. Risk generally increases as flows are reduced and decreases as the flow remaining in the channel increases. There is a large zone of uncertainty between the two endpoints, where the exact nature of the relationship between risk to aquatic biota and volume of residual flow is unknown (modified from Healey 1998).

Another major source of uncertainty in IFN estimates relates to that around the accuracy of the hydrologic modelling to predict naturalized flows at the nodes (i.e., uncertainty in the data; Pappenberger and Beven 2006). Furthermore, Hatfield *et al.* (2003) recommend that a minimum of 20 years of flow data should be used to form a baseline to accurately reflect natural variation in flows. The baseline period for the Okanagan surface water hydrology study is considerably shorter (11 years) and as a result will have added some additional uncertainty to flow estimates (see **Figure 4.2**). For instance, the mean annual inflow for 1996–2006 is actually higher than the long term (1973–2006) mean annual inflow (610 vs. 534 million m3). Consequently, IFN methods based on MAD for 1996–2006 will tend to generate higher flows relative to what would be generated using the longer term average. We have developed a MAD correction factor (see section 2.4.4) to adjust for this within our meta-analysis IFN approach. We have also quantified the effect of this reduced time series on our BCIFN recommended flows, for which we cannot apply a correction factor (see section 2.5.1).

There is also uncertainty inherent in the IFN method itself (i.e., what are the limitations of the IFN method?). For example PHABSIM studies will present spatial variance within individual studies and also variation among study sites, practitioners, and protocols. The meta-analysis IFN approach represents a useful planning tool in this regard because it incorporates all these sources of error across studies and explicitly captures them in prediction intervals (e.g., 25% on either side of the mean regression line—see Figure 2.14). Standards based on other methods generally give no estimates of the error around their IFN predictions. Identifying uncertainties represents a first step towards reducing the uncertainties at some point in the future (e.g., through monitoring and research). Where it is not possible to minimise the uncertainty, uncertainty should at least be incorporated into the decision making process so that the risk and risk tolerances in the contest of trade-offs between multiple water uses can be explicitly considered.

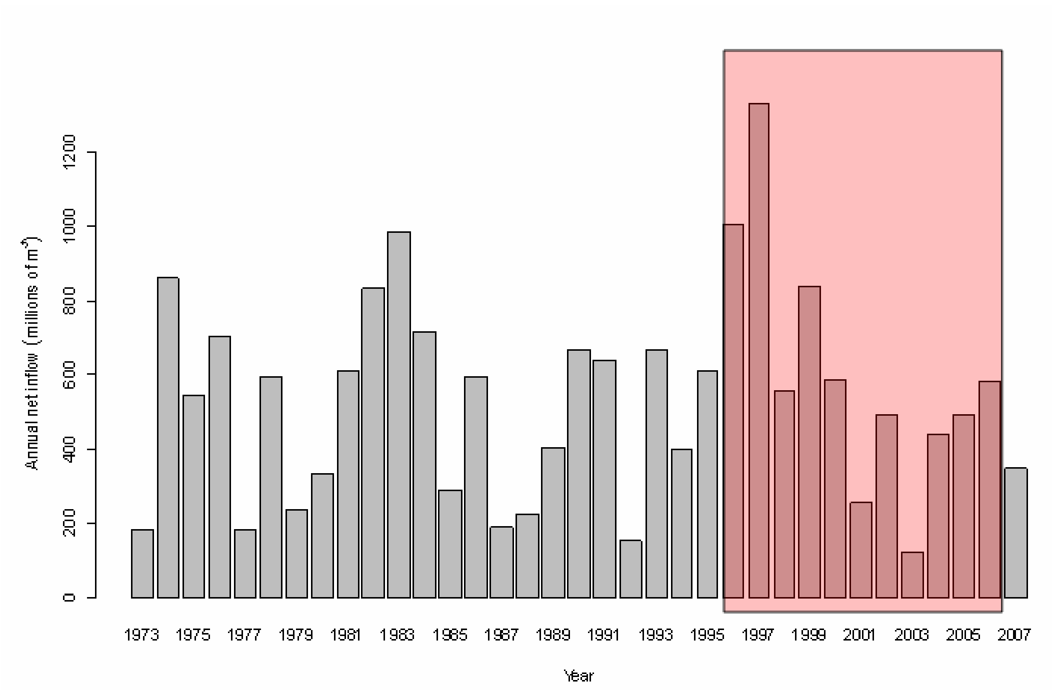


Figure 4.2. Time series of actual net inflows summed from daily observations of Okanagan lake levels courtesy of the OKFWM tool. The red box identifies the shorter time series used for developing estimates of naturalized stream flow in the Okanagan hydrology and hydrologic modeling study (Summit 2009).

4.1 Risk properties of and evidence for the different types of instream flow guidelines

Instream flow guidelines describe the timing and magnitude of stream flows needed to protect fish habitat in the absence of detailed biological and physical habitat information for a stream. It is critical to recognize, however, that not all defined instream flow guidelines present equal inherent risk to fish. Some are generally more conservative in their tolerance of risk to fish than others. The IFN approaches used in this report could be subjectively categorized into a 1–4 qualitative scale of relative risk such that:

1 – Least conservative (higher risk to fish if guideline followed)

2 – Intermediate (moderate risk to fish if guideline followed)

3 – More conservative flows (lower risk to fish if guideline followed)

4 – Most conservative flows (very low risk to fish if guideline followed)

Figure 4.3 illustrates conceptually how the different IFN guidelines can represent different levels of inherent risk to fish and other aquatic species. Essentially, there is a risk that at some times you will be allocating too much water to other users to the detriment of fish needs. This ecological risk can be lowered by choosing a generally more conservative guideline or by choosing a different guideline to apply at different times of the year (i.e., BCIFN minimum risk thresholds are generally more conservative but at certain times of the year meta-analysis thresholds may be more conservative dependent on the salmonid species present in the stream and the timing of their life stage requirements).

Table 4.1 describes each of the IFN guidelines we used for defining recommended flow thresholds at the Okanagan stream nodes and categorizes them as to perceived strength and weaknesses in approach, as well as categorizing their flow thresholds as to the general relative level of risk they represent to fish and other aquatic biota.

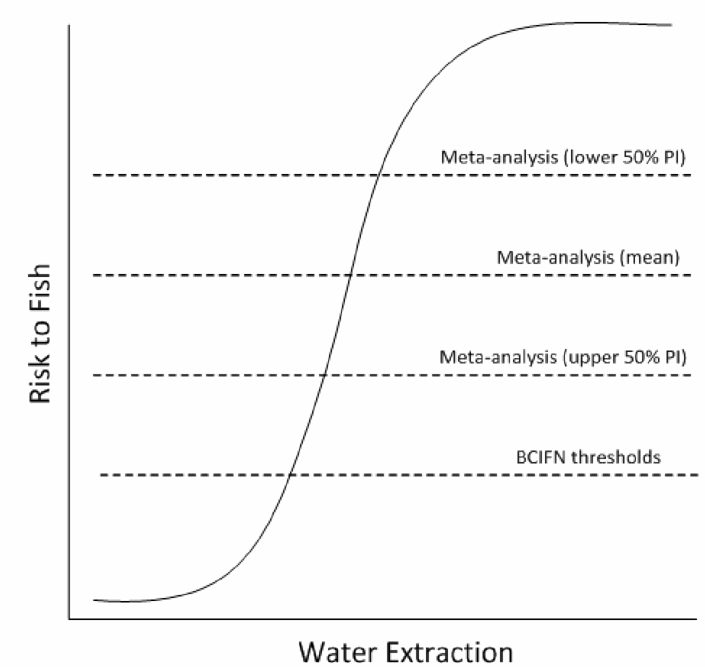


Figure 4.3. Relative inherent risk to fish of different guidelines used for setting IFN thresholds for Okanagan tributary stream nodes. Note that the relative difference in the level of risk between BCIFN thresholds and meta-analysis thresholds depicted here will apply generally over the year but will also vary dependent on salmonid species present in the stream and their seasonal flow needs (i.e., in some weeks BCIFN minimum risk thresholds will be set lower than meta-analysis-based thresholds).

Table 4.1. Risk categorizations and perceived strengths and weaknesses of proposed IFN guidelines. Risk categorizations for IFN guidelines range from 1–4 (highest to lowest risk respectively)

Instream flow guideline	Source	Intended use	Level of acceptance / peer review	Target frequency	Level of risk to aquatic biota	Strengths	Weaknesses
BCIFN Phase 2 Minimum Risk Flow	Hatfield *et al.* 2003	Ensure biota adapted to stream's natural hydrology remain healthy	Peer reviewed government publication – accepted by provincial and federal agencies in BC	Every year	Very Low (4) precautionary flow to protect biota, particularly in lower flow months	Is tuned to individual stream's hydrology; assumes that maintaining hydrograph will maintain dependent biophysical processes and biota	BCIFN minimum risk threshold may not be achieved in some weeks in dry years, which means no water withdrawal. This reflects real stress to biota (i.e. less water than biota need), but is interpreted by some that IFN level is "unrealistic".
BCIFN Maximum Diversion Rate	Hatfield *et al.* 2003	Human water extraction with safe limits for aquatic biota	- as above -	Every year	Very Low (4) limits total amounts of water that can be extracted so as to maintain sufficient flows for ecosystem needs, while permitting considerable water use in months with higher flows	- as above -	Maximum Diversion Rate is a general rule; could actually vary considerably across streams depending on hydrology
BCIFN Phase 2-derived Watershed Conservation Flow (natural flow in highest flow months – BCIFN Maximum Diversion Rate)	Methods outlined in this report based upon Hatfield *et al.* (2003)approach	Watershed Conservation Flow – ensure geomorphic processes for channel maintenance and habitat formation are maintained	- as above -	1 in 5 to 10 years	Very Low (4) ensures that geomorphic processes required for ecosystem functions, channel maintenance, wetland linkages will occur	- as above -	No certainty that achieving these IFN thresholds will successfully provide all ecosystem flow needs; uncertain how often such flows will need to be achieved to maintain functioning ecosystem processes

Instream flow guideline	Source	Intended use	Level of acceptance / peer review	Target frequency	Level of risk to aquatic biota	Strengths	Weaknesses
Meta-analysis regression line (mean)	Hatfield and Bruce (2000)	Optimal Fish Flow to maximize physical habitat for individual salmonid species/life stages	Peer reviewed journal paper	Every year during critical periods of concern	Intermediate (2) balances risk of IFN being too low or too high for optimal salmonid needs	Best estimate based on ~127 studies and 1500 sites; mean of regression line is most likely value; Okanagan data are balanced on both sides of regression line; meta-analysis prediction matches P. Epp PHABSIM work for kokanee and rainbow trout in Okanagan streams well	Meta-analysis speaks only addresses habitat needs of rearing/spawning salmonids and does not Incorporate other requirements for instream flows. PHABSIM methods that provide the foundation of the meta-analysis regressions have also been criticized for the lack of statistical rigor in development of habitat suitability criteria, and lack of validation of the relation between fish populations and habitat (e.g., Mathur *et al*. 1985; Gan and McMahon 1990; Williams 1996; Castleberry *et al*. 1996).
Meta-analysis regression line (lower 25th prediction interval)	Based on Hatfield and Bruce (2000)	- as above -	Based on data in Peer reviewed journal paper	- as above -	High (1) errs on side of having too little flow for optimal salmonid needs	Can be used in situations where other evidence (e.g. detailed studies) indicates that OFF is lower than that predicted by regression line, or in streams where water managers are willing to accept higher level of risk.	Less likely value than mean of regression line. If stream does have fish, and you have no evidence from detailed studies, then there is little justification for adopting this value rather than regression line. And once you have evidence from detailed studies, you might as well use the detailed evidence directly to set flows, rather than use lower 25th prediction interval.

Instream flow guideline	Source	Intended use	Level of acceptance / peer review	Target frequency	Level of risk to aquatic biota	Strengths	Weaknesses
Meta-analysis regression line (upper 75th prediction interval)	Based on Hatfield and Bruce (2000)	- as above -	Based on data in Peer reviewed journal paper	- as above -	Low (3) errs on side of having greater flow than needed for optimal salmonid needs	Can be used in situations where other evidence indicates that OFF is higher than that predicted by regression line, or in streams where managers want a lower level of risk because of important fish stocks.	Less likely value than regression line. Same weakness as above (i.e. in absence of evidence, you may need detailed studies to justify using this value rather than the mean of regression line.

4.2 Other caveats and limitations

Various assumptions have been made within our analyses which should be recognized and will affect the accuracy of the IFN thresholds we have defined. For our meta-analysis based IFN we have used default fixed life history timing for each species across all nodes. There will undoubtedly be variation in timing of life history events for salmonid species within different nodes and across different years. We do not have the data to adjust for this currently but further studies in the Okanagan may allow such node and year-specific adjustments to be made to improve the timing resolution of our recommended seasonal flows for optimization of fish habitat. As described in section 2.5.1 the available naturalized flow data for the Okanagan is of a different time step (only weekly flows vs. daily) and of shorter duration (11 years vs. at least 20 years) that is recommended for use with the BCIFN method. We have attempted to assess how much of a difference this has made to our minimum flow designations (appears negligible) but it must be recognized that we used a modification of the standard BCIFN approach, and so unrecognized error might be present.

Our default IFN recommendations apply only to tributary stream nodes and not to lakes or the mainstem Okanagan River. We can not capture IFN needs for lakes using our methods and currently there have not been naturalized flows modeled for the Okanagan mainstem that we can use as inputs for our analyses. We have addressed some IFN needs for the Okanagan River (for sockeye) as captured within the Okanagan Fish Water Management Tool but IFN needs for other species within the river are not addressed. At a later date, when naturalized flow data exist for the mainstem, it will be possible to develop our full suite of default IFN for the Okanagan River mainstem using the methods described in our report.

The IFN thresholds developed in this report directly assess only the needs of fish and other aquatic biota. Other natural resources (e.g., wildlife) or interests (e.g., public safety) will generally also need to be considered in relation to water allocations. It is expected that water use conflicts will arise where flow thresholds for fish indicate water levels that are suboptimal for other resources or interests. Our recommended flows for fish cannot anticipate these cases, and it would be expected that relevant agencies would undertake studies or negotiations to assess the appropriate trade-offs across the varied interests.

In the Okanagan, as in many other parts of B.C., a currently unfolding storyline is one of converging trends in population growth, water consumption, climate change, and the status of freshwater ecosystems, such that we can expect greater conflicts between human and ecosystem needs for water in the future (Nelitz et al. 2009). These converging trends suggest an increase in the vulnerability of water supplies and reliant freshwater species, such as Pacific salmon, and the potential for greater conflicts between human and ecosystem needs in the future. Current evidence illustrates that climate change has significantly affected water availability in the past, and is expected to further reduce the capacity of watersheds to store water in the future (through declines in snowpack and glaciers). Climate induced changes in precipitation and air temperature are expected to extend into the next century, which will continue to affect the timing and availability of water supplies. In the Okanagan Basin, Global Climate Models predict an increase in winter temperatures from 1.5 to 4.0 °C and winter precipitation from 5 to 20% by the 2050s, as well as a decrease in precipitation of 20% during summer (Merritt et al. 2006). Analyses within this report **did not** address current or future water temperature issues for fish in the Okanagan or seek to explore the potentially synergistic effect of flow and water temperature on fish habitat in the Okanagan.

4.3 IFN in a meta-population and landscape context

River flow regimes show patterns that are determined largely by river size and by geographic variation in climate, geology, topography, and vegetation cover (Poff et al. 1997). Variability in the intensity, timing, and duration of precipitation and in the effects of terrain, soil texture, and plant evapo-transpiration on the hydrological cycle combine to create local and regional flow patterns. Consequently, some streams within the same region will show relatively stable hydrographs naturally (e.g., due to high groundwater inputs, etc.) whereas other streams will fluctuate greatly and are highly variable in seasonal and annual flows. A high degree of spatial and temporal variability within and across streams in a landscape is a normal characteristic of natural flow regimes. Variability over short time scales, such as seasonal flooding, maintains habitat complexity and promotes species diversity by providing recruitment opportunities and refuges from competition (Townsend 1989). These processes affect the viability of instream populations through changes in recruitment, survival, and dispersal that persist from one generation to a few generations (Anderson et al. 2006). In contrast, flow components that affect ecological processes and changes in connectedness among habitat patches embedded in a spatially variable regional landscape can have consequences for population viability and community structure over a broad range of temporal scales. Natural flow patterns (or the altered regulation of these flows by humans) can therefore cause changes that appear both immediately or more slowly over multiple years or decades (Anderson et al. 2006), and can affect both individual streams or a suite of connected streams (Schlosser & Angermeier 1995). These longer term temporal and broader interconnected spatial units are typically ignored in most IFN assessments.

The terms of reference for this study asked for evaluation of IFN on a tributary node-by-node basis. This formulation tends to create a “zoom-in” level that ignores the wider basin-wide distribution of habitats. Subbasin watersheds (“nodes”) are not closed systems isolated from one another. Important ecological processes operate at landscape scales and over long time periods. These include source–sink dispersal dynamics, that is the colonization from “source” areas to “sink” areas that have been unable to support reproduction for a period of time and from which populations have become extirpated (e.g., a stream that experienced a period of continuing drought at sensitive periods and from which fish have disappeared) but which could be opportunistically re-colonized when conditions are improved (Fausch et al. 2002). Connections such as these among different habitat types (i.e., “patches”) that allow animal movements (connectivity) support refuge seeking behaviours, an evolutionary strategy that enables fish (and other) populations to survive drought periods (Anderson et al. 2006). As more and more potential refuge habitats become impacted through human activities and/or isolated from one another, the resilience of different species deteriorates. Thus, landscapes that are homogeneously impacted by human activities, have lost connectivity, and fail to provide pristine protected areas demand a *higher* local standard for instream flow needs. Those landscapes that have connected pristine protected areas with suitable habitat for species of concern will tend to demand a *lower* local standard of care for instream flow needs. This (preferred) latter situation involving a mixture of connected habitat types (some of which are in a low impact to pristine state) enables fish populations to display meta-population dynamics and utilize their evolved refuge seeking movement behaviours to persist during difficult conditions (Fausch et al 2002).

Figure 4.4 (from Schlosser and Angermeier 1995) illustrates the concept of a dynamic landscape model for steam fish. Such dynamics relate to the importance of identifying regional “strongholds” among Okanagan Basin streams where flows and flow-mediated habitat types (as well as other important elements such as groundwater upwelling zones) that promote survival and production of fish populations are more stable, and working to protect these so that they could serve to provide resiliency within a broader Okanagan Basin context (e.g., as important population sources and regional refugia during periods of greater ecosystem stress).

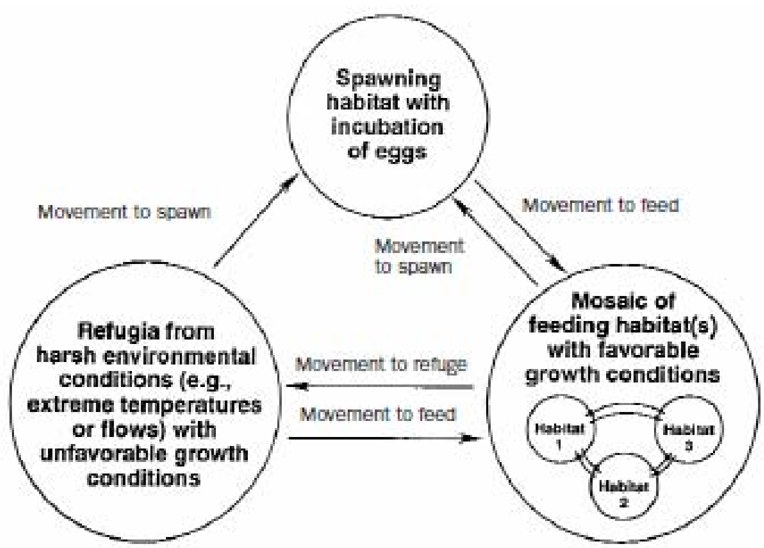


Figure 4.4 Dynamic landscape model of stream fish life history (taken from Schlosser and Angermeier 1995). Movements of different life stages of fish among spatially separated habitats (within and between streams) for spawning, feeding, and to find refugia are a key feature of this conceptual model (Faush et al. 2002).

Accurately predicting the influence of natural flow regimes across the landscape and changes in those regimes caused by human activities on the viability or community structure of fish and other aquatic-dependent organisms will require integrating spatially explicit models of physical processes (that can characterize hydrologic connectivity across the managed landscape) with population-dynamic models (Power 2005; Anderson et al. 2006). Understanding and predicting population and community responses to the integrated spatial and temporal variability in flow across the Okanagan Basin represents a major future challenge for regional IFN studies. Research will need to focus on how the suite of heterogenous Basin habitats are arrayed in space and time and are linked by stream flow events and fish movement to influence the persistence, abundance and regional productivity of salmonid populations, and similarly for other aquatic-dependent sentinel species.

Perhaps the 'take home challenge' question for Okanagan basin fish/water managers is this: "*how many subbasin watersheds that are important, representative habitats for key focal species are currently protected from human water extraction and other habitat altering activities?*" As this list is populated in the affirmative, it becomes more ecologically responsible to move away from the minimum risk flows identified by BCIFN and PHABSIM meta-analysis optima.

4.4 Future directions and next steps

Some immediate future elements that the Steering and Instream Flow Needs Committees may wish to consider include:

- Re-running the exceedance probability risk analysis in this report vs. **net water availability** time series following completion of water balance modelling scenarios. This is required to enable a proper ecological vulnerability assessment for setting fish protection priorities.
- Enhancing the prototype *desktop* reporting tools used by our team (and demonstrated to the IFN committee in April 2009), and releasing it on a pilot basis to select water license managers.

- Based on the results of #2 (or instead of-), simplify and web-enable one or more of these reports inside the WSD Web-Reporting Tool application to allow wider dissemination and use throughout the Okanagan basin fish/water management community.
- Support a research project that explicitly considers water temperature requirements and impacts on recommended flow thresholds. Decreased flows due to water extraction activities combined with climate warming, particularly in late summer, is now widely considered a primary reason for increased stream temperatures in many areas, with consequent negative effects on cold/cool water fish.
- Preparing short summaries of these results for different stakeholders. In the interim, our Executive Summary and Frequently Asked Questions (FAQ) section will provide valuable summaries of the extensive analysis results provided in our report.

While IFN standard setting provides a useful initial filter for addressing aquatic ecosystem needs across a broad scale, empirically-based site-specific habitat-flow studies are likely to provide more complete information on instream flow needs and should be undertaken wherever possible, especially for systems in the Okanagan perceived to be at high aquatic ecosystem risk (as has been suggested recently for Trout Creek - Ptolemy 2009). Analyses within this report can help identify watersheds within the Okanagan that seem at most inherent flow risk, and use this information to target particular streams for site-specific studies in later phases of the Okanagan Water Supply and Demand Project.

An earlier project (Matthews and Bull 2003) developed a technical ranking scheme to determine the relative importance of watersheds in the Okanagan. A score for each of the Okanagan watersheds was developed based upon:

- whether they support (or could support) wild, indigenous fish stocks;
- whether their production potential is considered significant (based on the size of the watershed and the judgement of agency biologists as to the extent of water flows and the amount of usable habitat); and
- the degree to which the watershed has been impacted by habitat alterations.

A combination of all these scores was used to rate each stream for fisheries importance and select the highest priority watersheds for potential protection and/or restoration purposes (Matthews and Bull 2003). Further work during Phase 3 of the Okanagan Water Supply and Demand project could include an effort to develop a more rigorous assessment of relative production potential (i.e., going beyond the expert-based approach used in this past study) by incorporating the node-specific information on instream flow needs for different species at different times of the year developed as part of this project.

IFN analyses within this report did not explore future climate change scenarios which could potentially have significant hydrological impacts on fish habitat in the Okanagan. It could be very useful, as a next step, to compare flow threshold exceedance probabilities based on the historical naturalized flows developed within this report to exceedances demonstrated under altered hydrologies as predicted from down-scaled climate models developed or being developed for the Okanagan (e.g., Merritt et al. 2006; current development of MikeSHE water balance model).

Neither the BCIFN guidelines nor the Hatfield-Bruce meta-analysis approach used for this project explicitly considers water temperature in regards to fish habitat requirements. For full interpretation of climate change scenarios, it will be necessary to consider models which look at stream temperatures in addition to flow. Decreases in late summer/fall flows particularly could result in increased stream temperatures with potential negative effects on cool or coldwater dependent fish species. Predictive water temperature models for streams and watersheds have been developed recently by ESSA in partnership with the BC MOE and used with climate change models for the Cariboo-Chilcotin region (Nelitz et al. 2009b). These models could be used to develop an index for stream temperatures that could be incorporated with the modeled instream flow data for a more complete assessment of current and future risk to Okanagan streams.

Our preliminary assessment of exceedance probabilities for regulated flows indicated a potential for improvements over naturalized flows at key periods. This suggests that developing management strategies involving increasing storage (where possible) combined with releases of stored flows at targeted periods for fish could be a productive further step within the Okanagan Water Supply and Demand Project. Part of developing such strategies is, of course, an acceptance that instream values have a prior, or at least equal, right to water comparable to other rights holders. Historically water has often been allocated among priority rights holders first with instream needs being allocated as an afterthought or only if "excess" water exists. Hopefully promoting such attitudes will be a key component of the Okanagan Sustainable Water Strategy as it seeks to attain a better balance between human and ecosystem needs.

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Appendix A. Occurrences of fish species in Okanagan Basin stream, river and lake nodes

● = species present at node,
p = species not currently present but potential presence here possible if species recovery should occur at some future date

Node #	Node Description	Rainbow trout	Chinook	steelhead	kokanee	sockeye	coho	bull trout	lake trout	eastern brook trout	cutthroat trout	chiselmouth	burbot	lake whitefish	mountain whitefish	Pygmy Whitefish	whitefish (general)	northern pikeminnow	longnose sucker	bridgelip sucker	largescale sucker	sucker (general)	leopard dace	longnose dace	dace (general)	prickly sculpin	Mottled Sculpin	sculpin (general)	redside shiner	carp	peamouth chub	Yellow perch	slimy sculpin	Pumpkinseed	largemouth bass	smallmouth bass	Tench	Chub (general)	Black catfish	black crappie	Goldfish
1	Vernon Creek (at outlet of Kalmalka L.)	●			●							●	●		●			●			●	●			●	●		●	●	●	●			●							
2	Kalamalka - Wood Lake	●			●				●						●		●	●			●								●	●	●	●		●							
3	Deep Creek	●			●					●								●			●					●		●	●	●								●			
5	Irish Creek																																								
8	Equesis Creek	●			●																					●						●									
10	Nashwito Creek	●			●																					●															
12	Vernon Creek (mouth)	●			●								●					●				●				●		●			●										
14	Whiteman Creek	●			●																																				
16	Shorts Creek	●			●					●											●			●		●		●													
18	Lambly Creek	●			●					●									●		●	●		●	●							●									
20	Kelowna (Mill) Creek	●			●					●			●					●	●		●		●	●		●			●	●	●										
22	Mission Creek	●	p		●		p			●			●		●			●				●		●		●		●	●		●		●								
24	Bellevue Creek	●																								●															
26	McDougall Creek	●																																							
28	Powers Creek	●	p		●		p			●																		●													
30	Trepanier Creek	●	p		●		p						●								●	●				●		●													
32	Peachland Creek	●			●					●															●	●															
34	Chute Creek	●			●					●																															
36	Eneas Creek	●			●					●												●		●				●	●												
38	Robinson Creek	●			●																																				
40	Naramata Creek	●			●																																				
42	Trout Creek	●	p		●		p			●					●						●			●		●		●	●		●										
44	Turnbull Creek				●																							●			●										
46	Penticton Creek	●			●					●														●																	
47	Okanagan Lake	●			●				●	●		●	●	●	●	●	●	●	●		●	●	●	●	●	●		●	●	●	●	●	●	●				●			
48	Okanagan River at Penticton	●			●	●						●						●	●			●				●	●	●	●	●		●		●		●	●				
51	Shingle Creek	●			●					●					●						●			●		●		●			●										
52	Ellis Creek	●			●																	●		●						●											
55	Marron River	●																																							
58	Skaha Lake	●			●	●						●	●	●	●	●	●	●			●	●				●		●	●	●	●	●	●			●		●			
59	Okanagan River at Okanagan Falls	●			●	●				●		●	●	●	●	●		●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●				
60	Shuttleworth Creek	●																						●																	
64	Vaseux Lake	●			●	●						●		●	●			●			●									●	●	●		●	●	●			●		
66	Vaseux Creek	●		●		●									●					●				●		●															
69	Park Rill									●														●																	
71	Wolfcub Creek	●																●																							
73	Testalinden Creek																																								
75	Okanagan River near Oliver	●	●	●	●	●				●		●	●	●	●	●		●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●			●	

Node #	Node Description	Rainbow trout	Chinook	steelhead	kokanee	sockeye	coho	bull trout	lake trout	eastern brook trout	cutthroat trout	chiselmouth	burbot	lake whitefish	mountain whitefish	Pygmy Whitefish	whitefish (general)	northern pikeminnow	longnose sucker	bridgelip sucker	largescale sucker	sucker (general)	leopard dace	longnose dace	dace (general)	prickly sculpin	Mottled Sculpin	sculpin (general)	redside shiner	carp	peamouth chub	Yellow perch	slimy sculpin	Pumpkinseed	largemouth bass	smallmouth bass	Tench	Chub (general)	Black catfish	black crappie	Goldfish
78	Inkaneep Creek	●		●		●				●																															
80	Osoyoos Lake	●	●	●	●	●						●		●	●			●			●									●		●		●	●	●			●	●	●
81	Okanagan River at Oroville, WA.	●	●	●	●	●				●		●		●				●	●			●				●	●	●	●	●		●		●	●		●			●	
25	Residual area E-5 (Lebanon & Deeper Creek)																																								
27	Residual area W-8 (Westbank Creek)				●																																				
37	Residual area W-12 (Prairie Creek)	●			●																																				
54	Residual area E-11 (McLean Creek)	●			●																																				

Appendix B. Weekly minimum flow thresholds, conservation flow thresholds, and optimal spawning and rearing flows for salmonid species present at Okanagan Basin tributary stream nodes

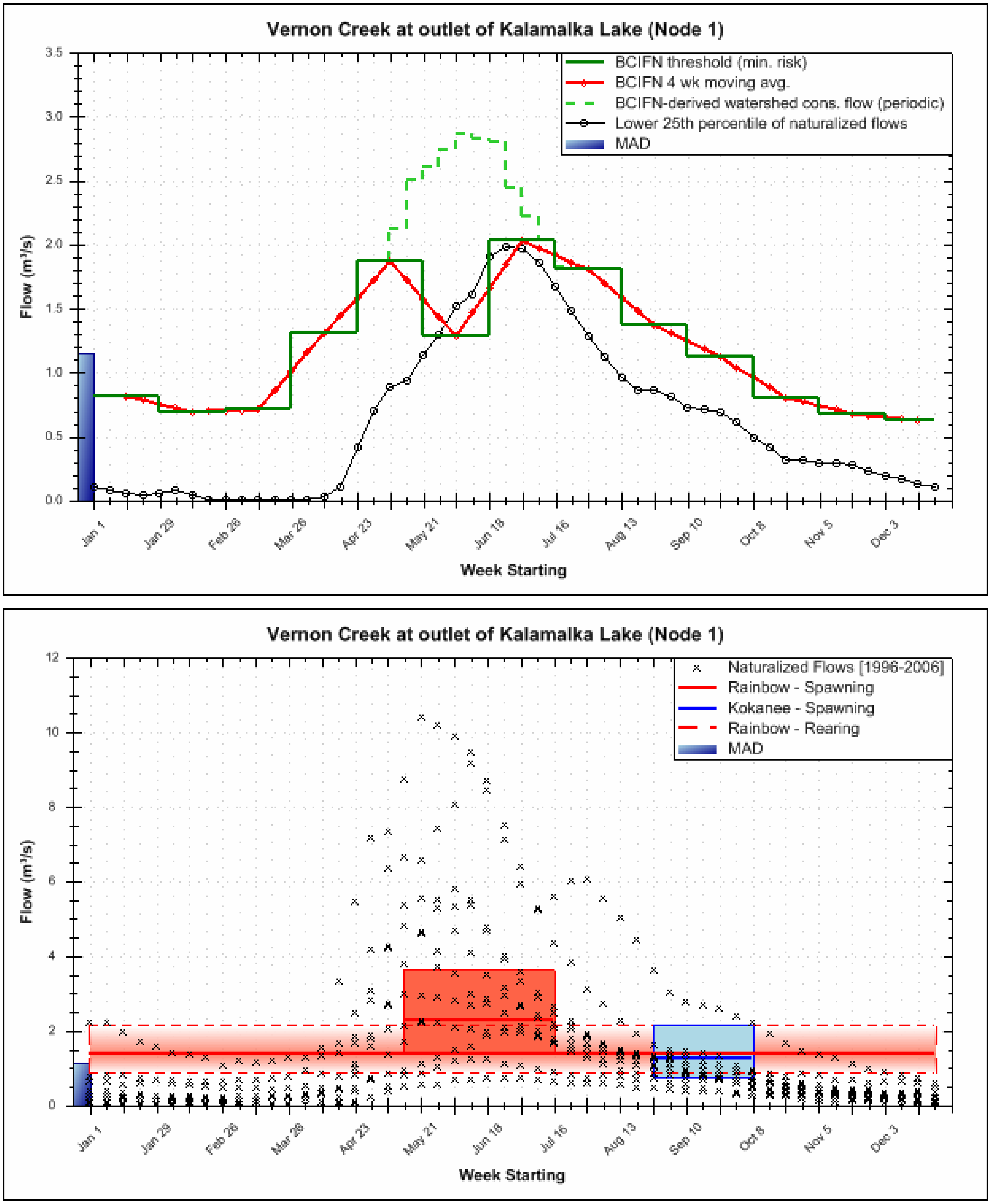
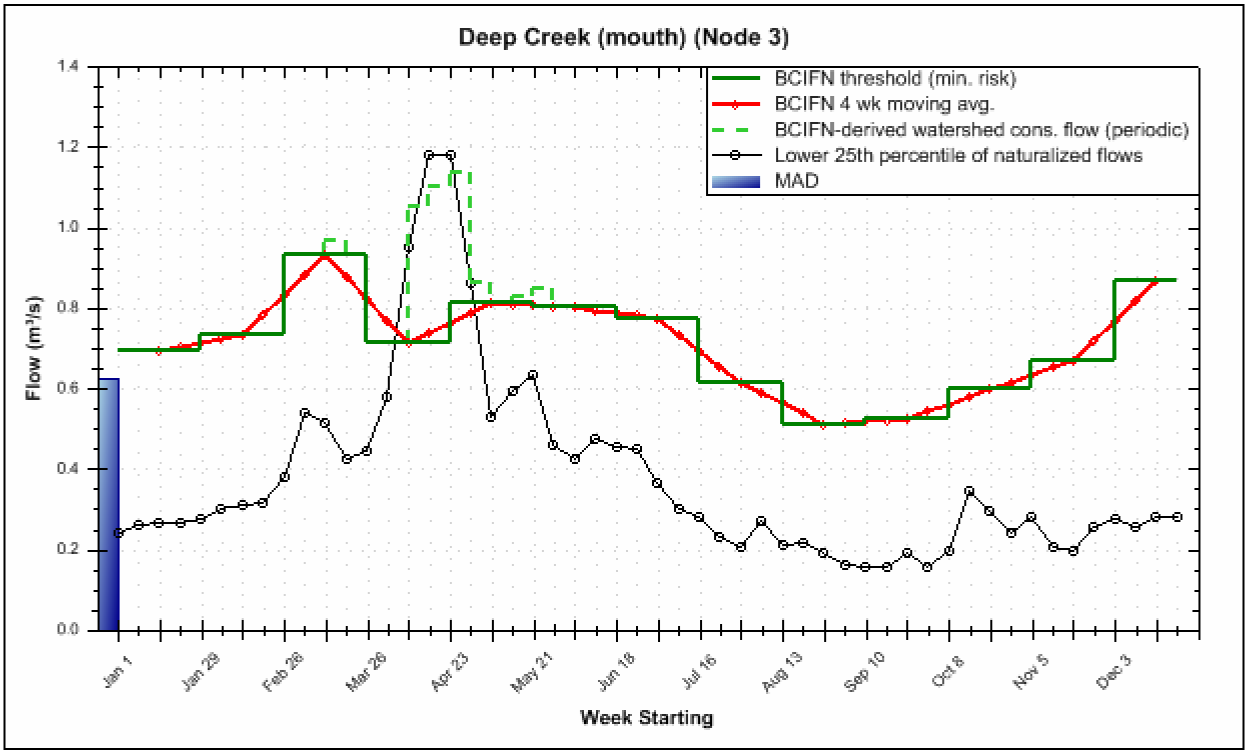


Figure B.1. Vernon Creek (node 1) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



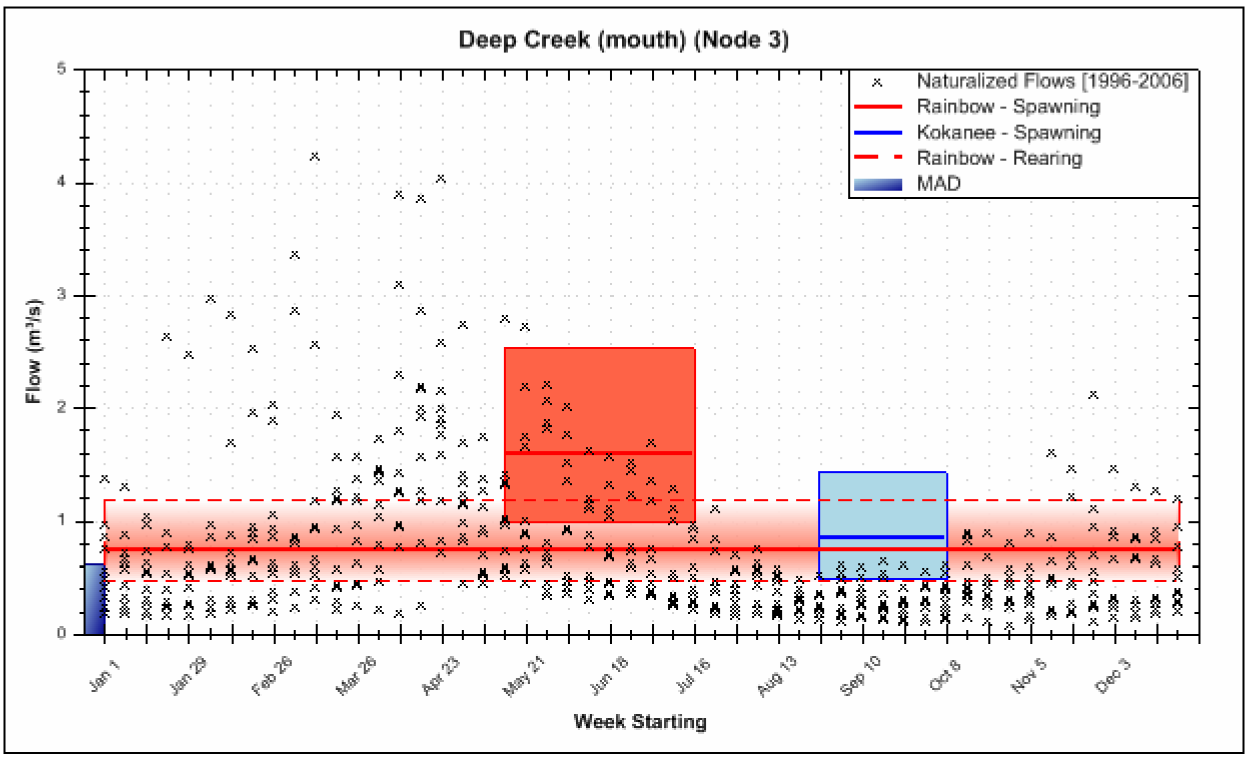
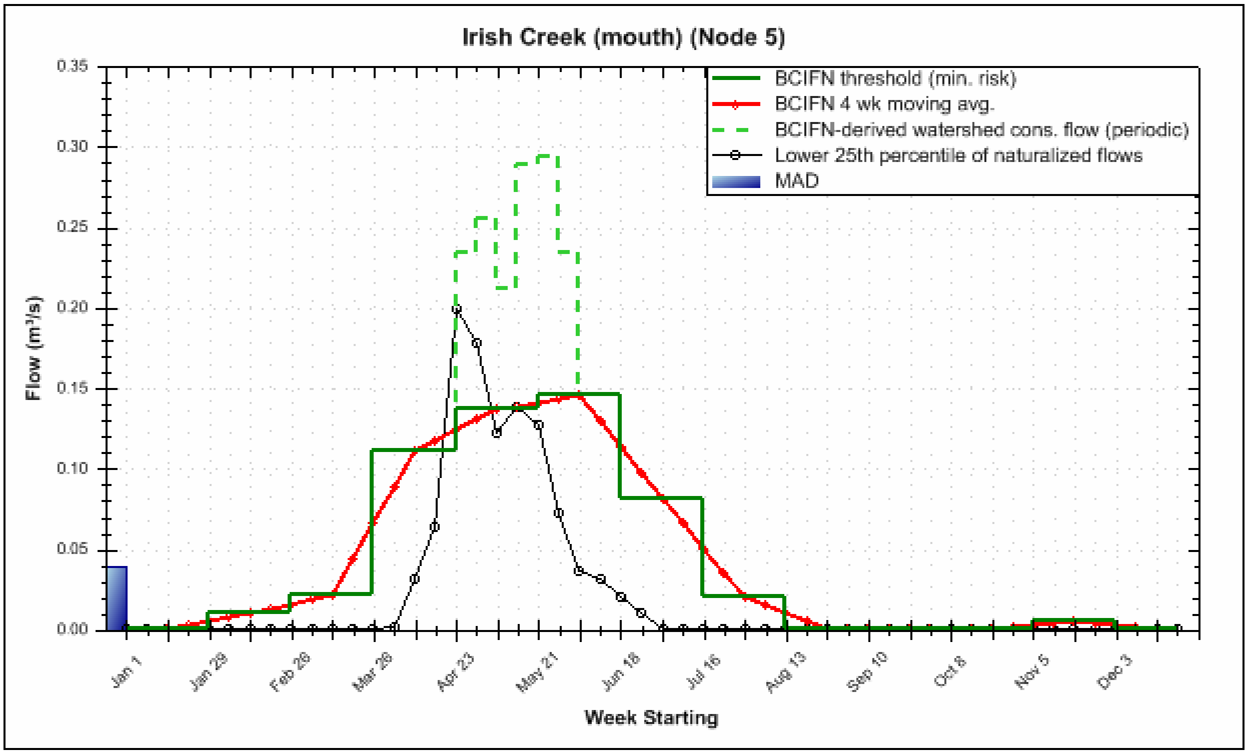


Figure B.2. Deep Creek (node 3) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



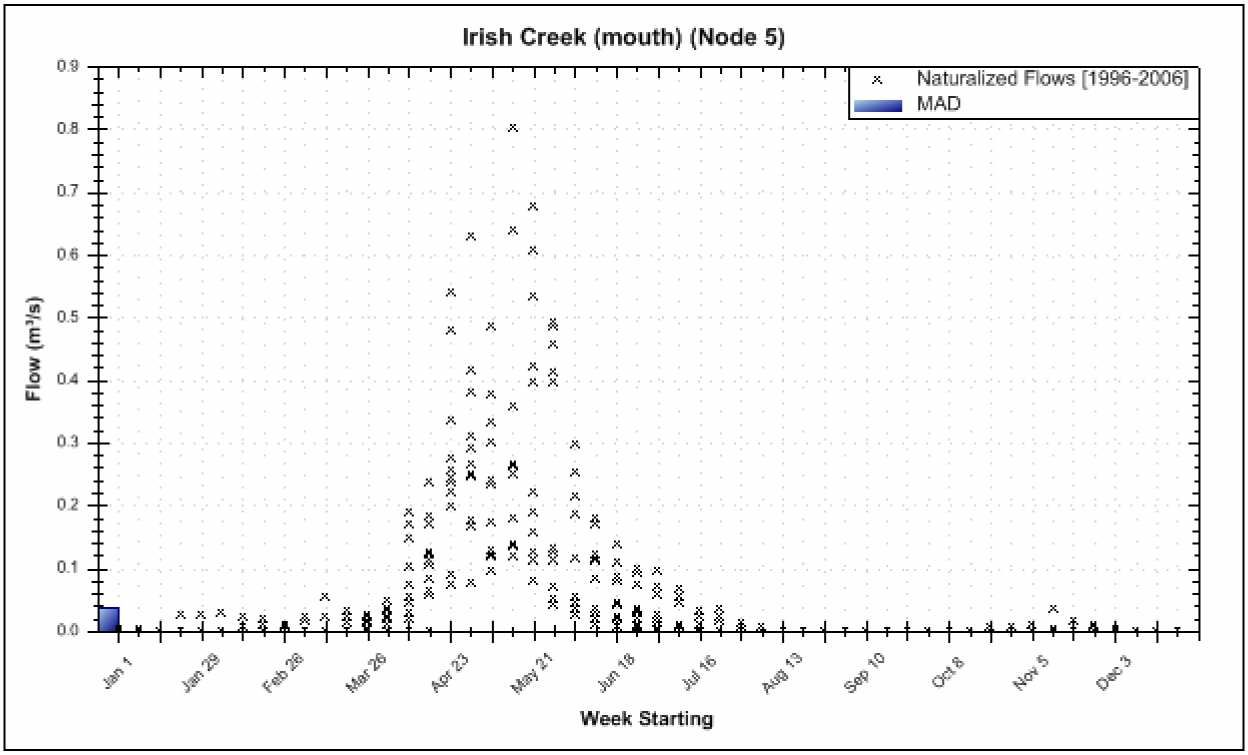


Figure B.3. Irish Creek (node 5) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

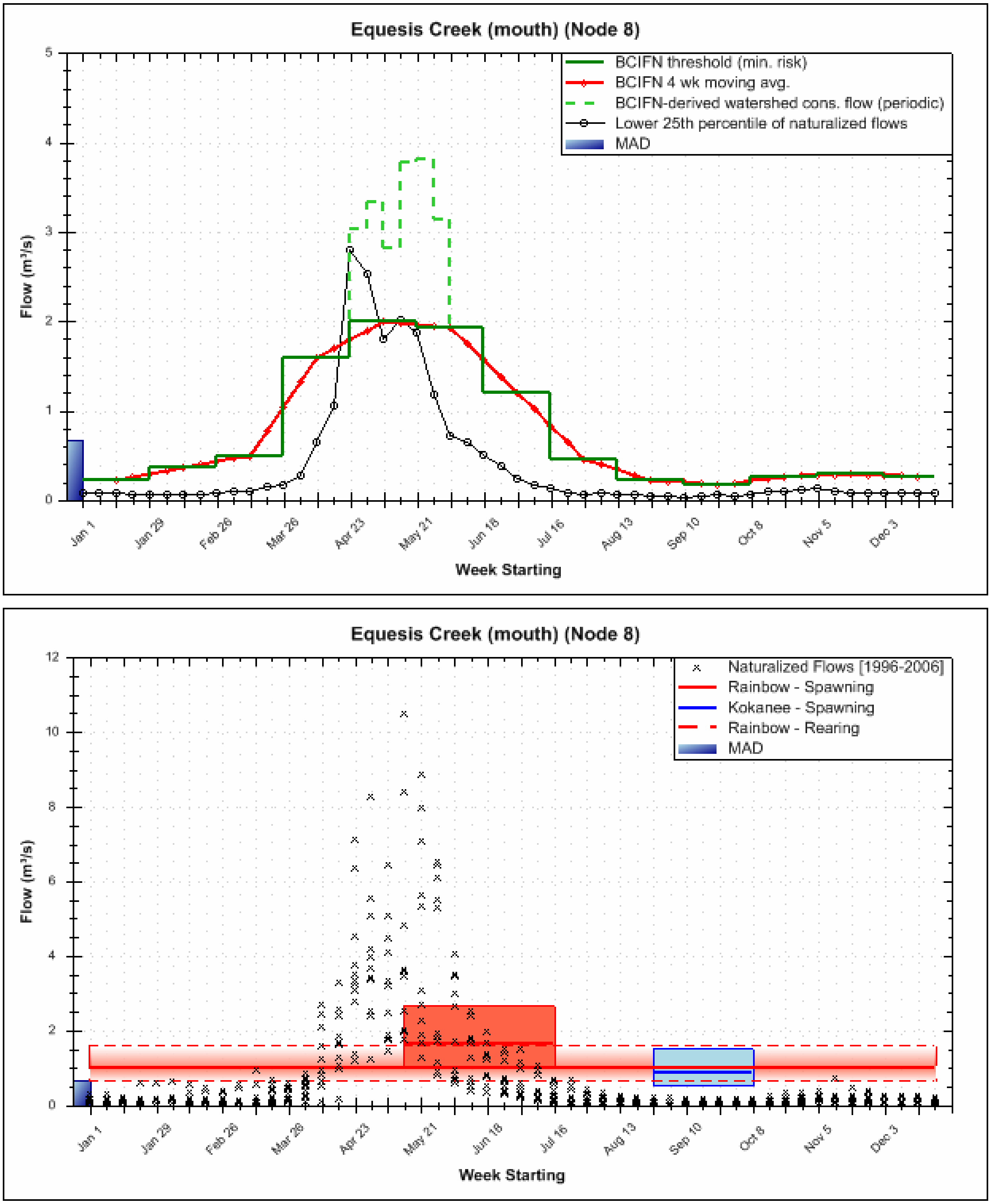


Figure B.4. Equesis Creek (node 8) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

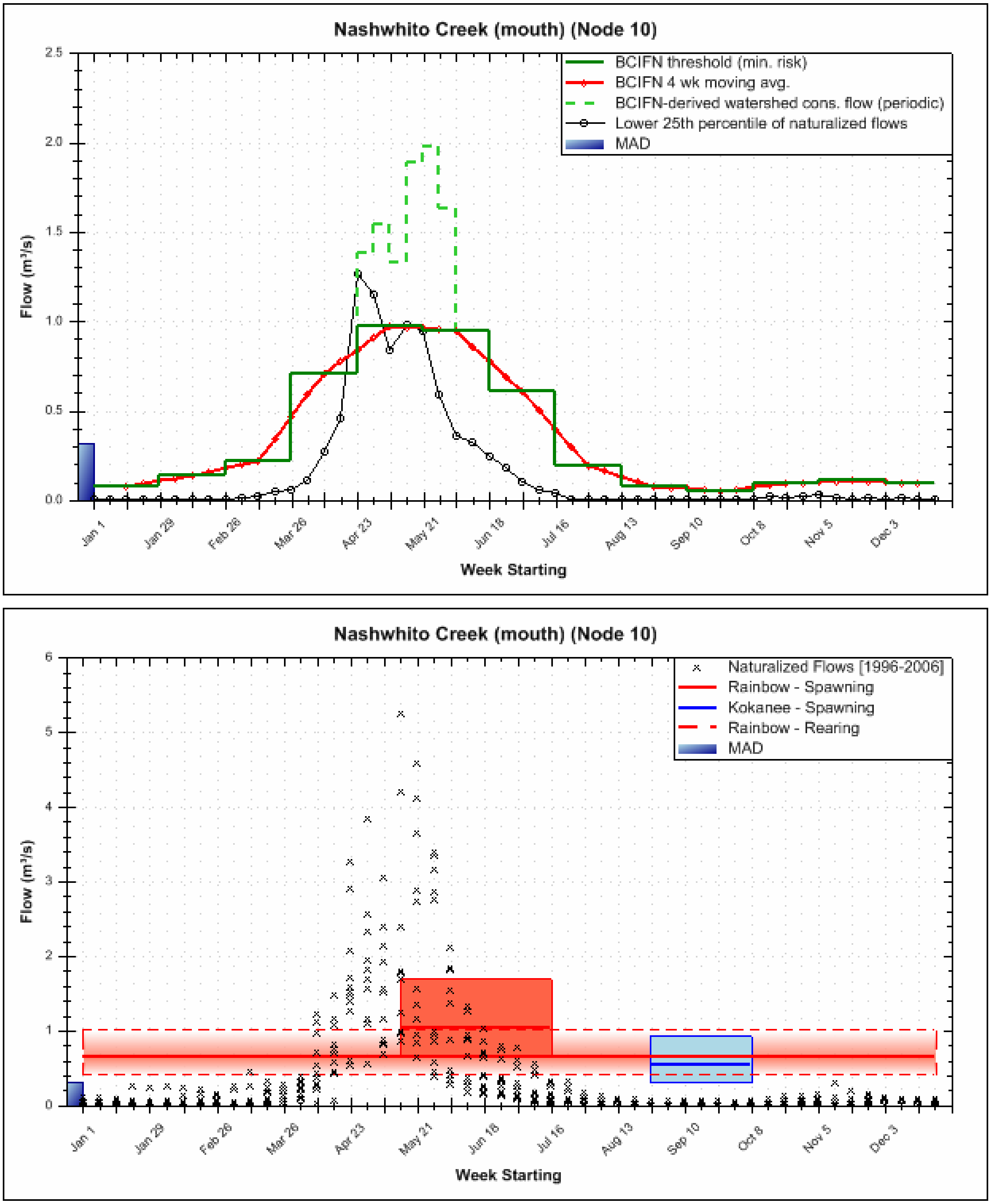
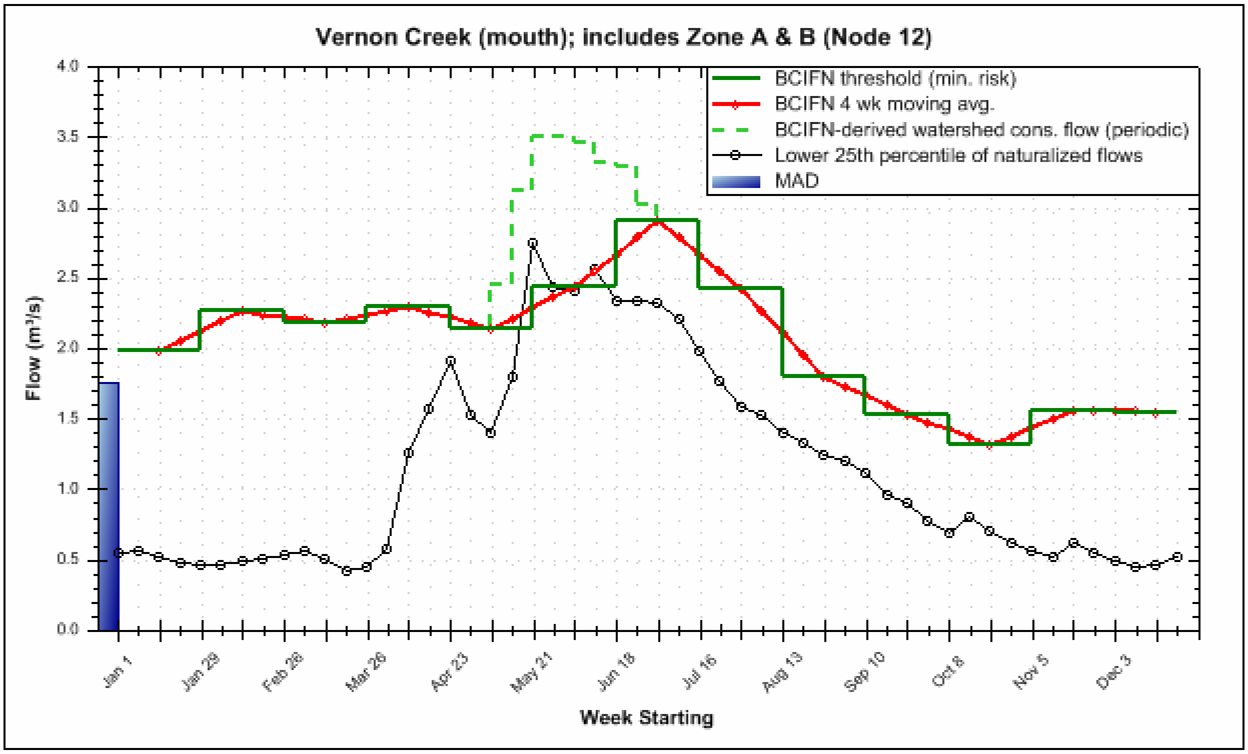


Figure B.5. Nashwhito Creek (node 10) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



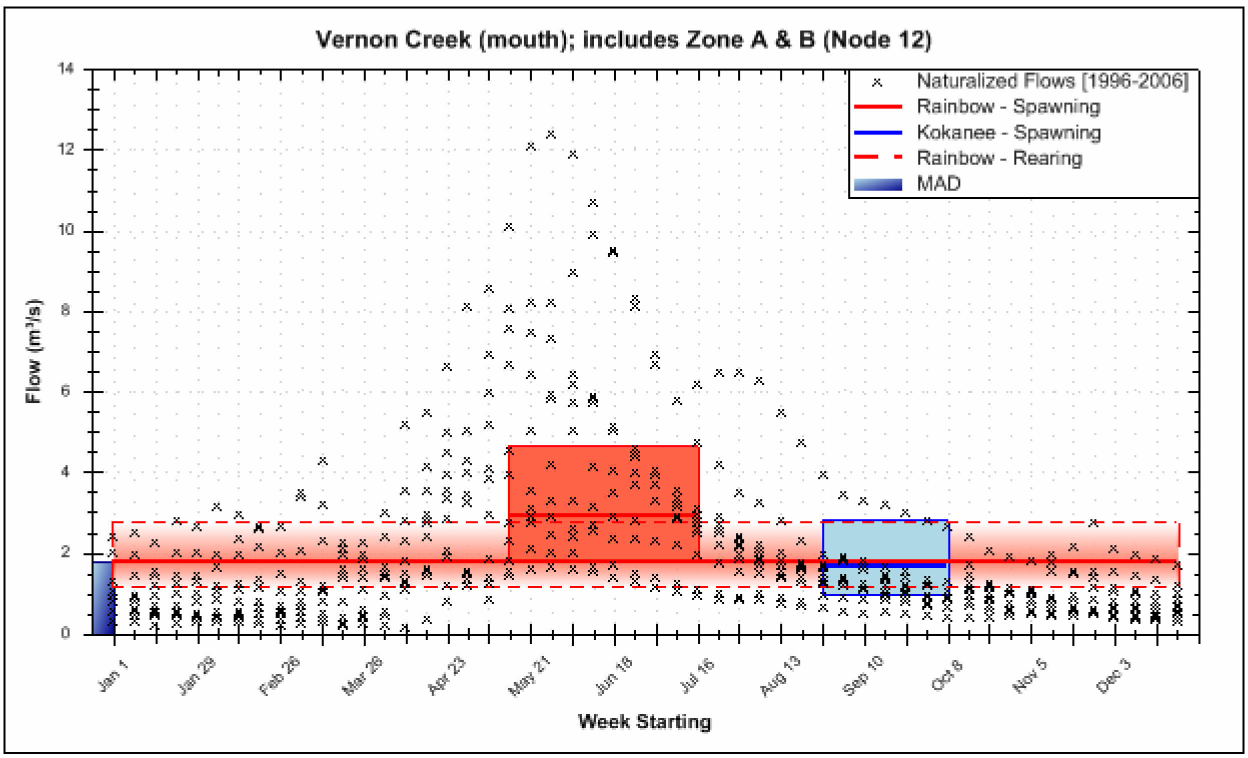


Figure B.6. Vernon Creek (node 12) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

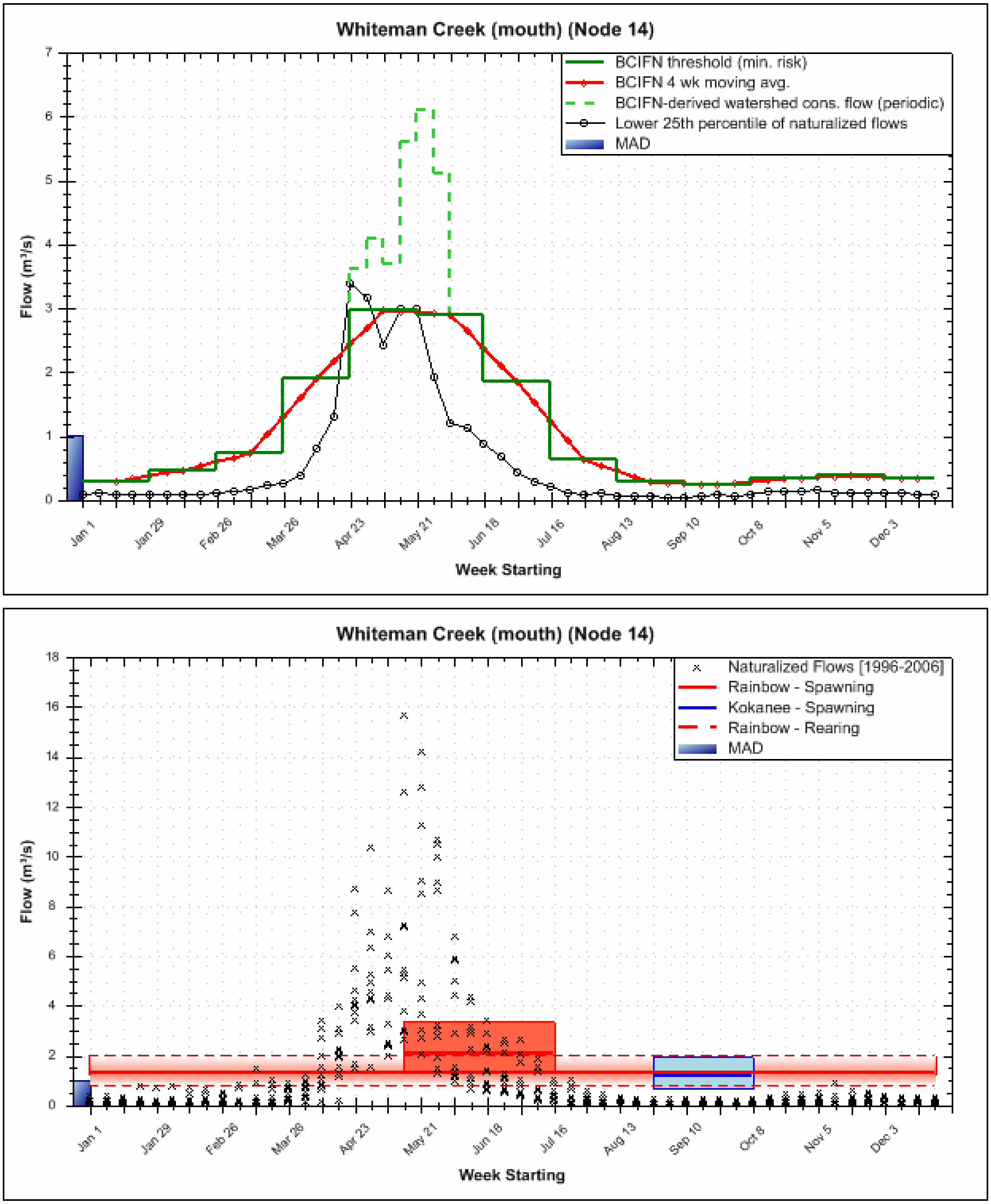
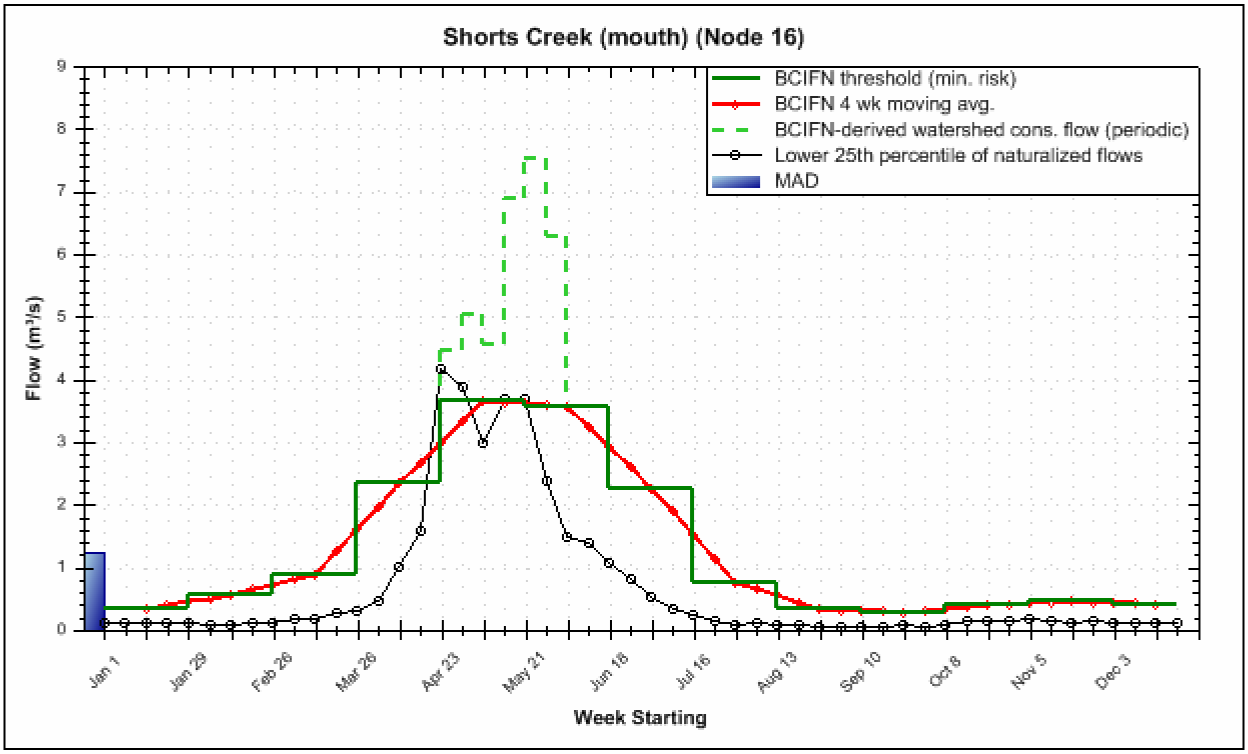


Figure B.7. Whiteman Creek (node 14) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



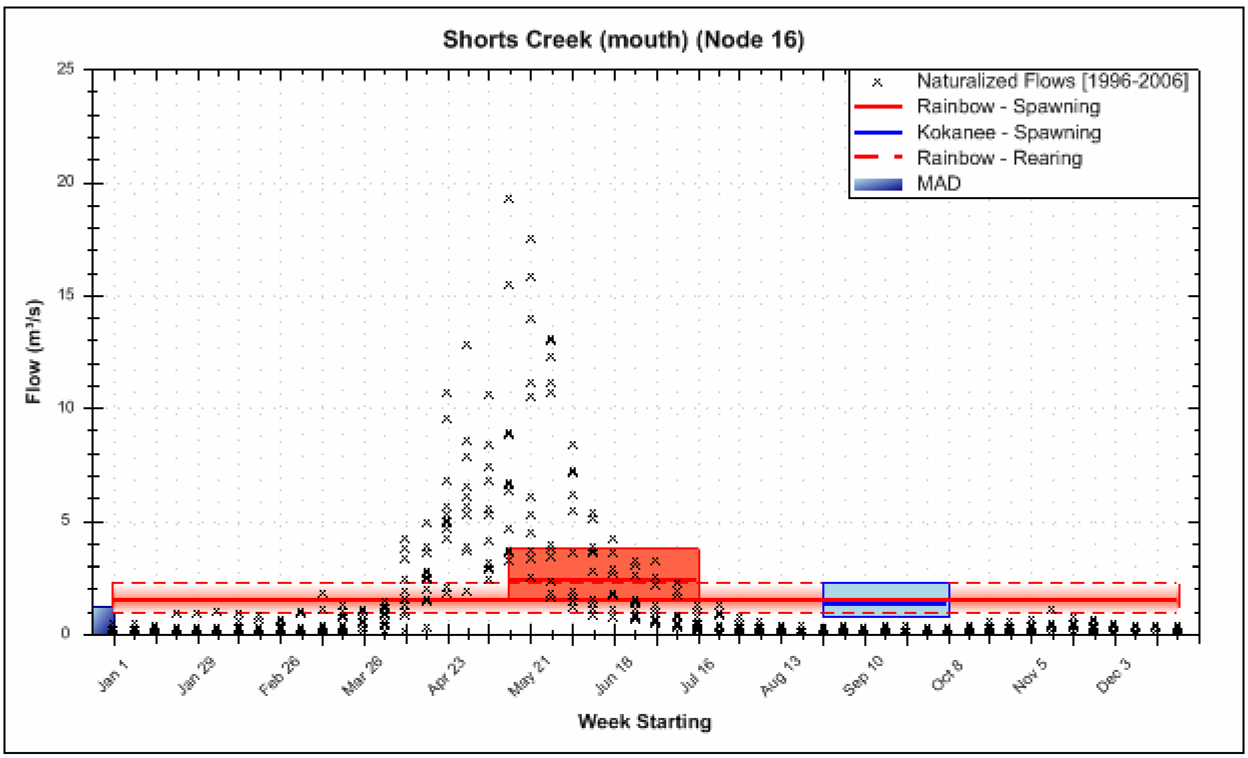


Figure B.8. Shorts Creek (node 16) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

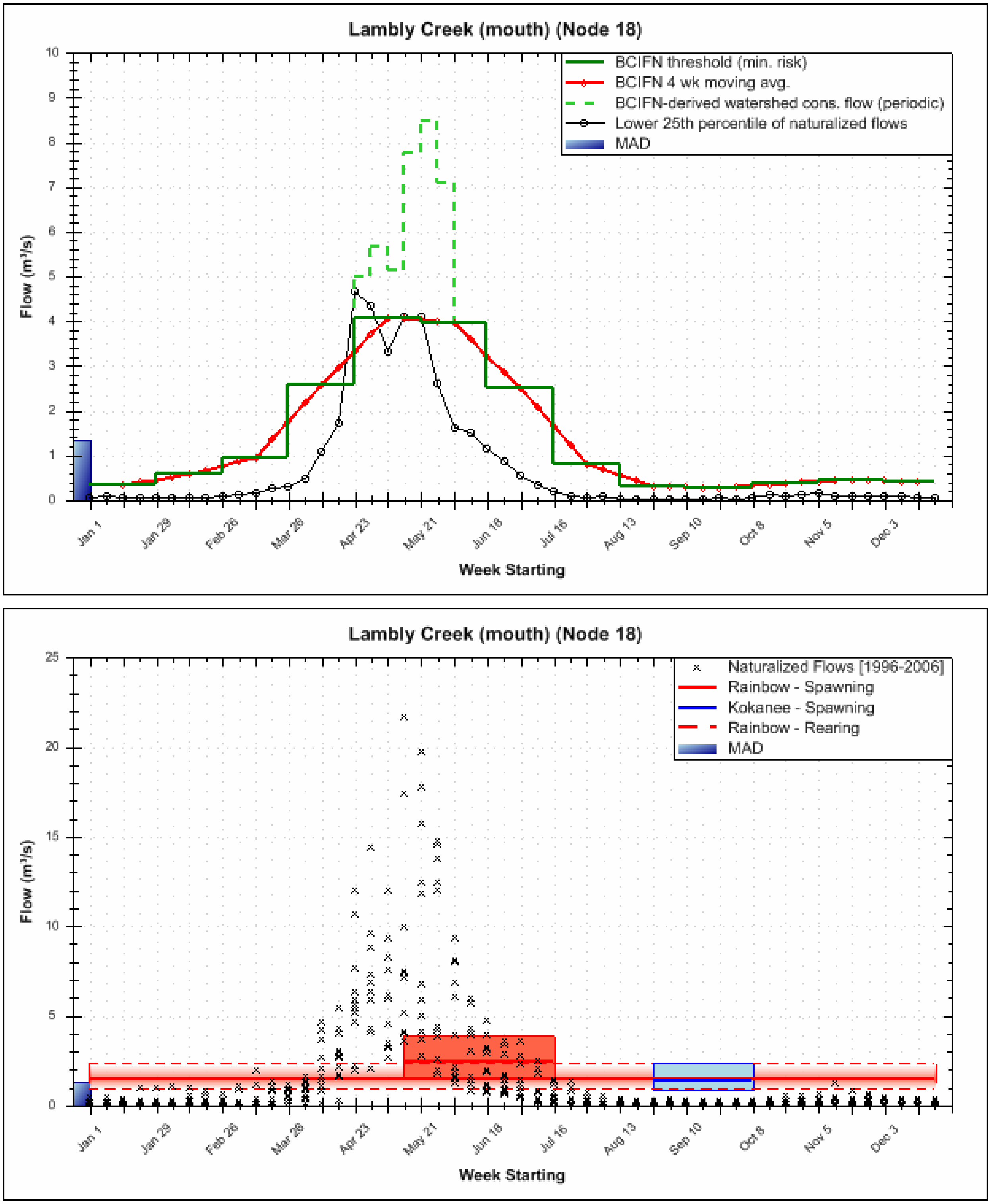
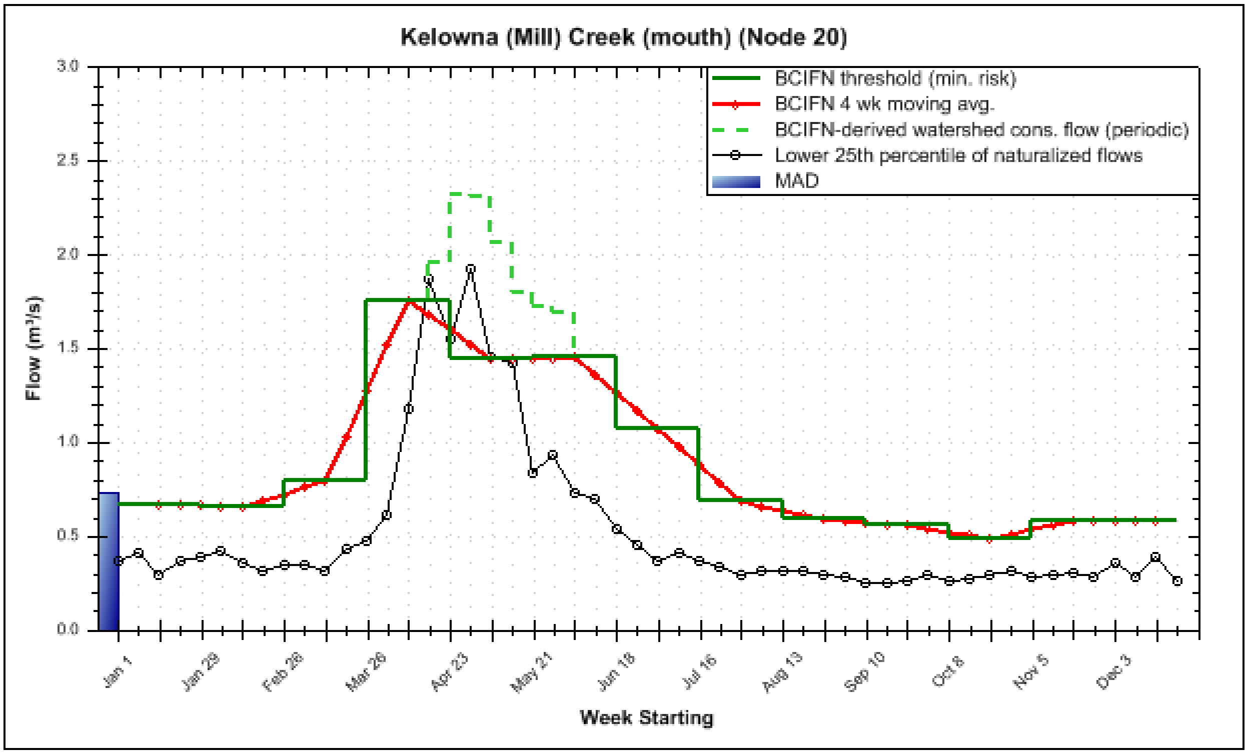


Figure B.9. Lambly Creek (node 18) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



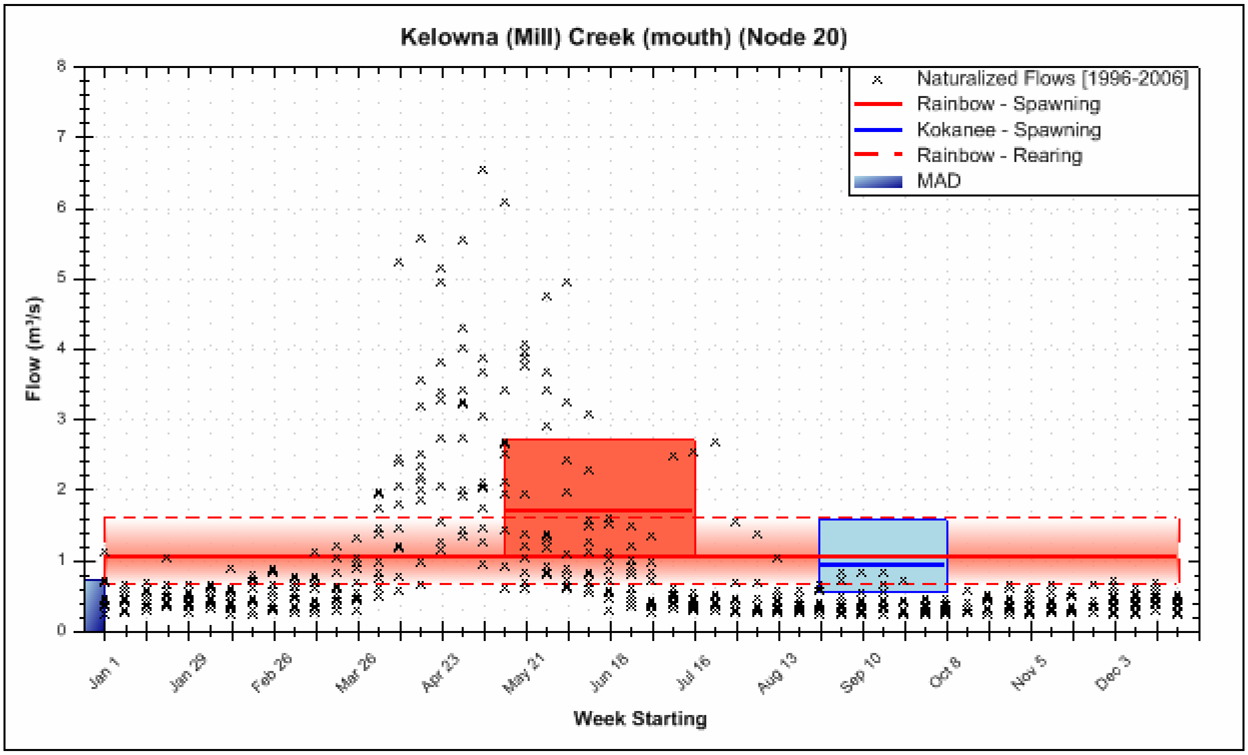
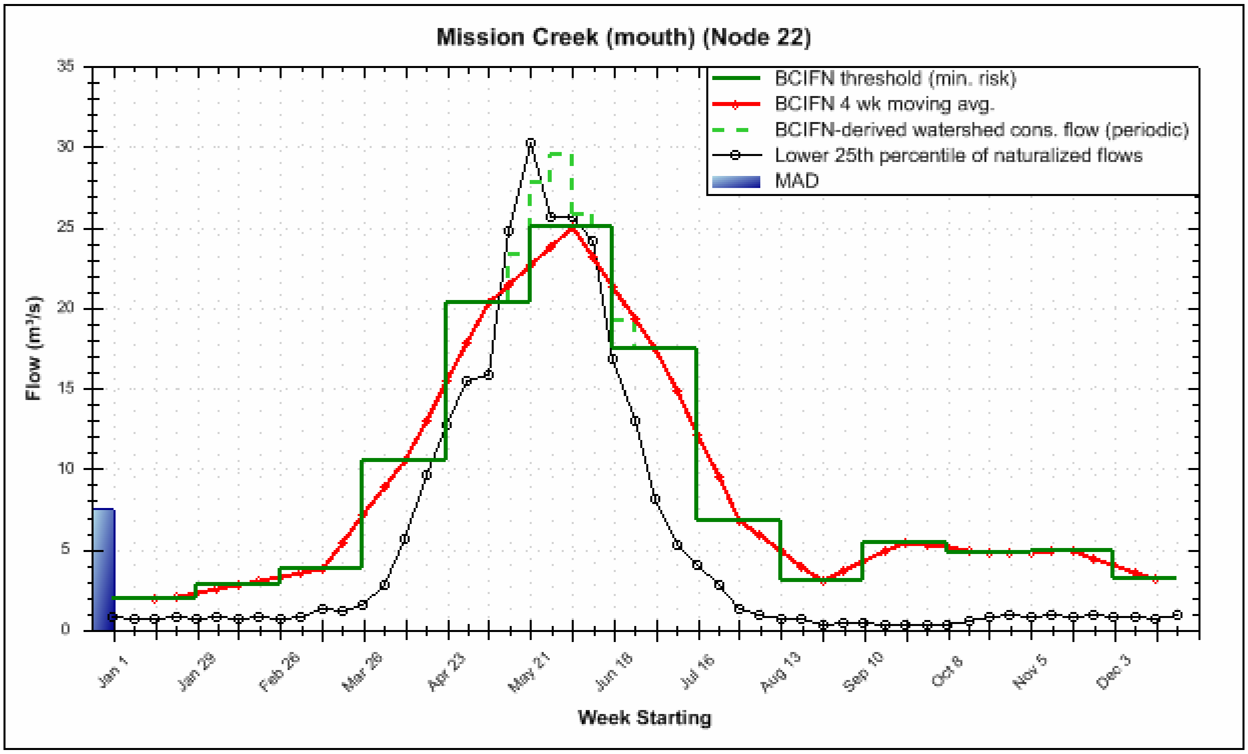


Figure B.10. Kelowna (Mill) Creek (node 20) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25[th] percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



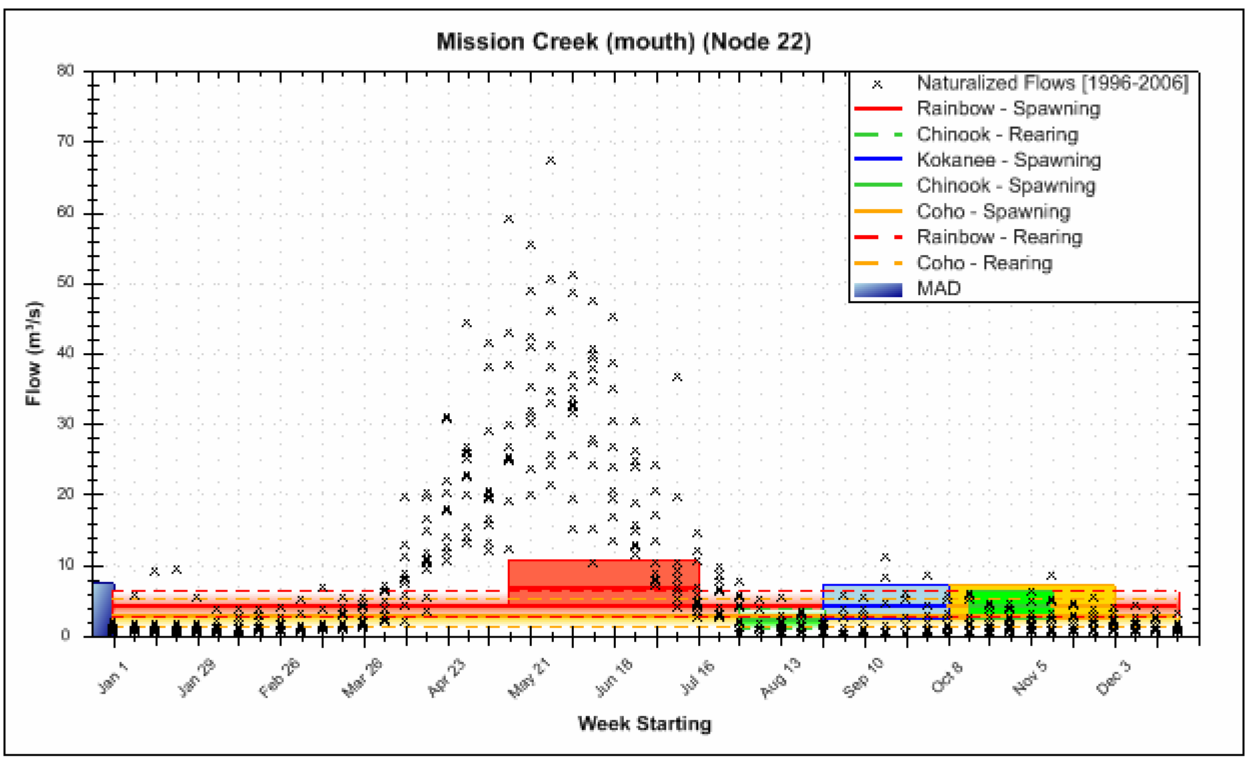


Figure B.11. Mission Creek (node 22) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

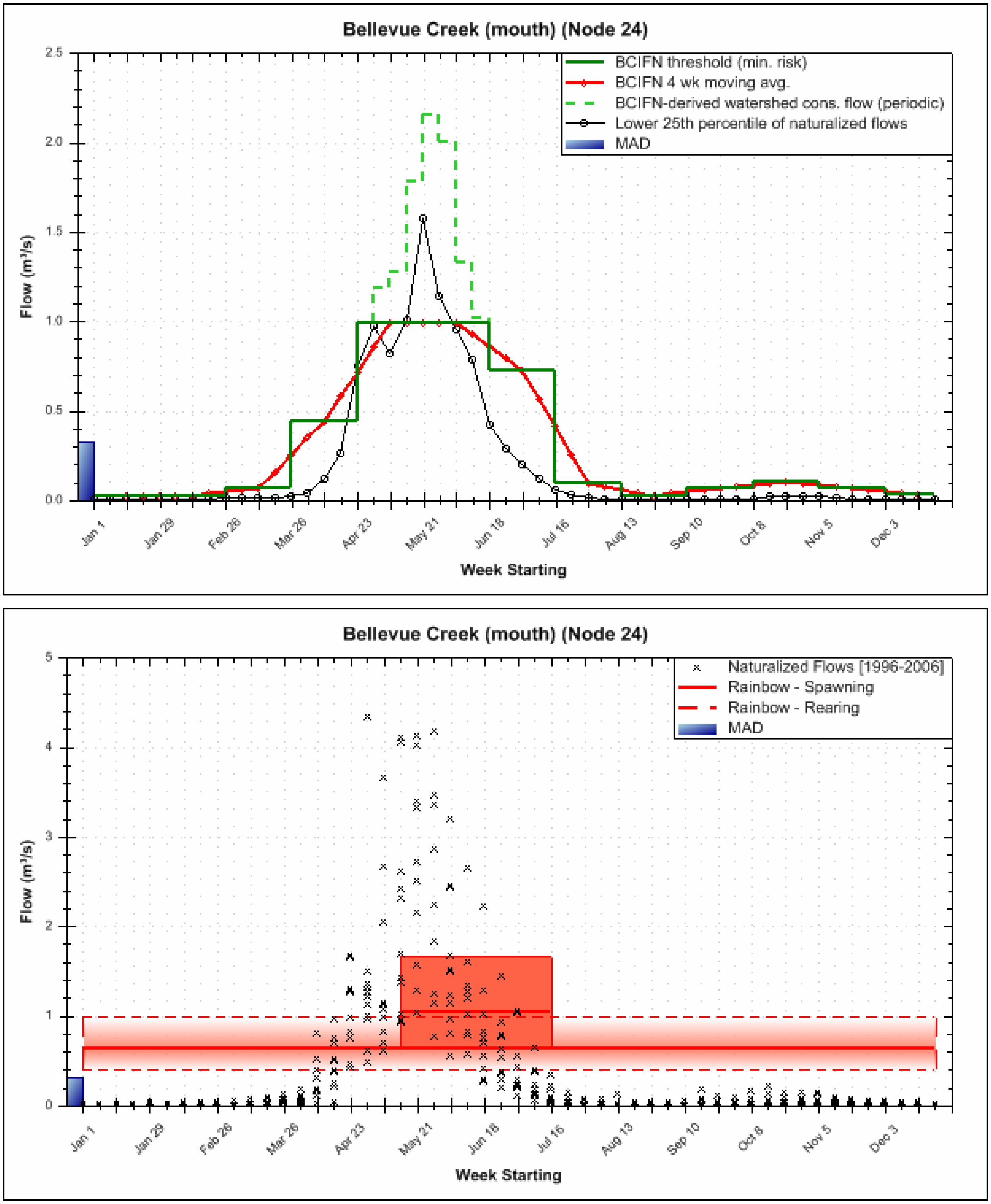
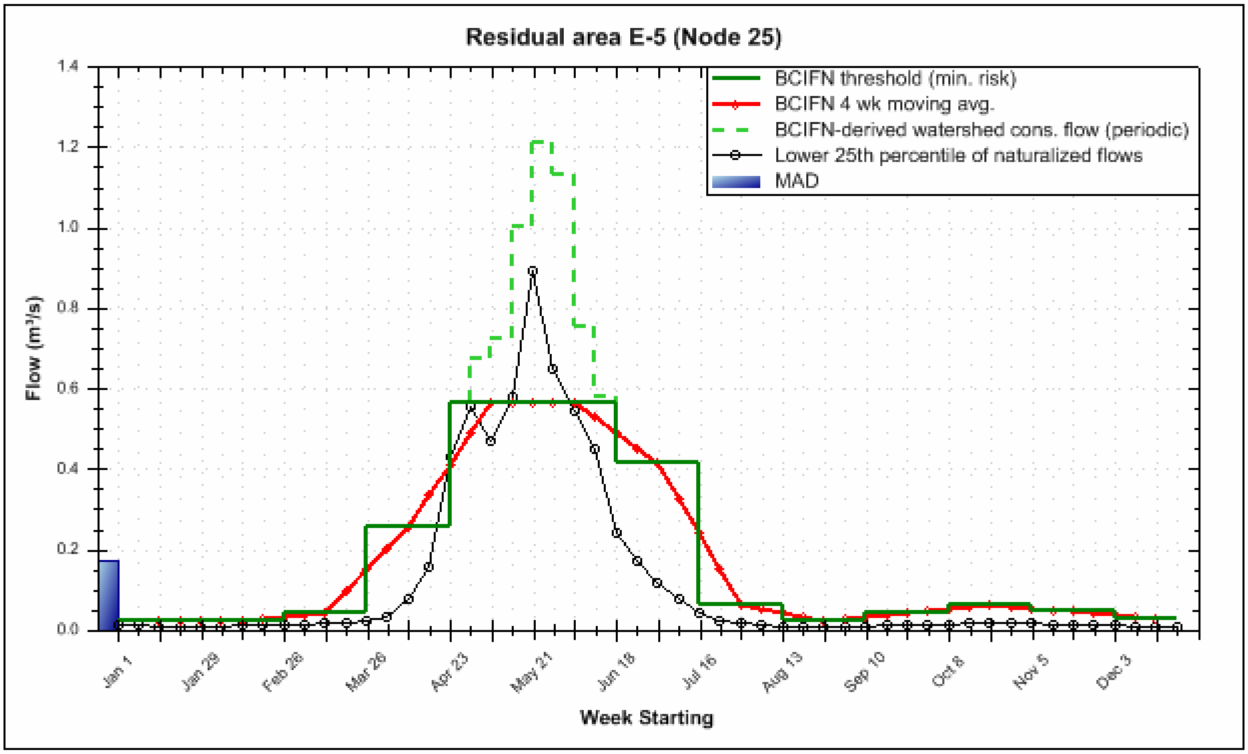


Figure B.12. BellevueCreek (node 24) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



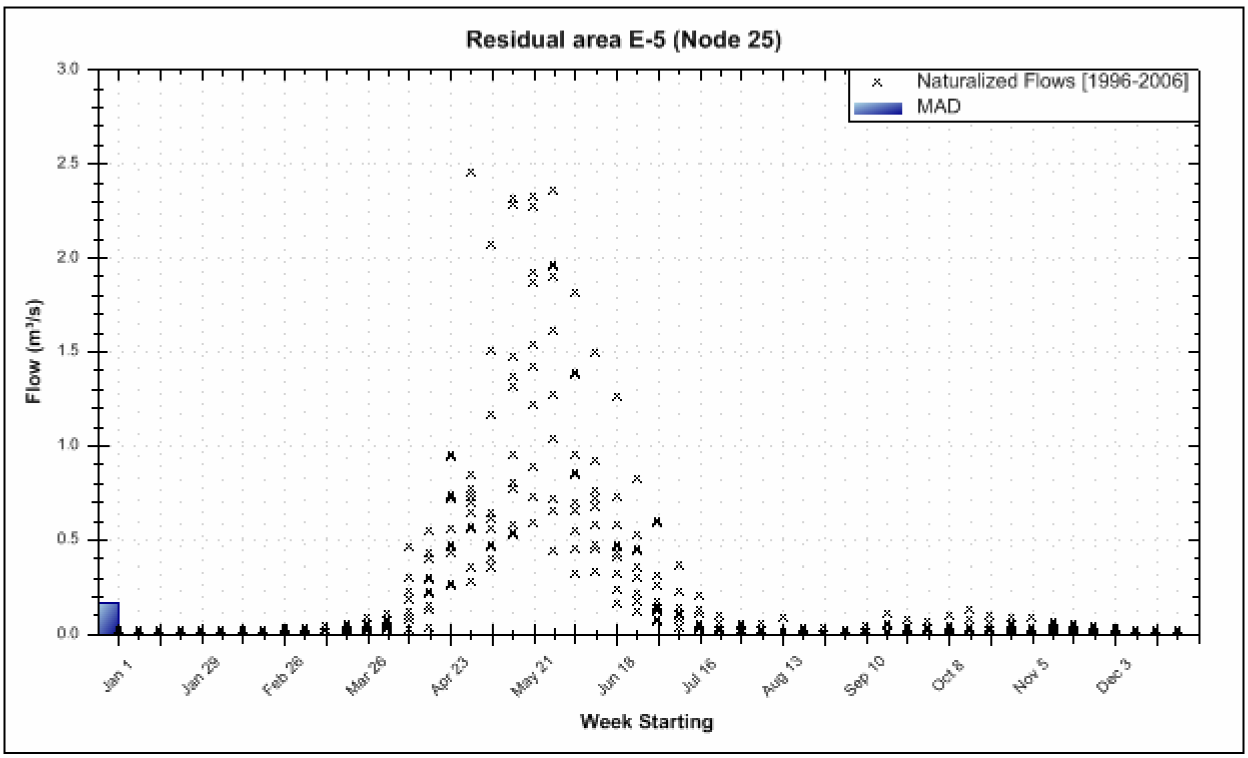


Figure B.13. Residual area E-5 (node 25) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

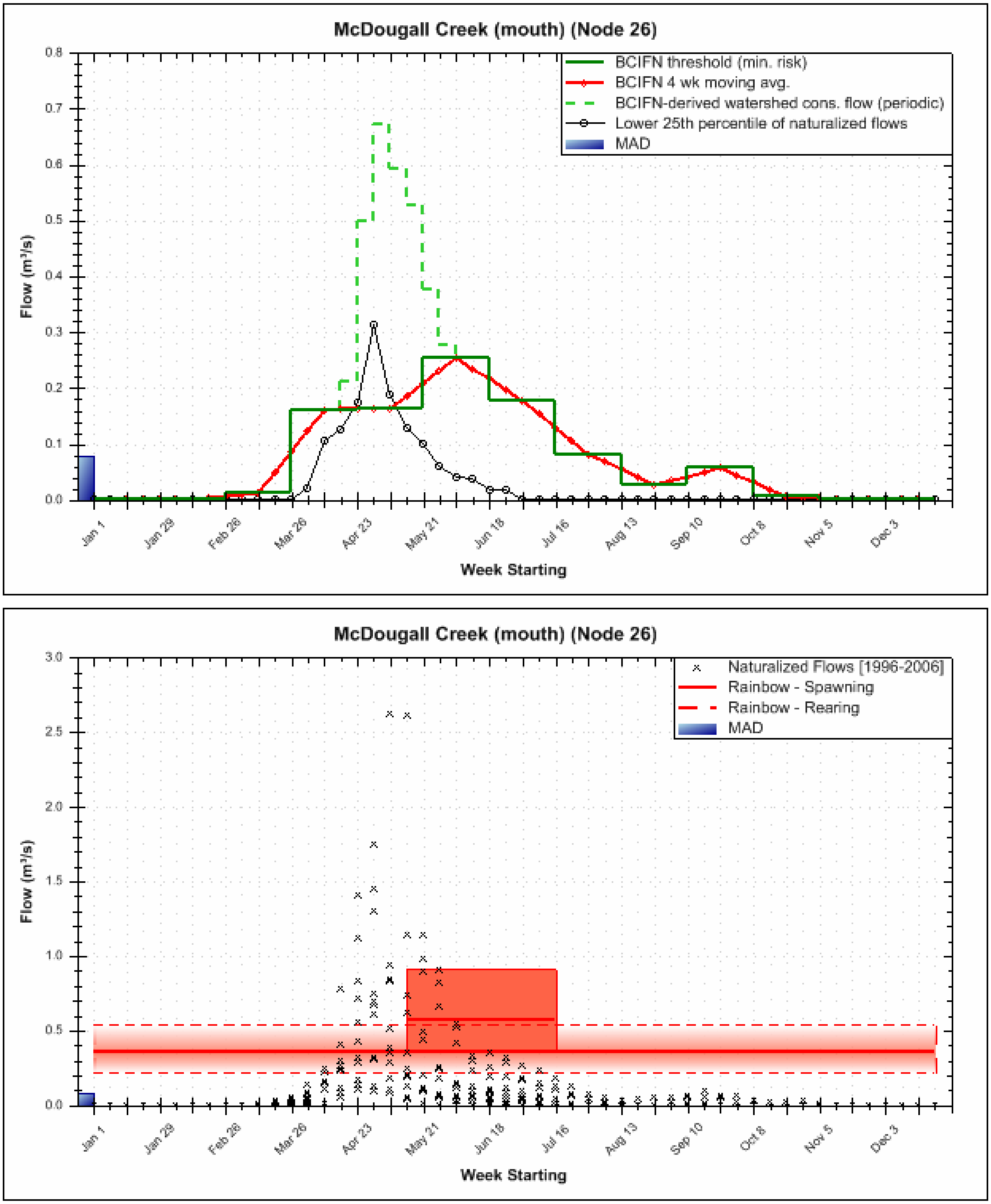


Figure B.14. McDougall Creek (node 26) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

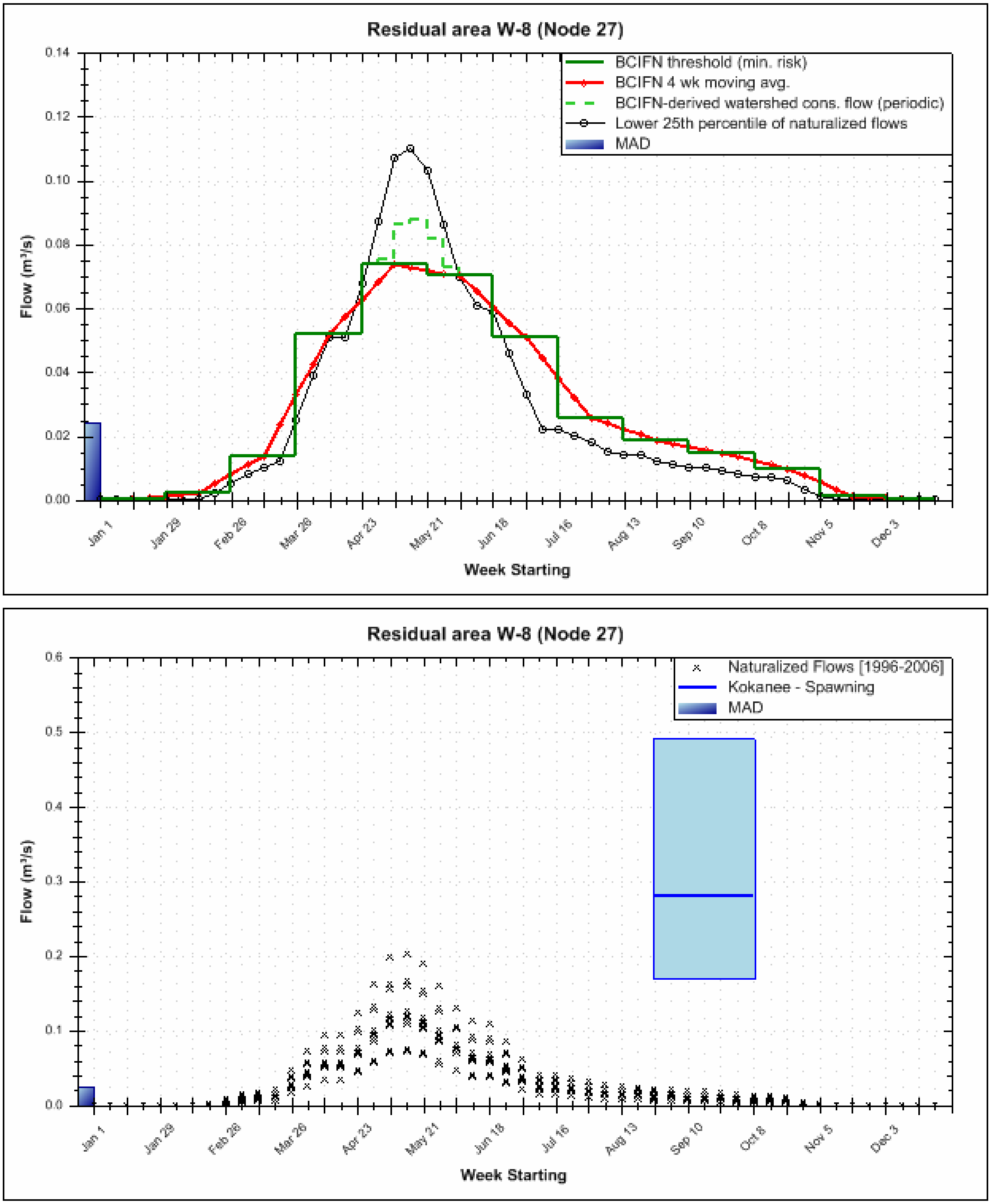
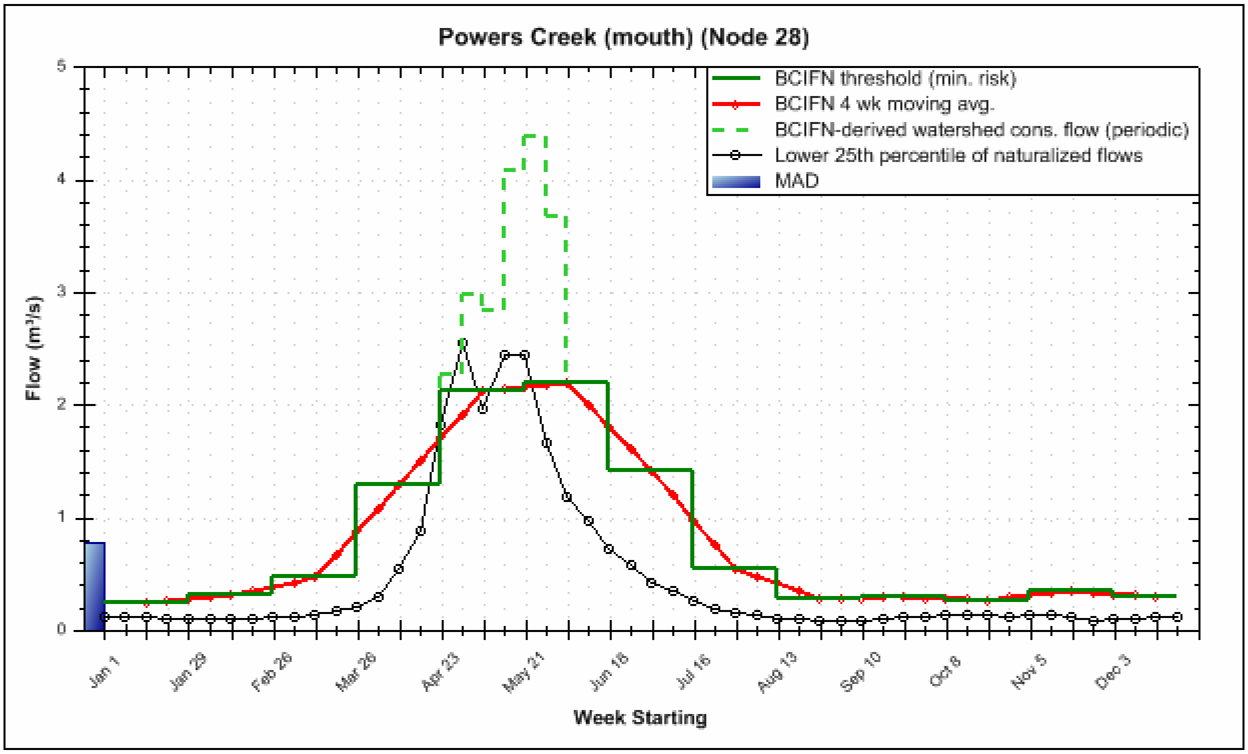


Figure B.15. Residual area W-8 (node 27) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



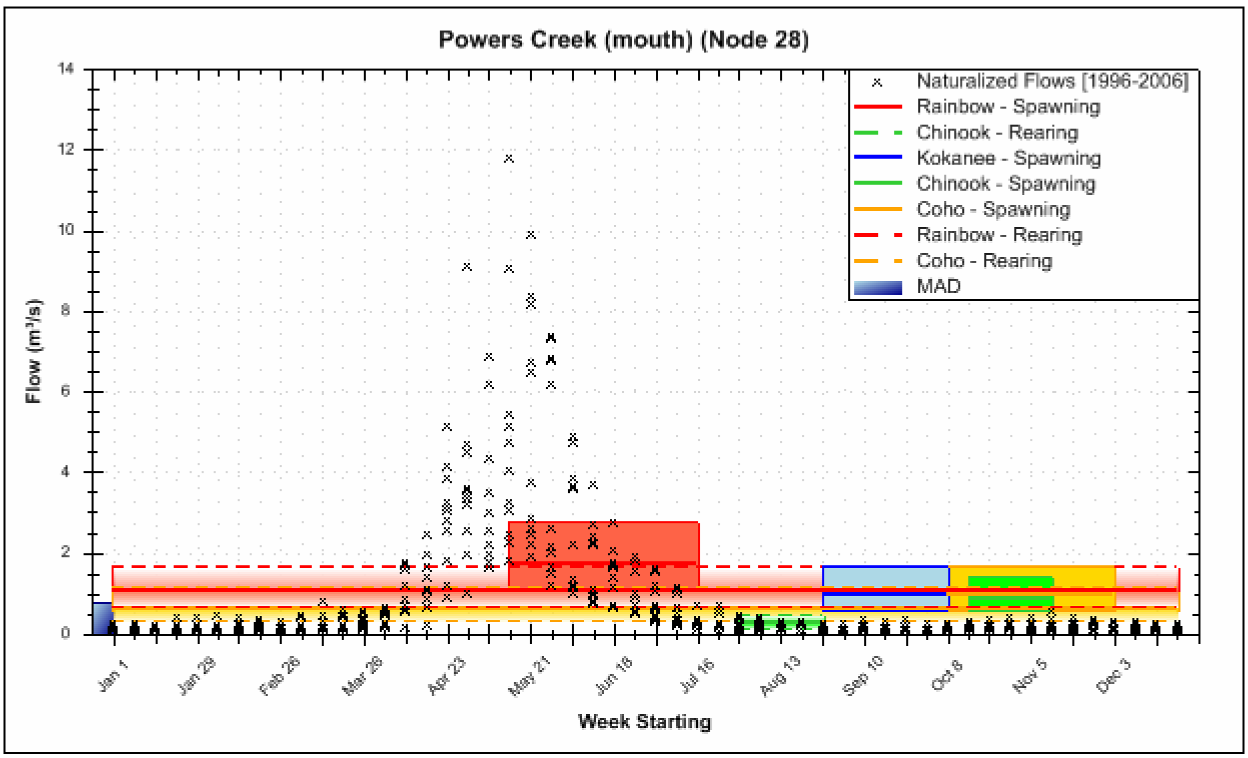


Figure B.16. Powers Creek (node 28) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

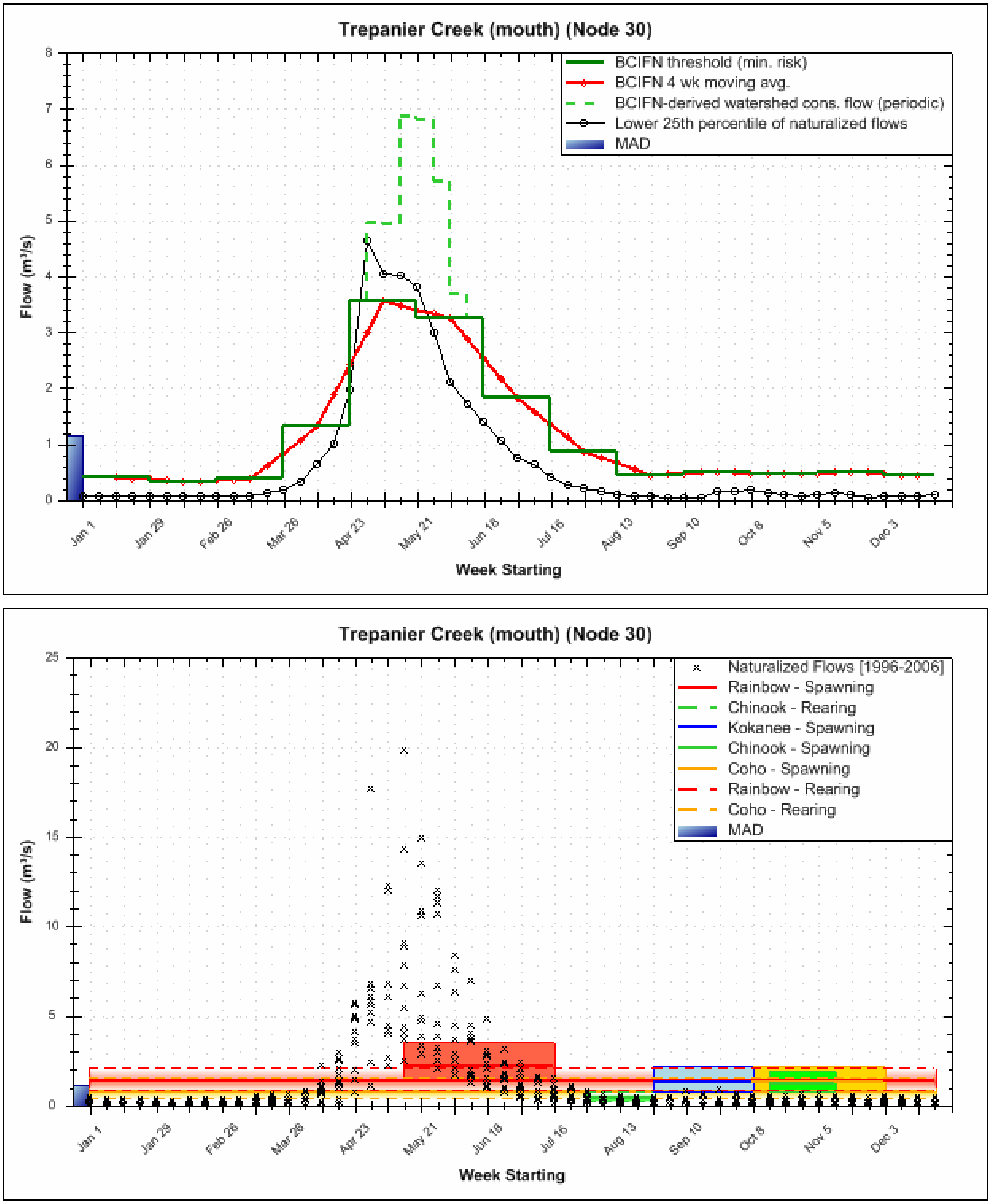


Figure B.17. Trepanier Creek (node 30) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

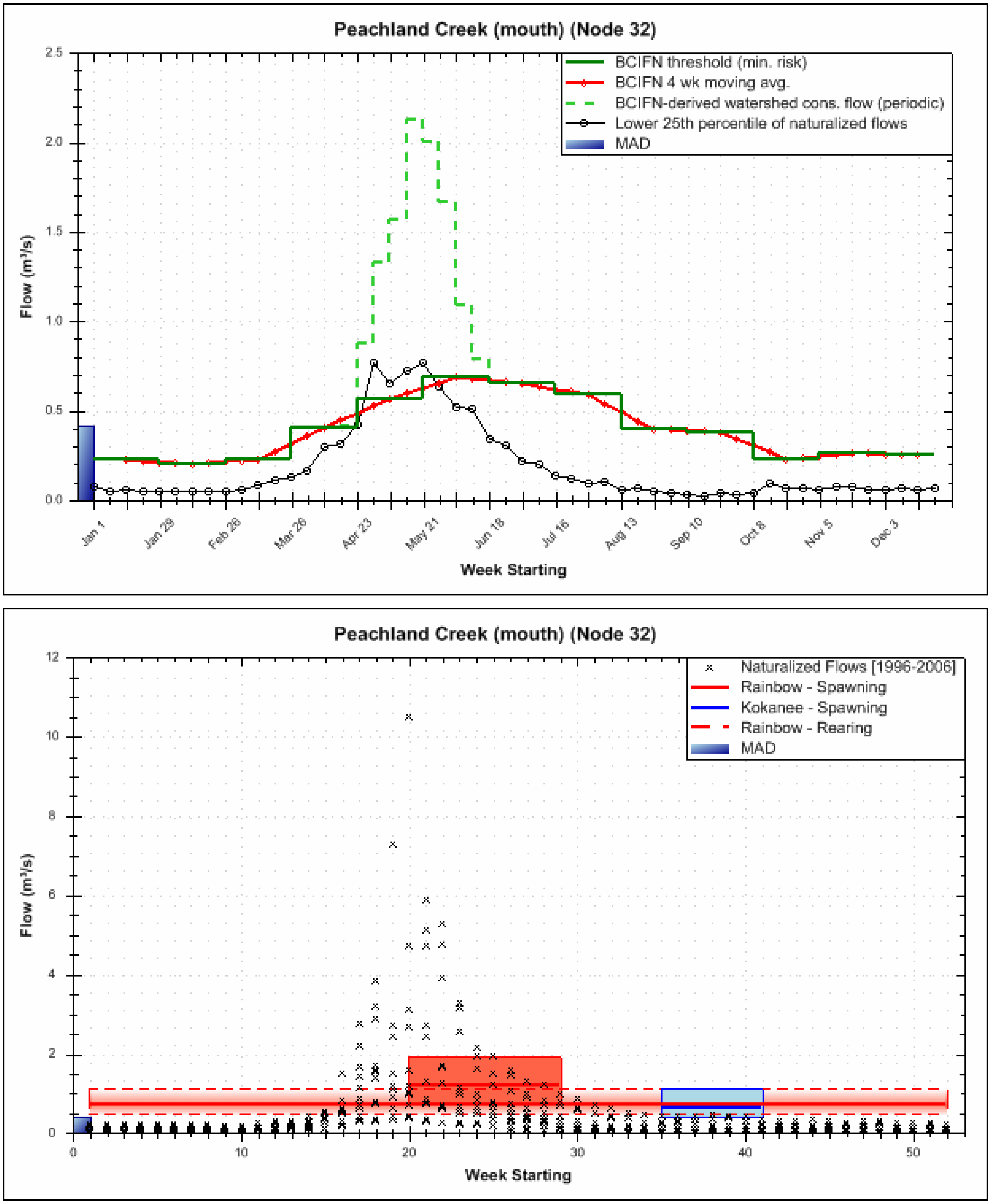
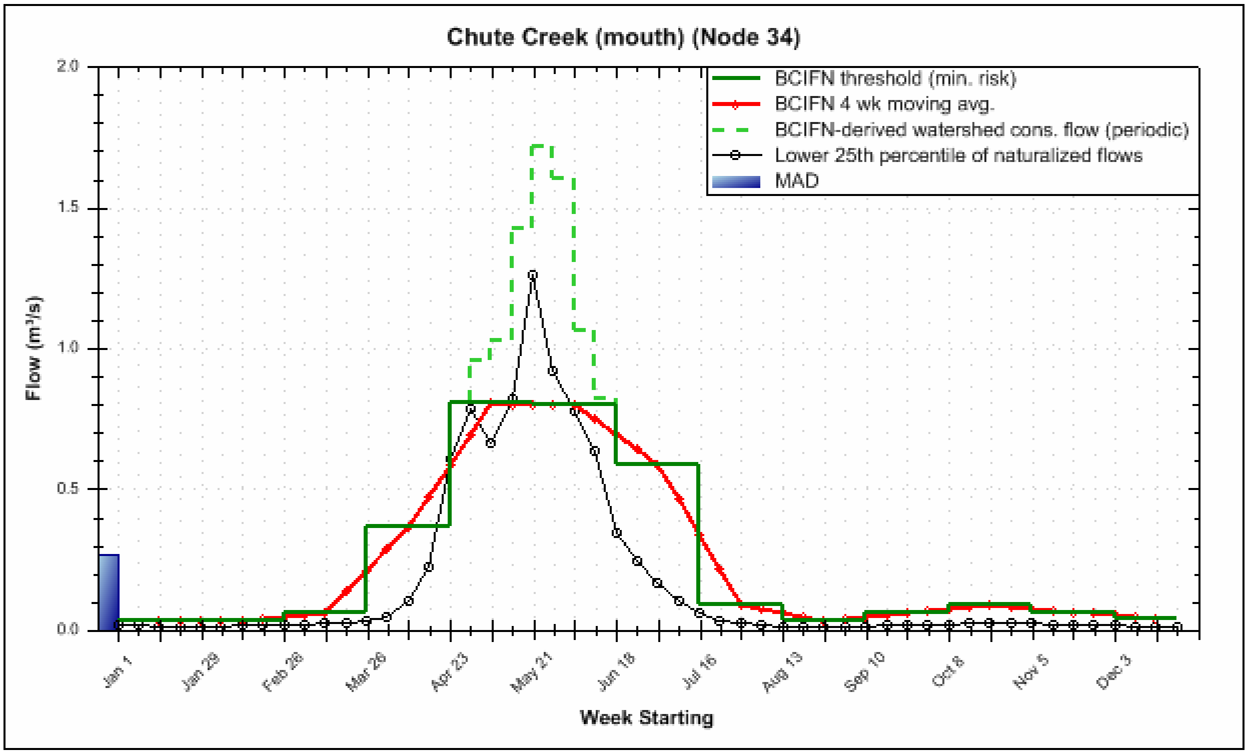


Figure B.18. Peachland Creek (node 32) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



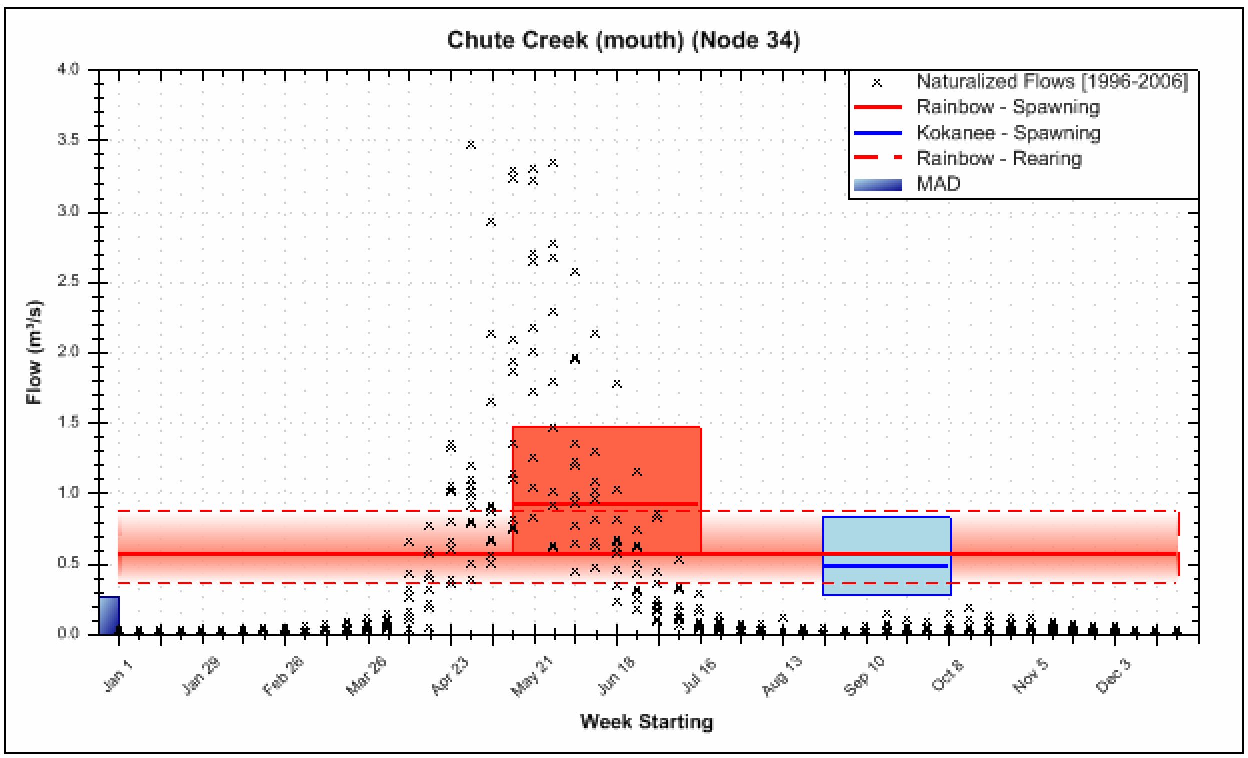
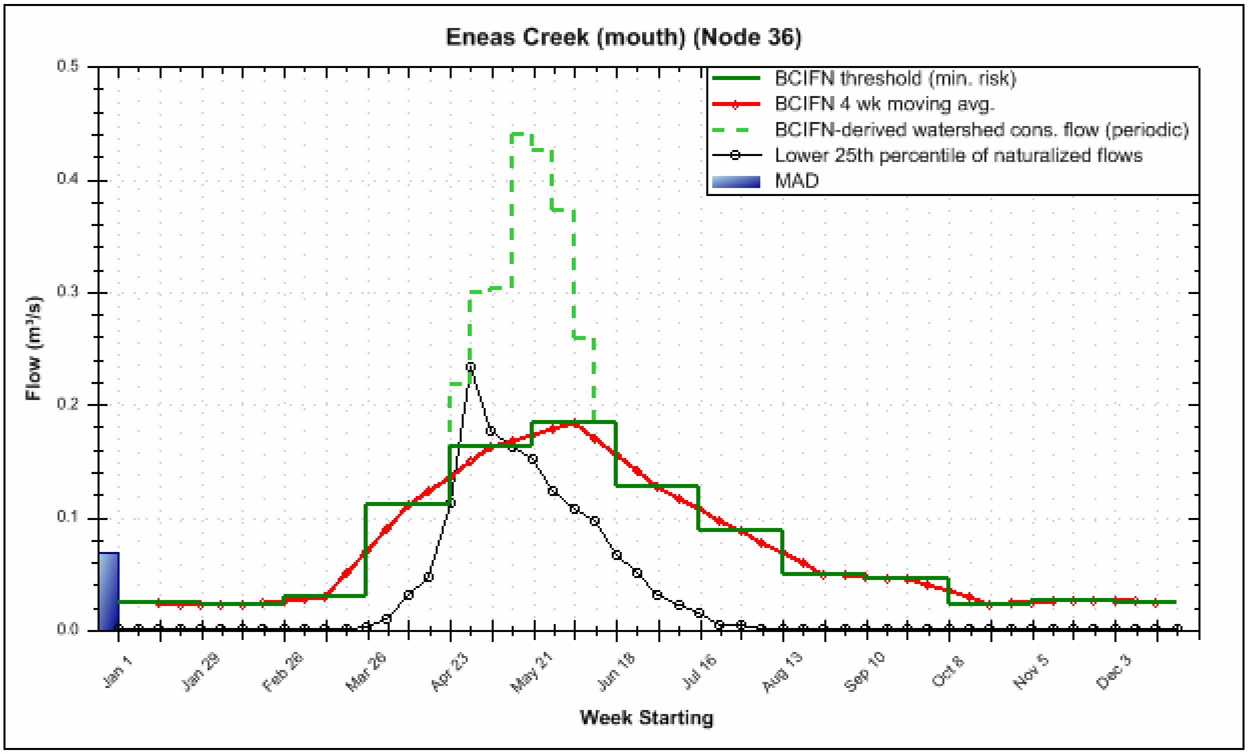


Figure B.19. Chute Creek (node 34) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



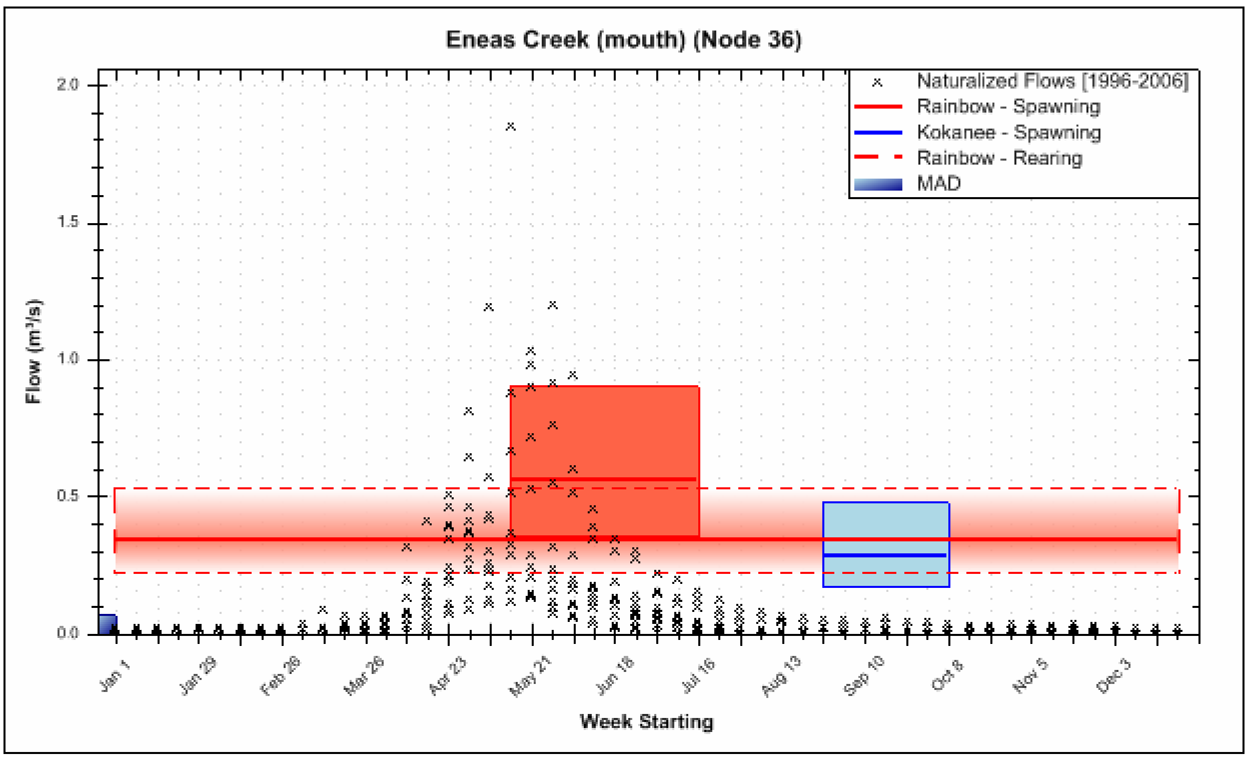
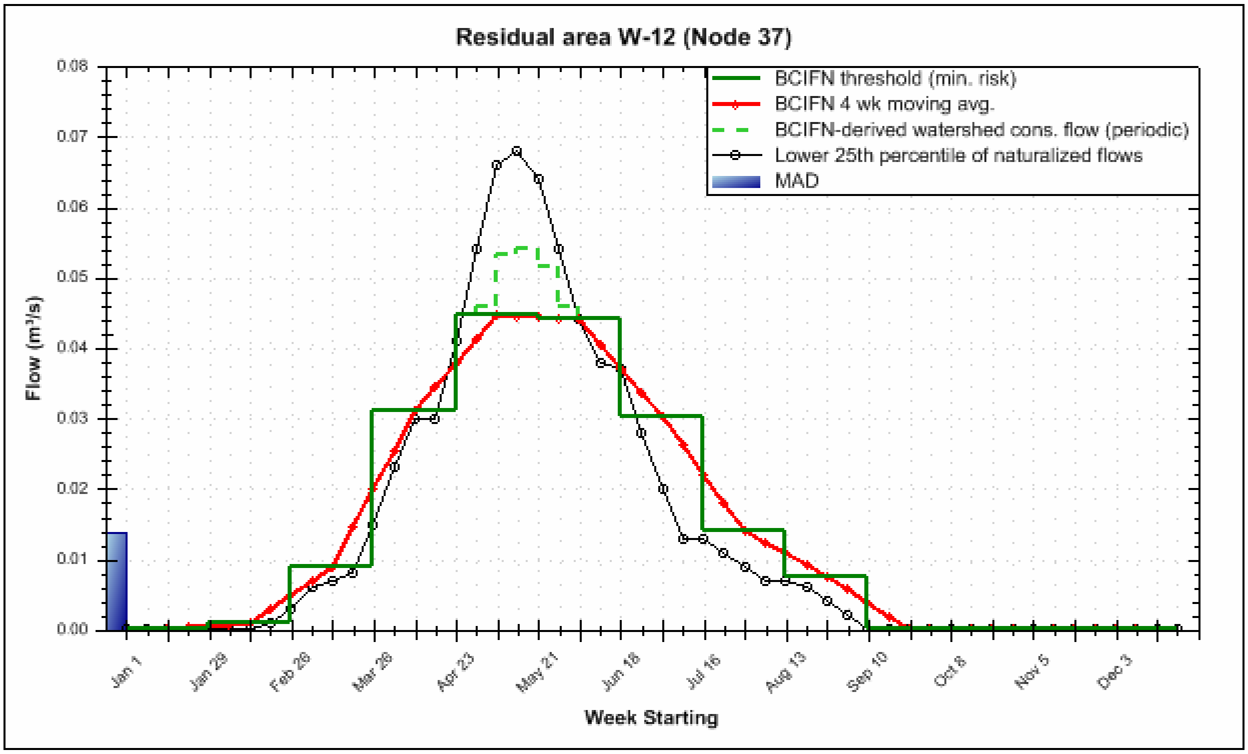


Figure B.36. Eneas Creek (node 36) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



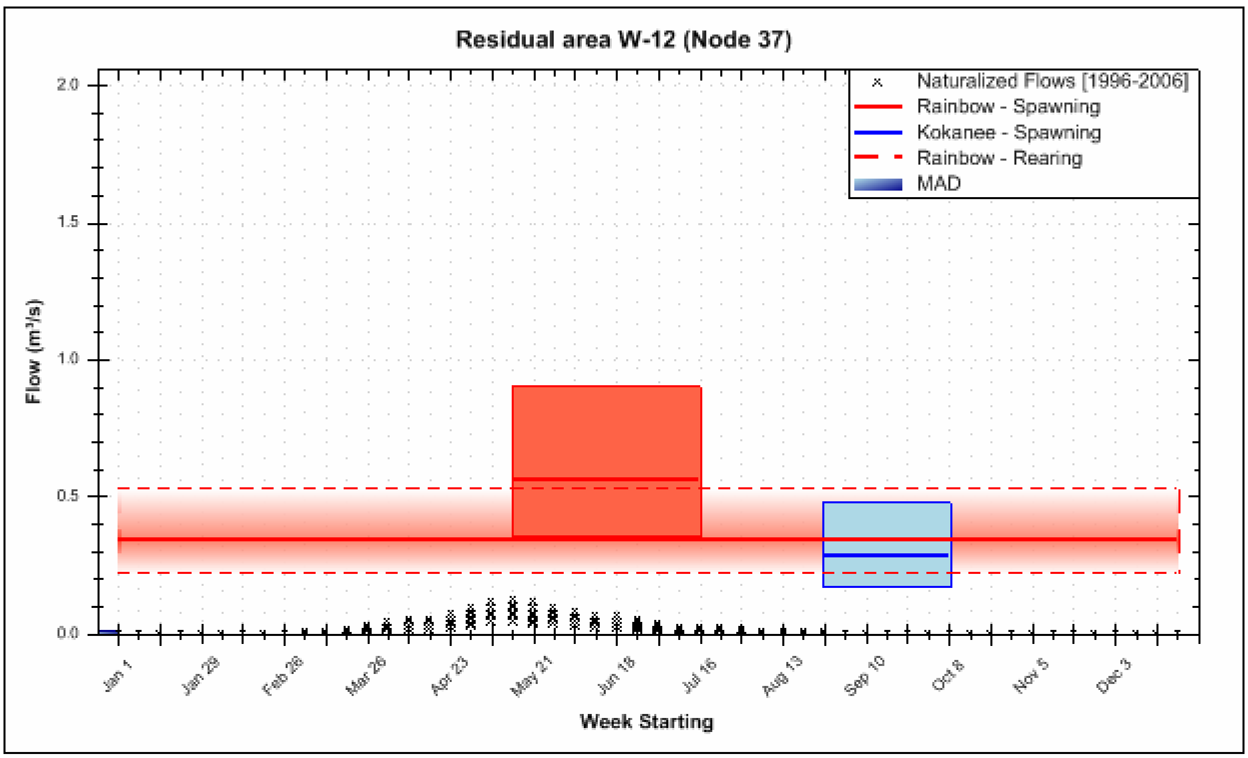
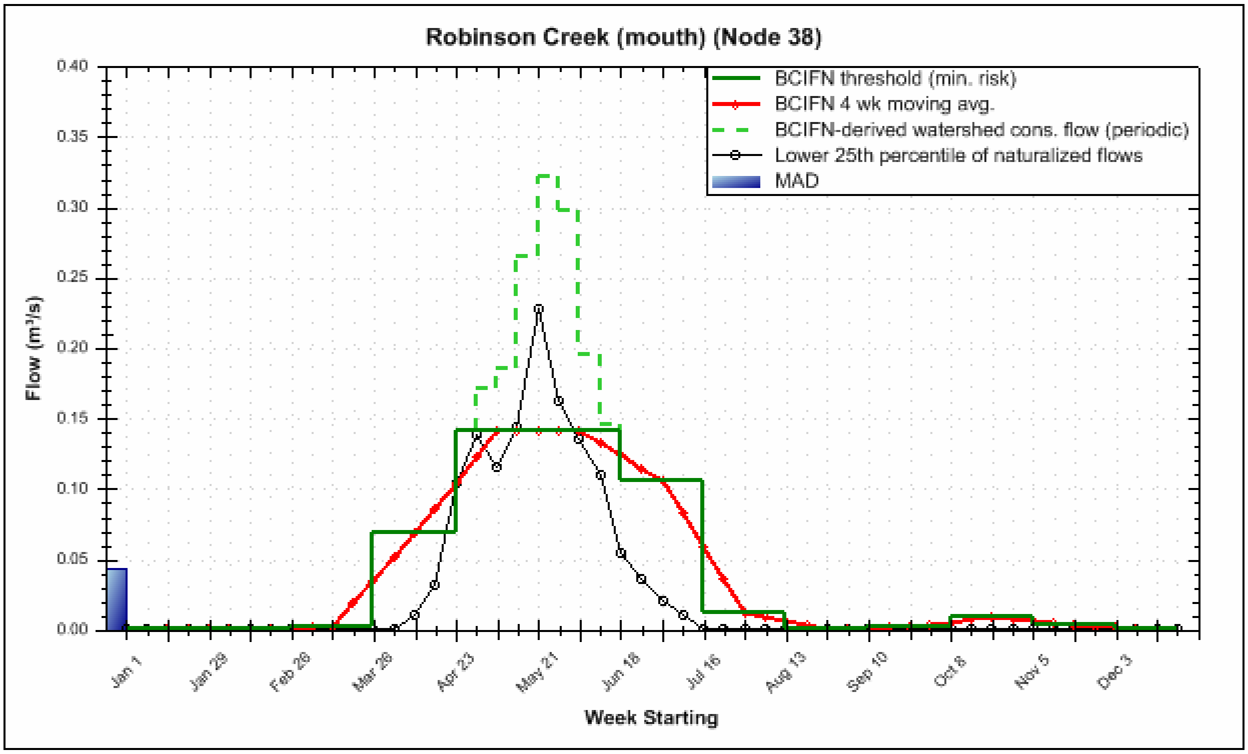


Figure B.37. Residual area W-12 (node 37) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and +50% Prediction Intervals) and weekly naturalized flows (bottom).



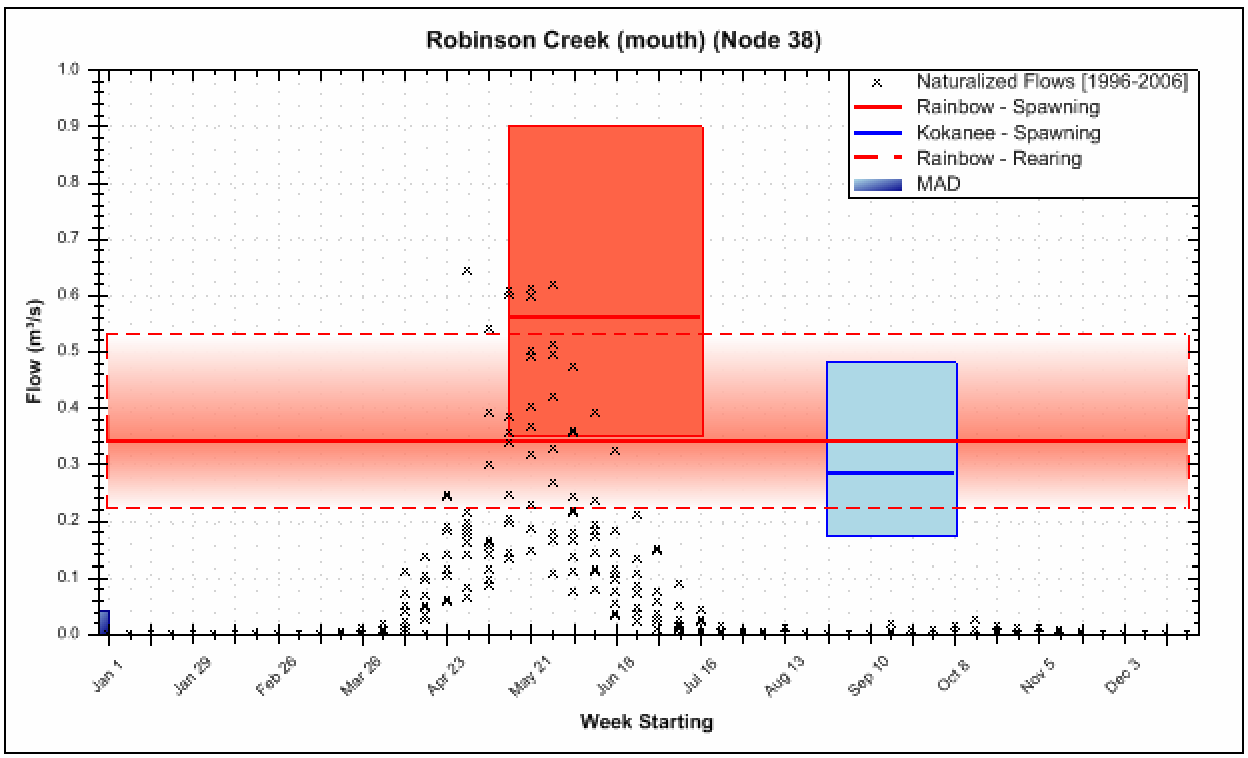


Figure B.22. Robinson Creek (node 38) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

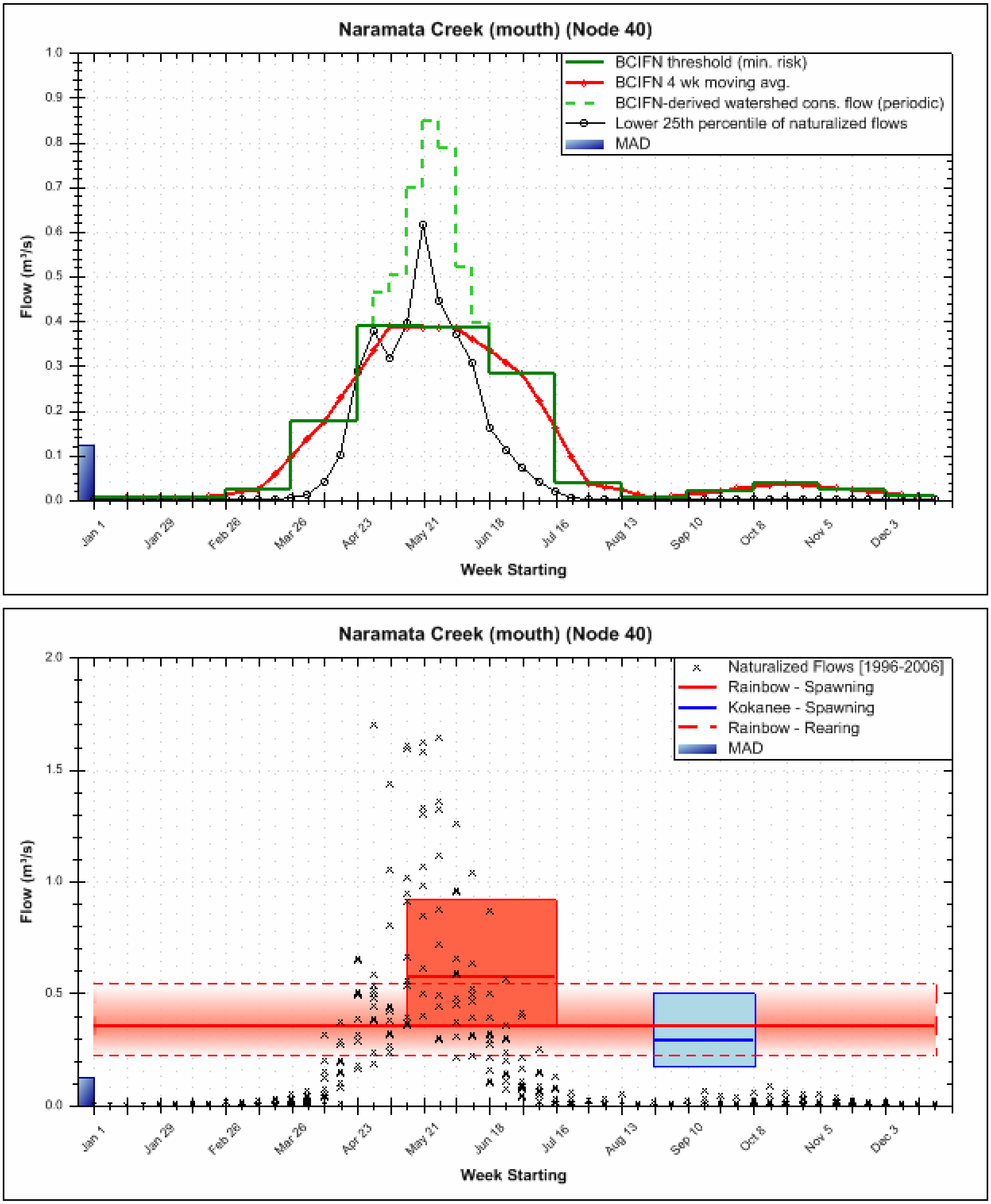
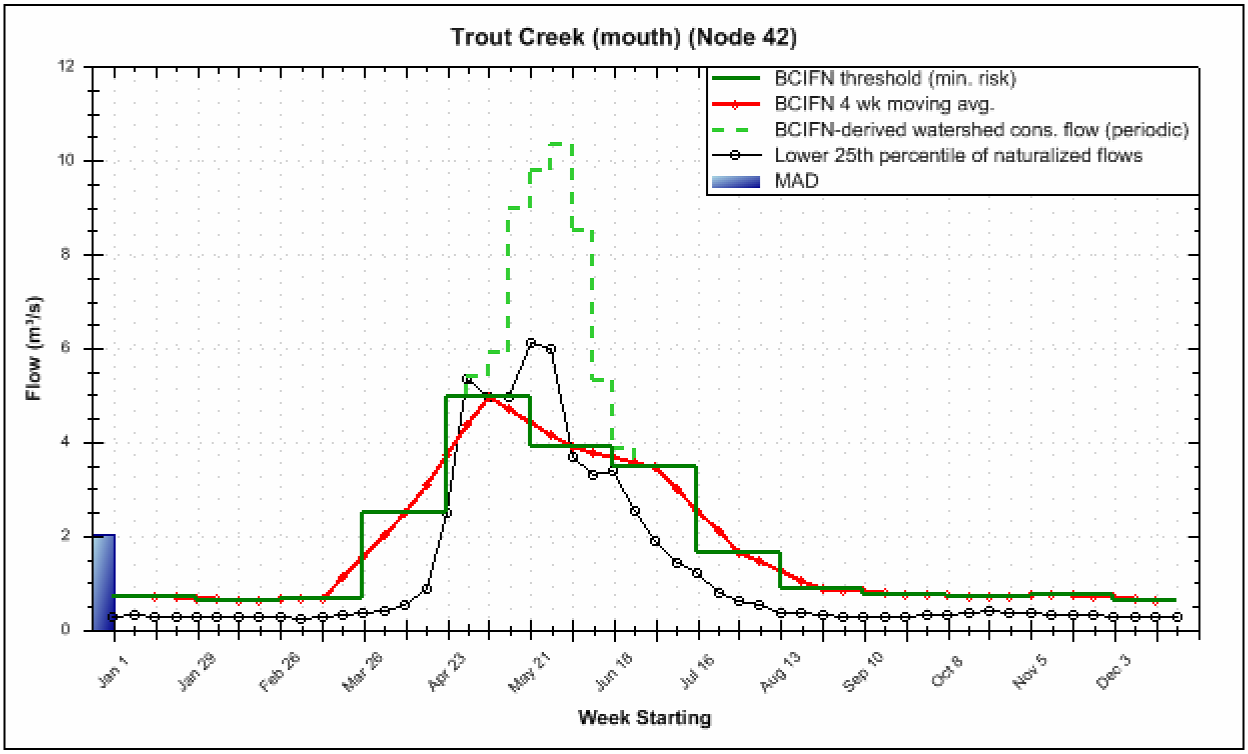


Figure B.23. Naramata Creek (node 40) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



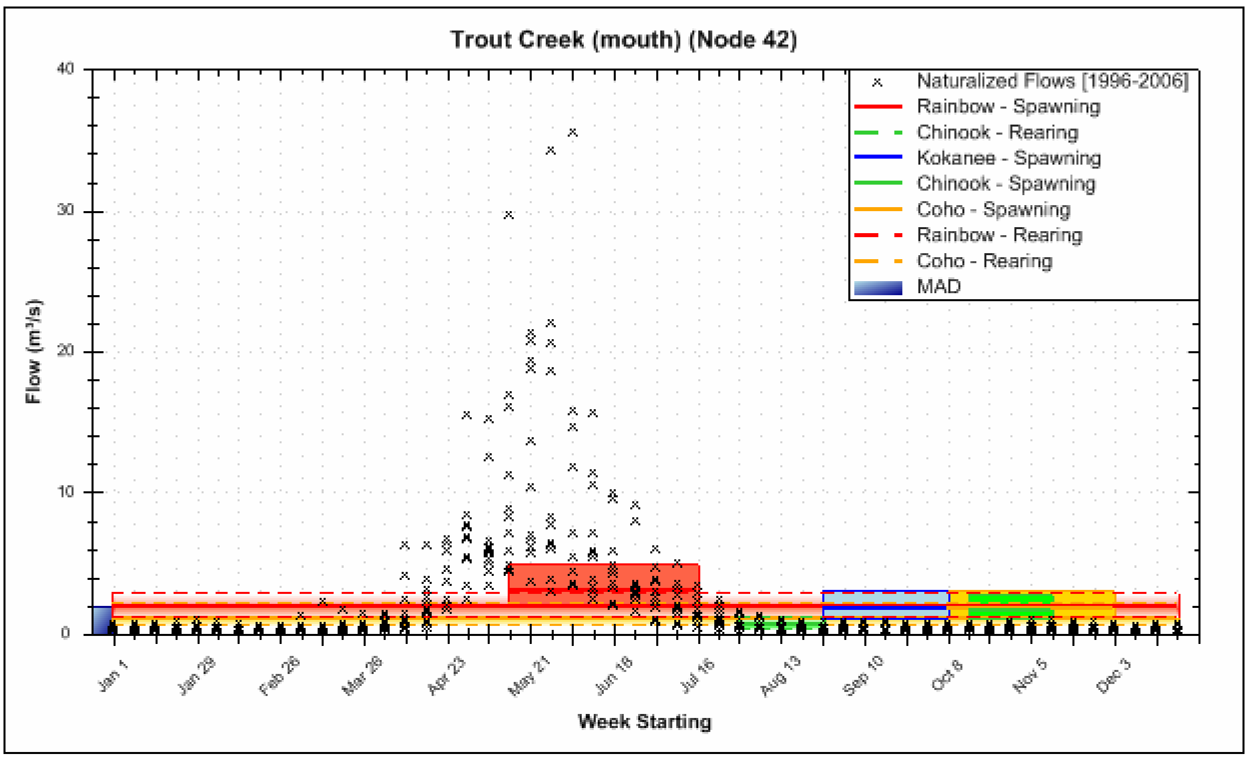


Figure B.42. Trout Creek (node 42) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

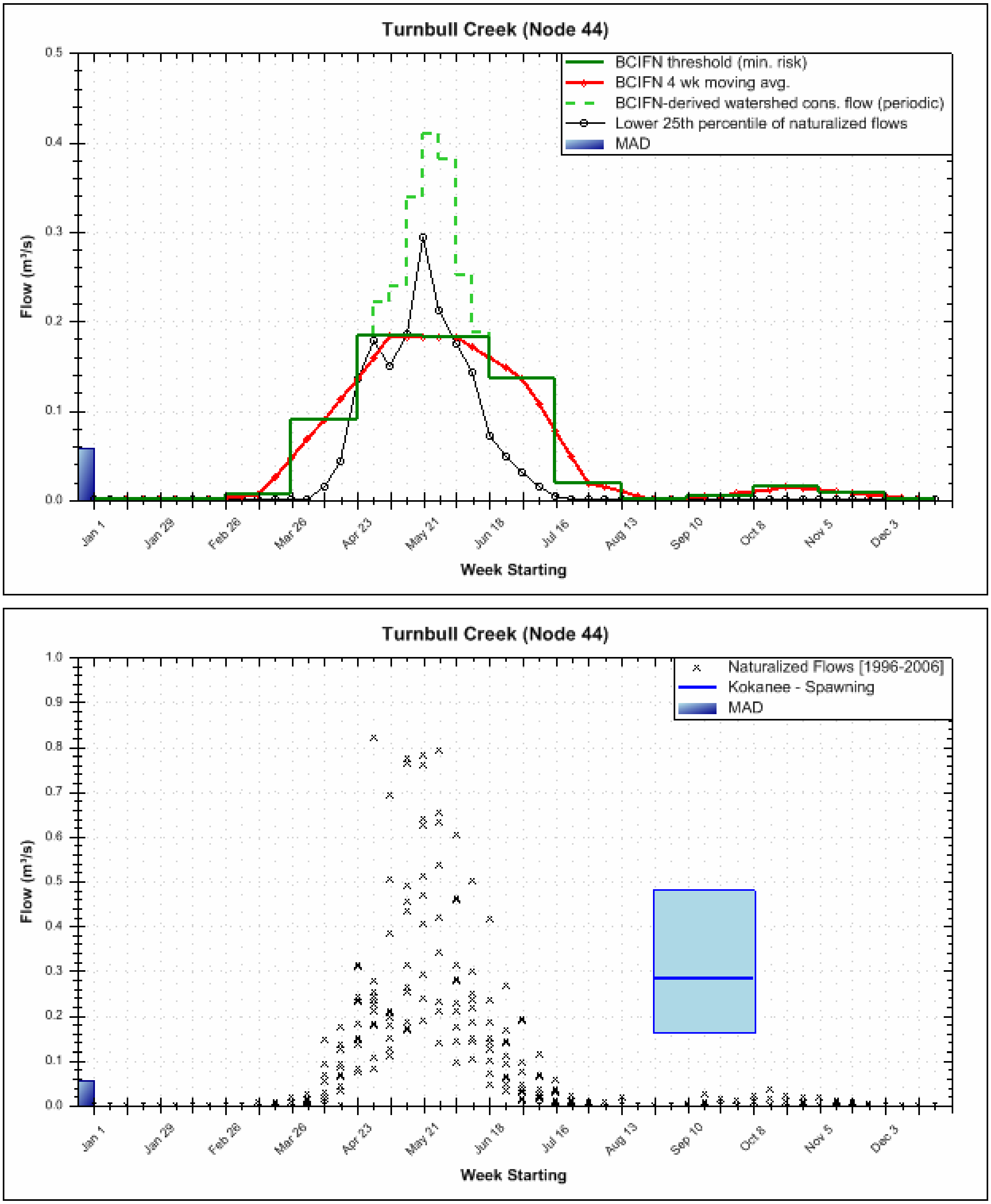
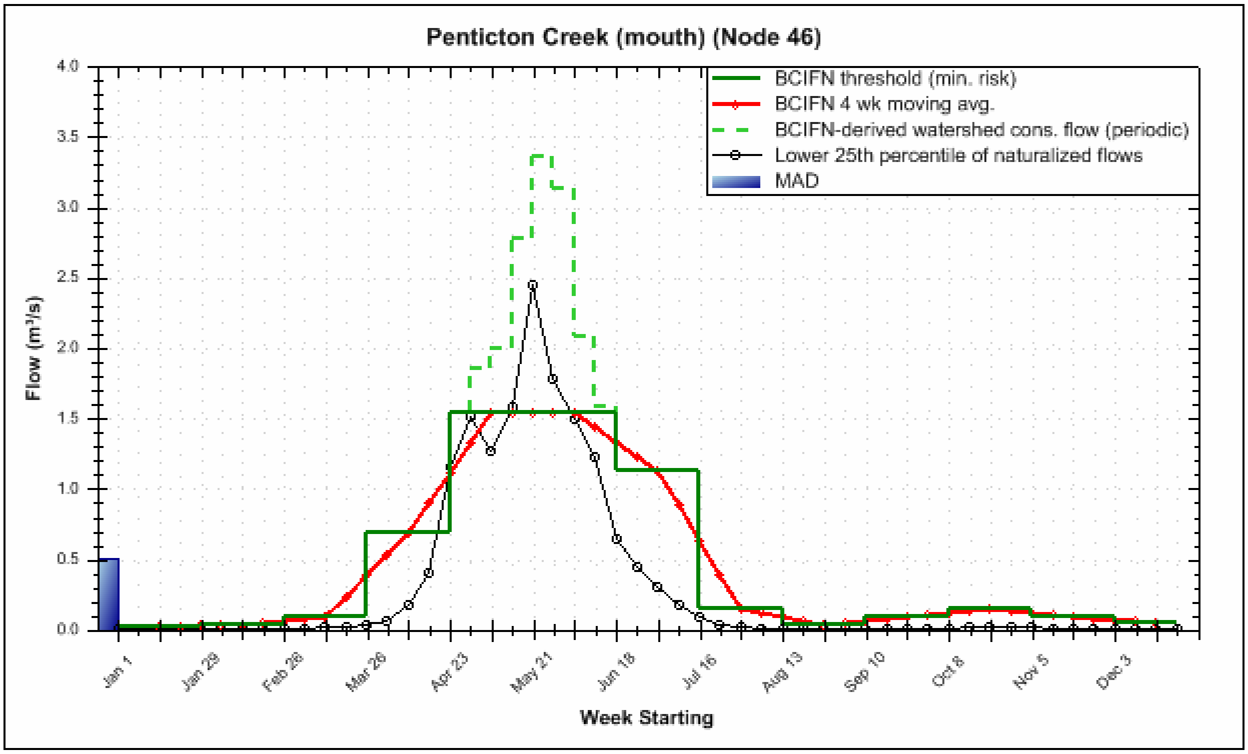


Figure B.25. Turnbull Creek (node 44) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and +50% Prediction Intervals) and weekly naturalized flows (bottom).



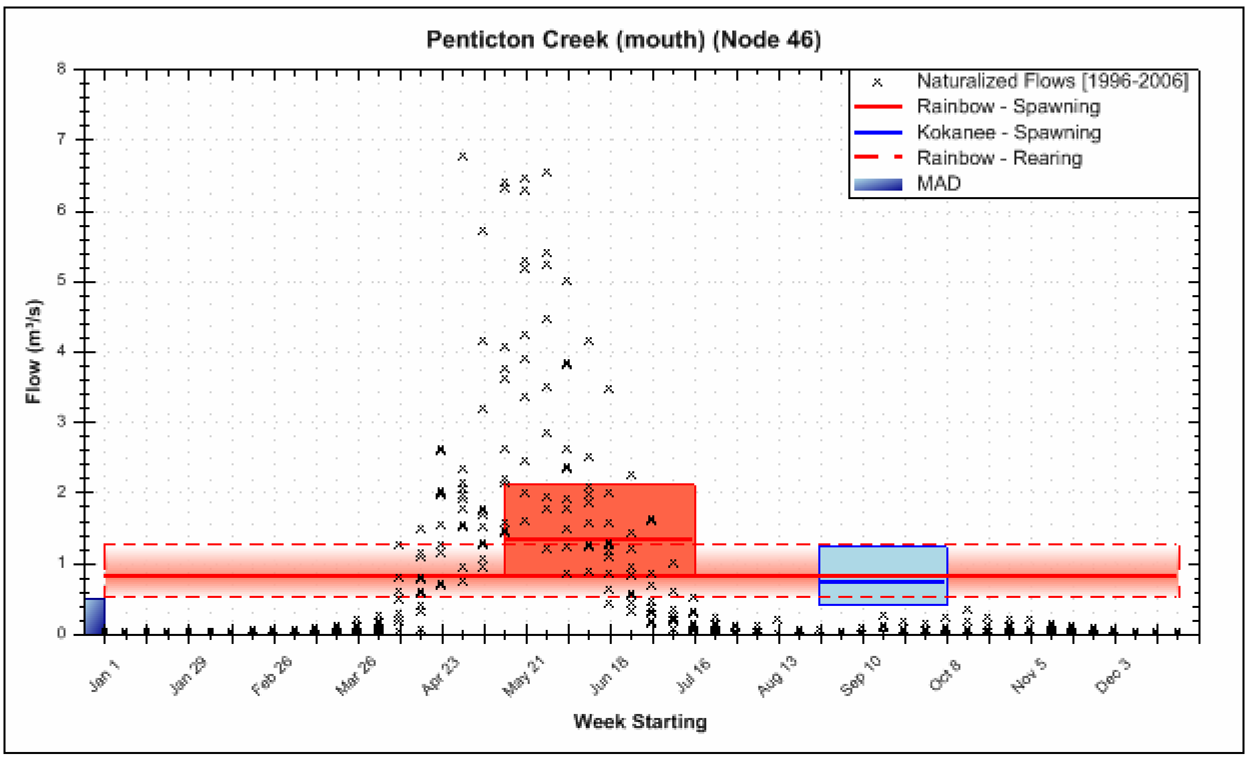
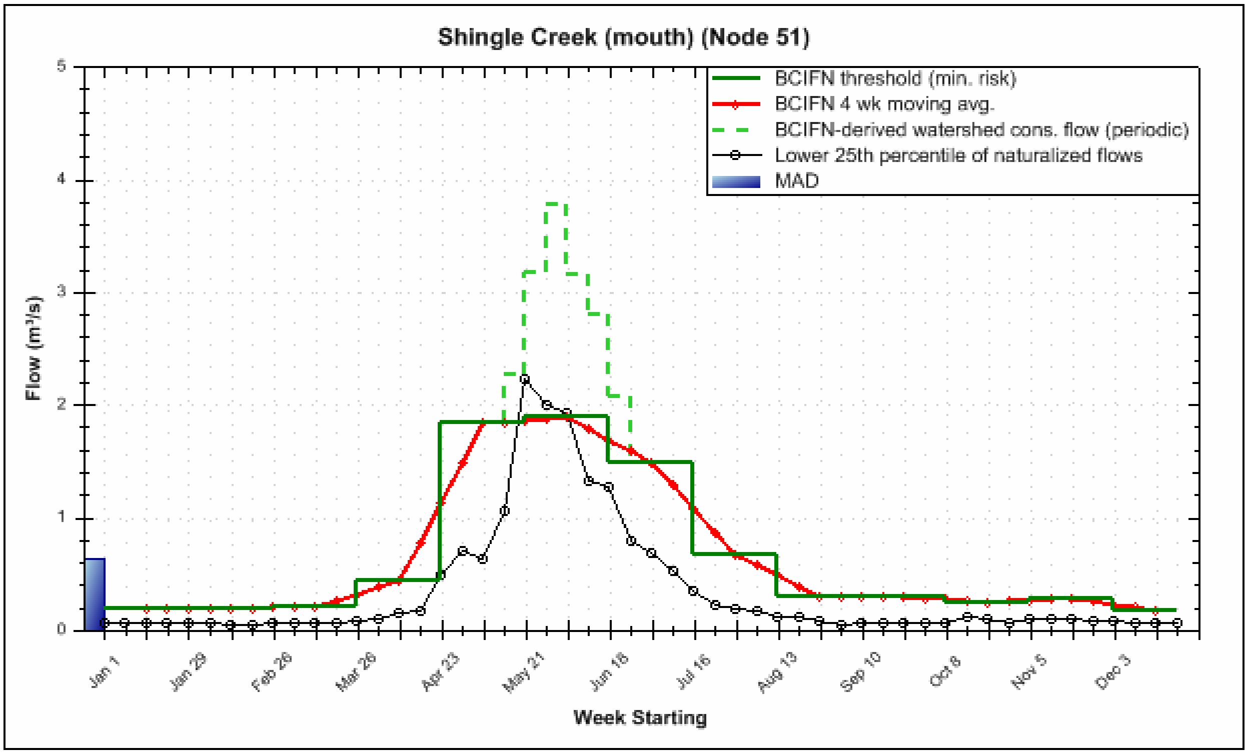


Figure B.26. Penticton Creek (node 46) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



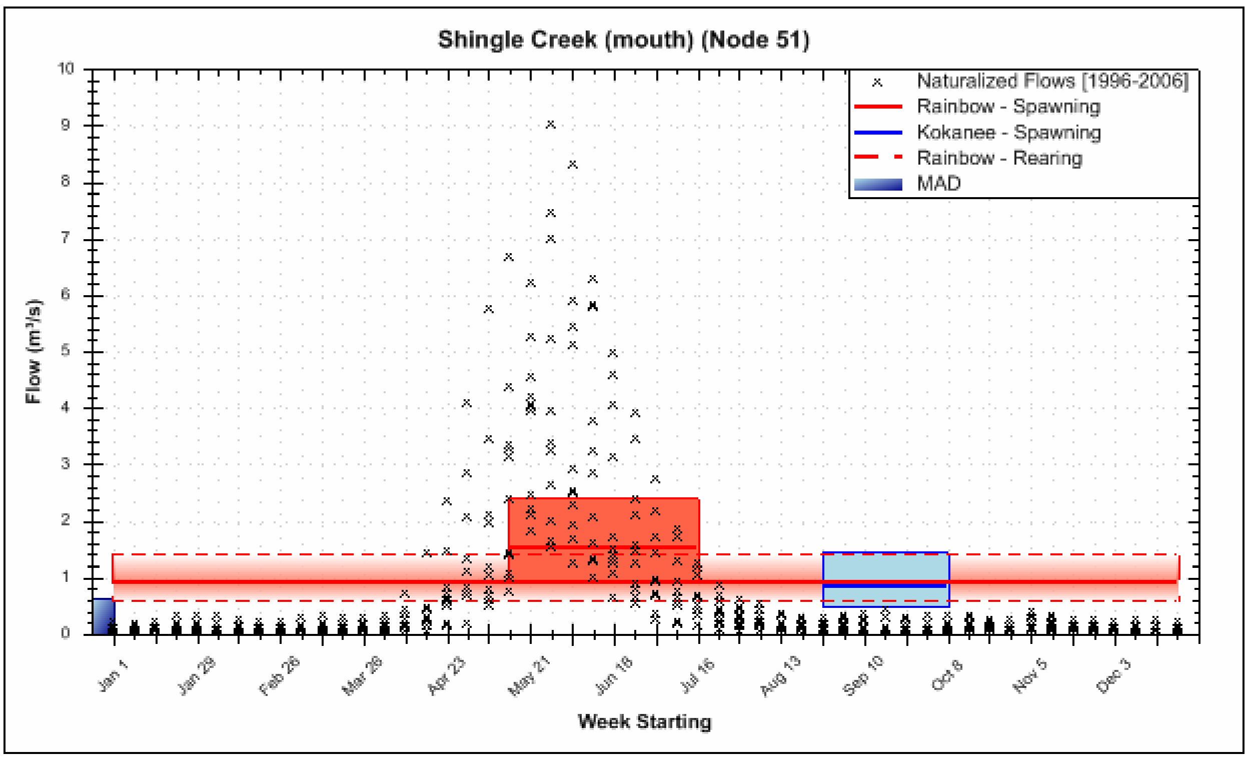


Figure B.27. Shingle Creek (node 51) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

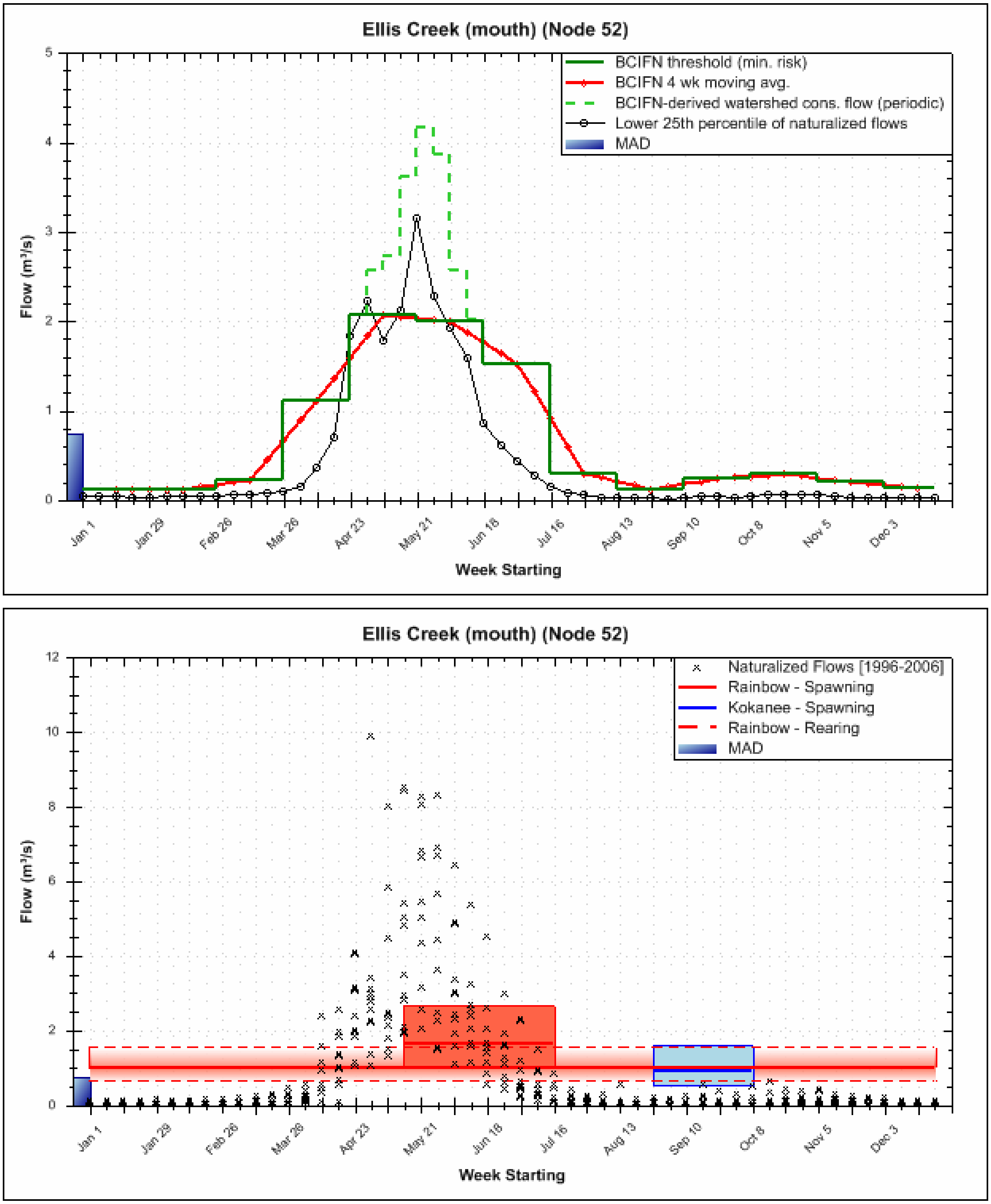
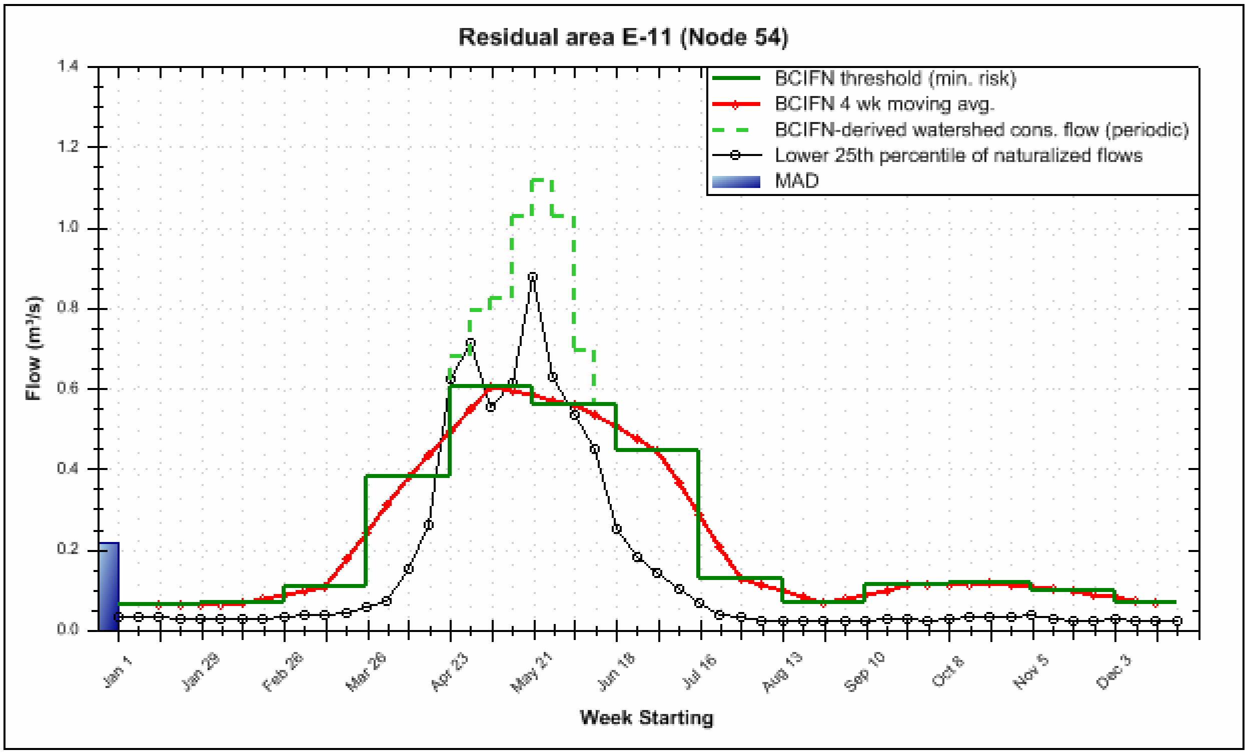


Figure B.28. Ellis Creek (node 52) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



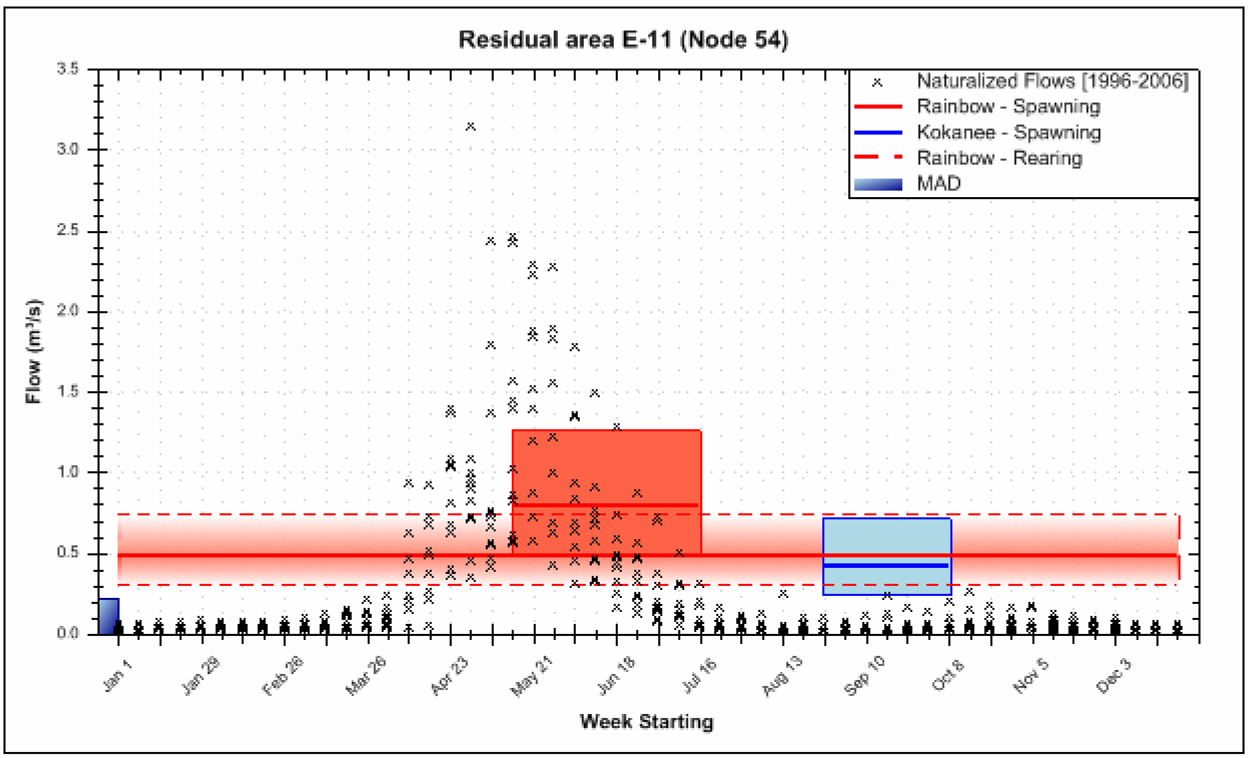
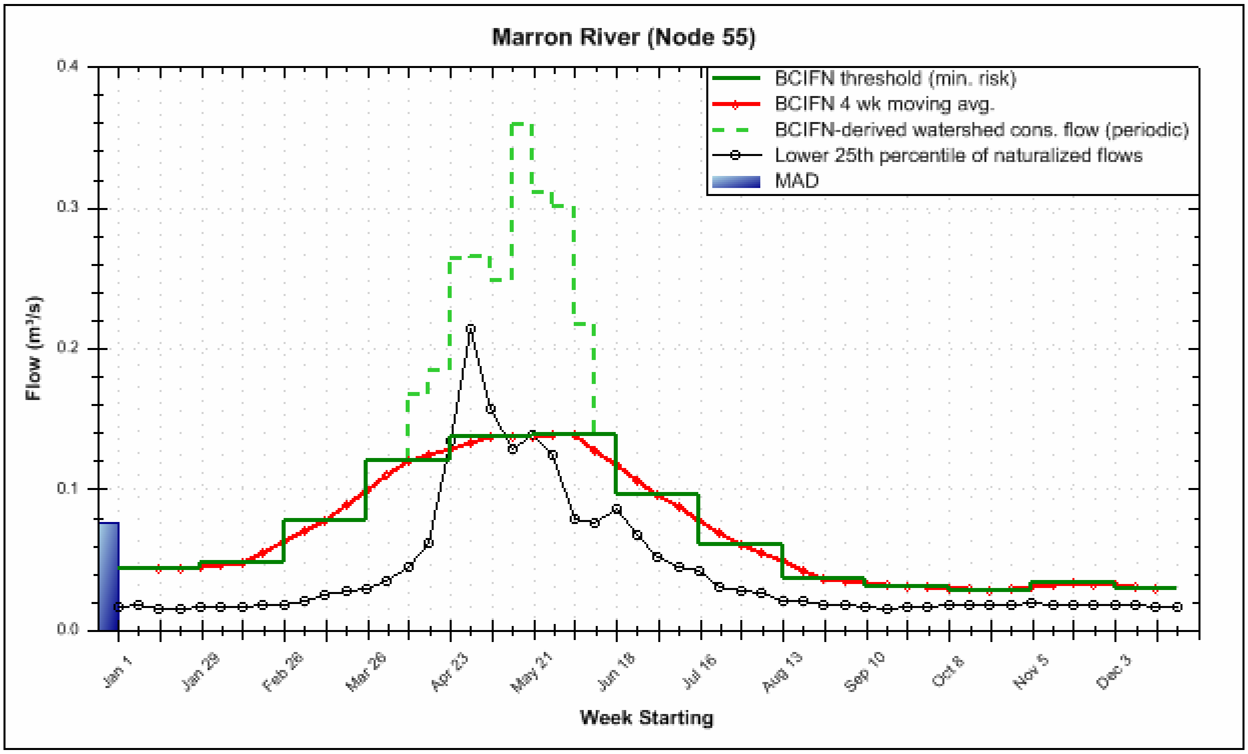


Figure B.29. Residual area E-11 (node 54) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



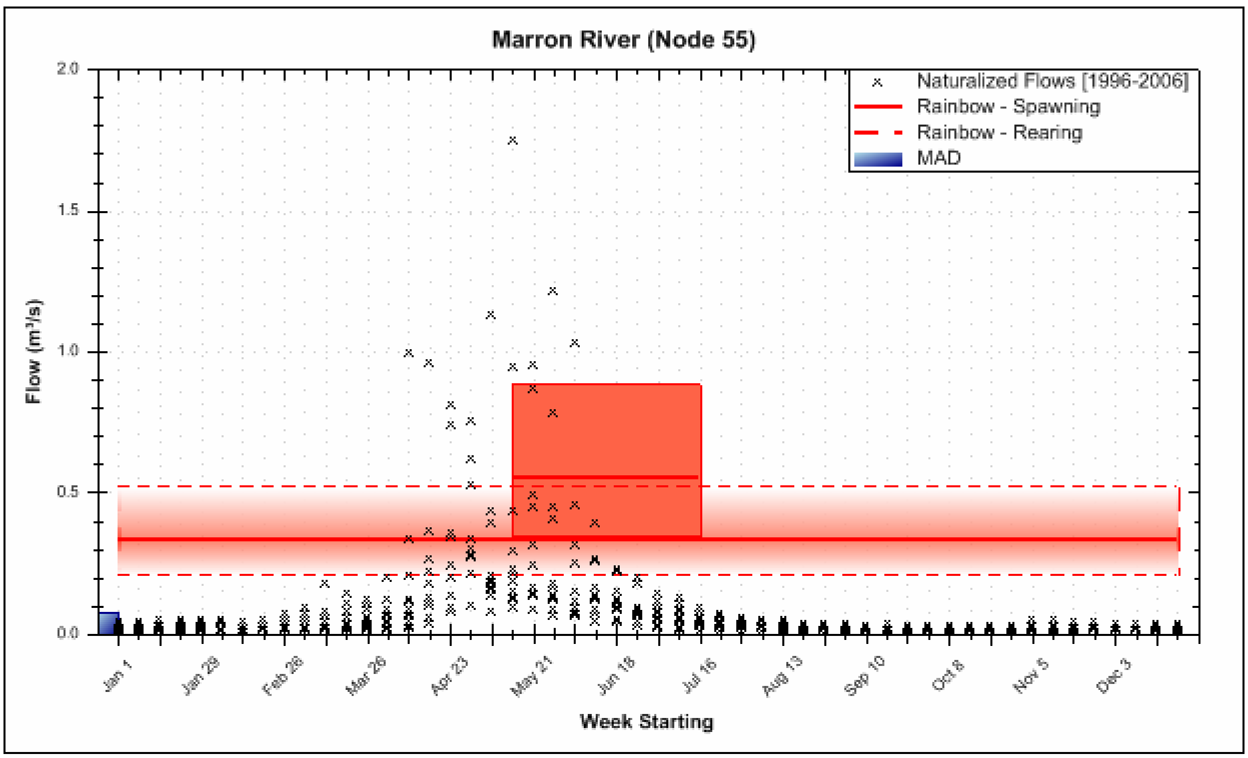


Figure B.30. Marron River (node 55) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and +50% Prediction Intervals) and weekly naturalized flows (bottom).

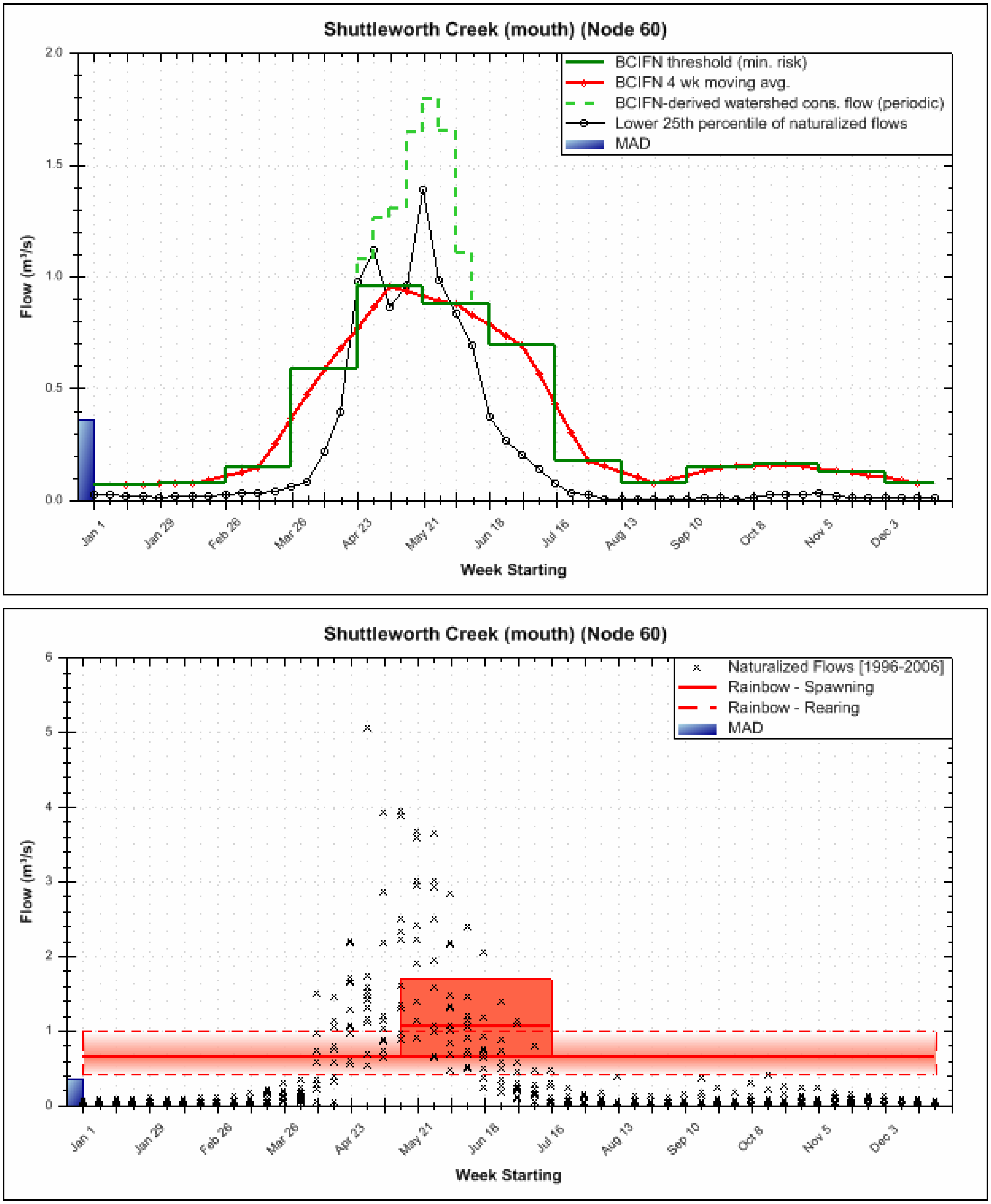
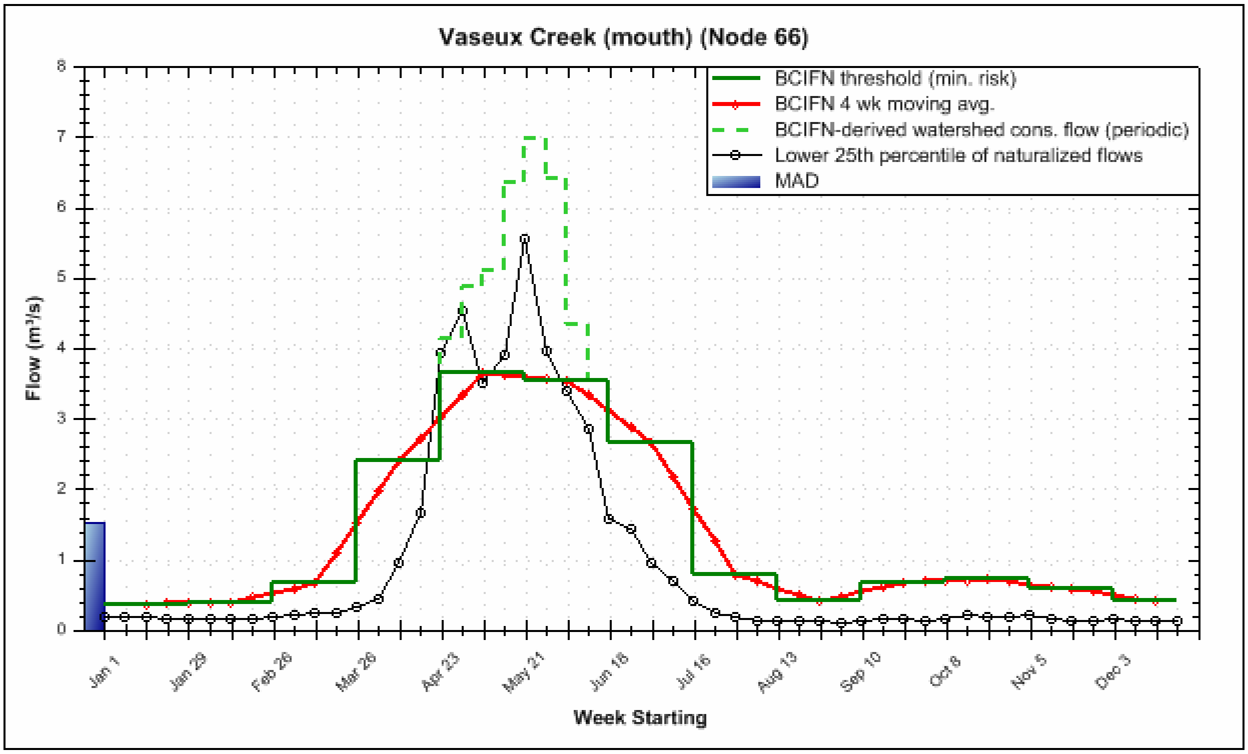


Figure B.31. Shuttleworth Creek (node 60) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and +50% Prediction Intervals) and weekly naturalized flows (bottom).



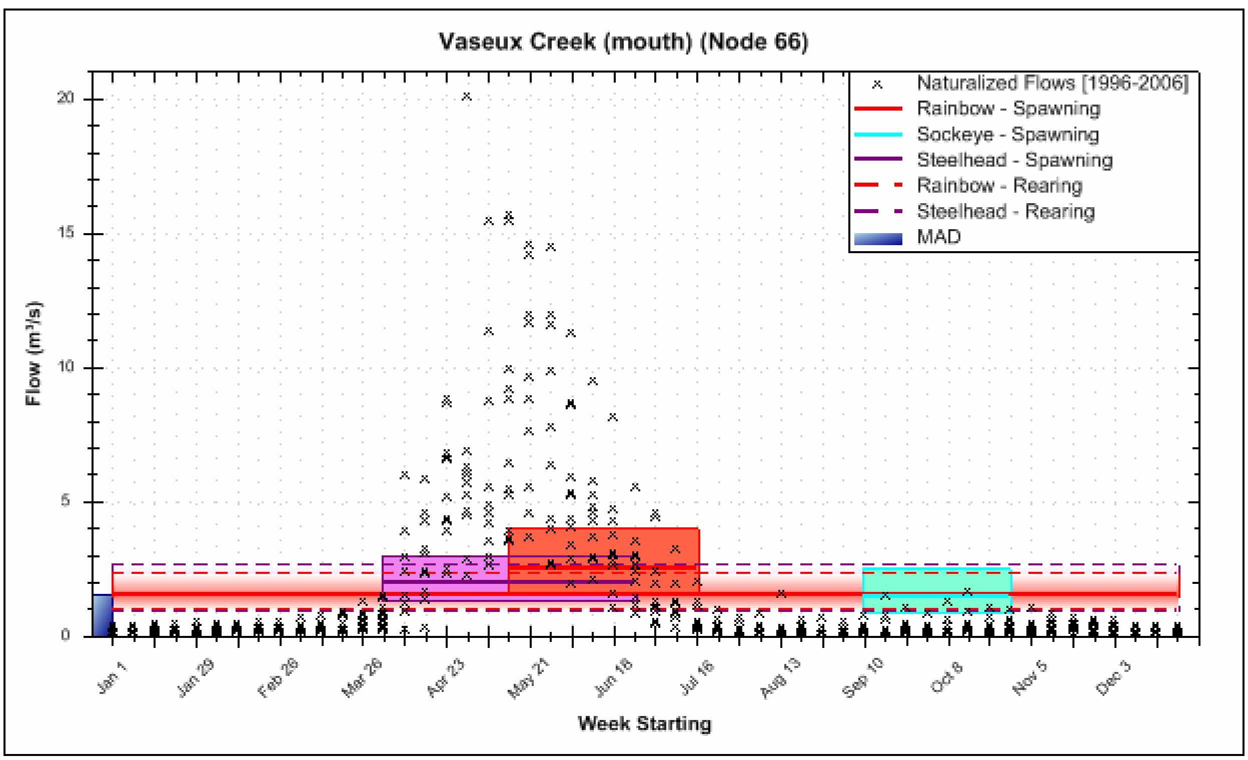


Figure B.32. Vaseux Creek (node 66) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

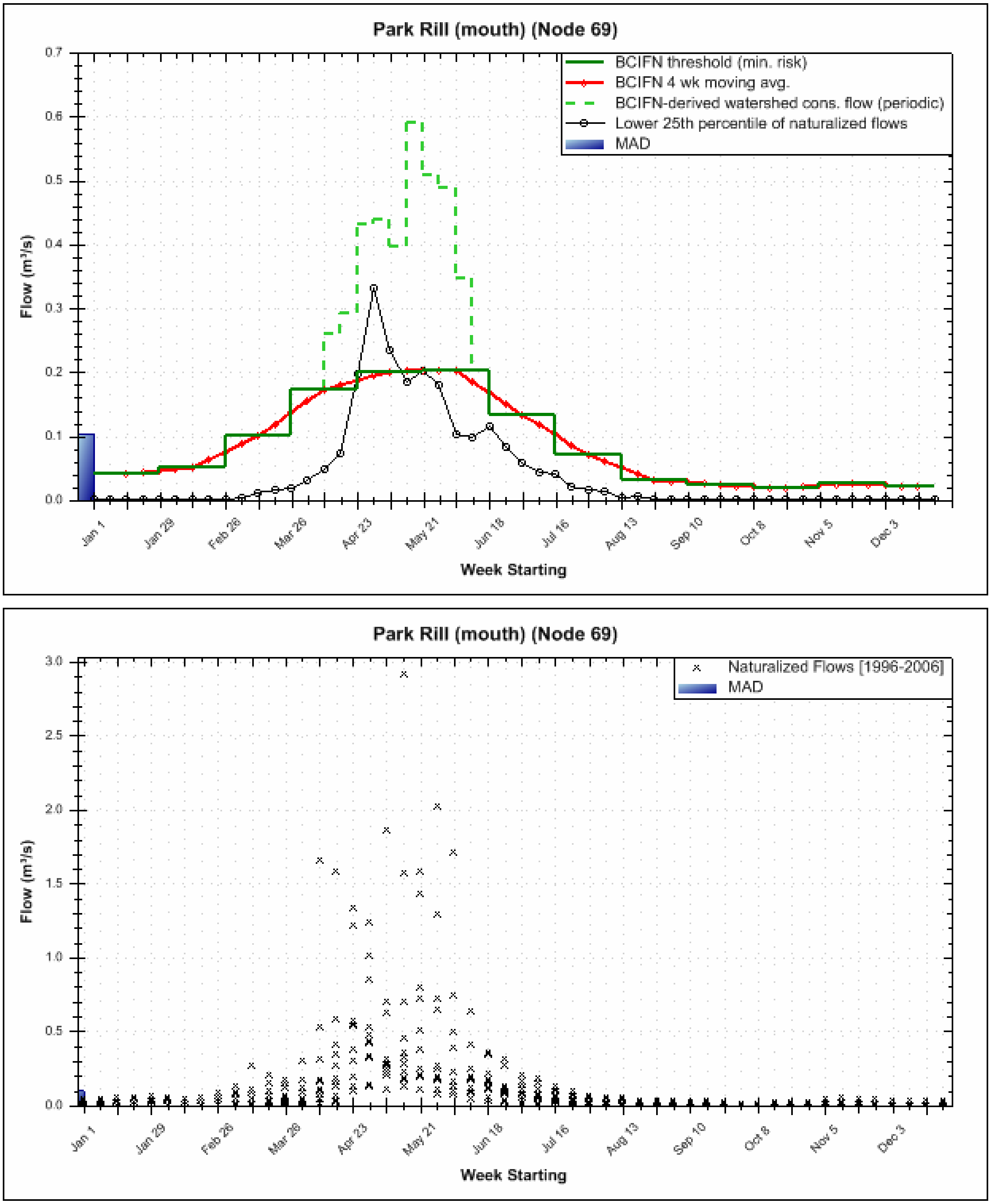
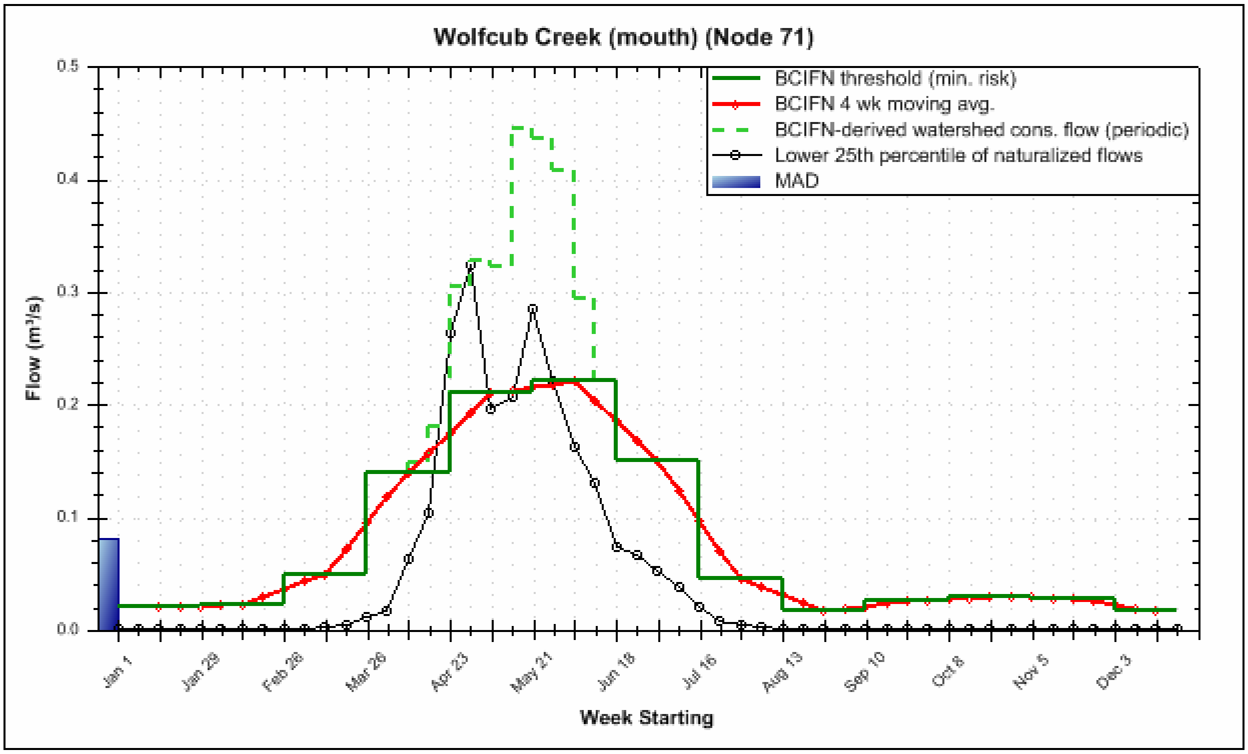


Figure B.33. Park Rill (node 69) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



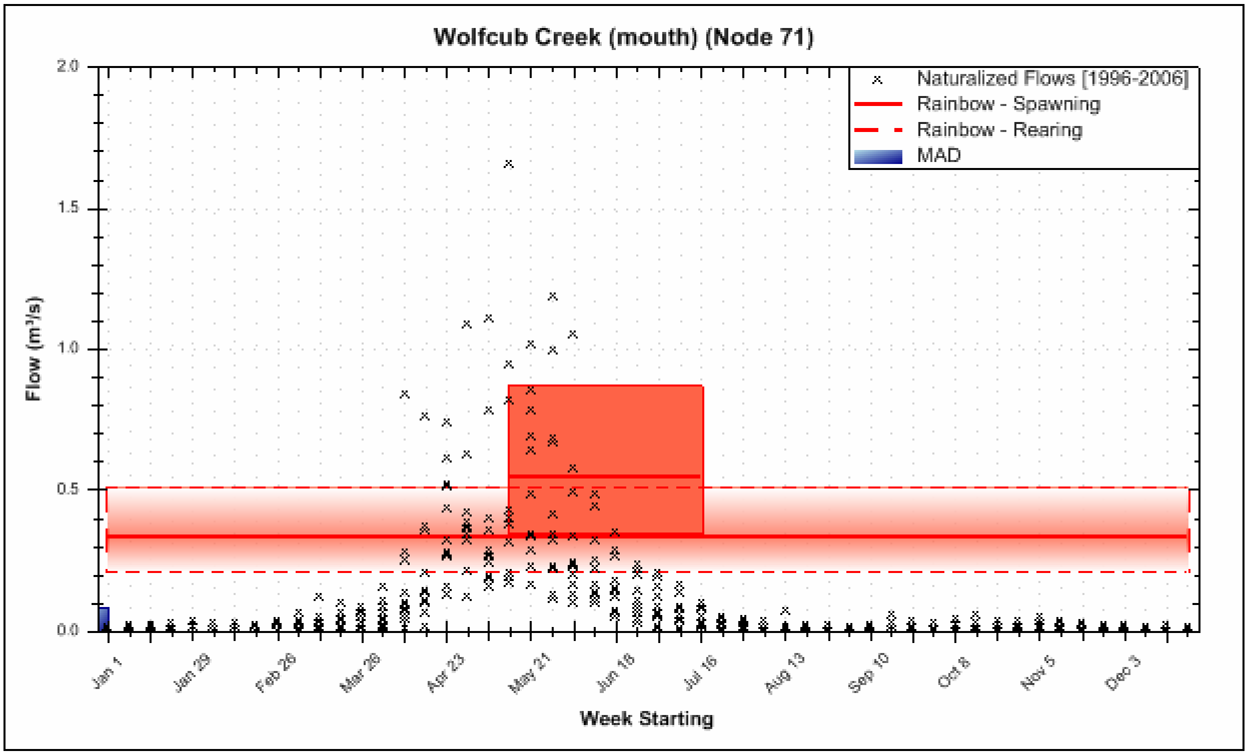
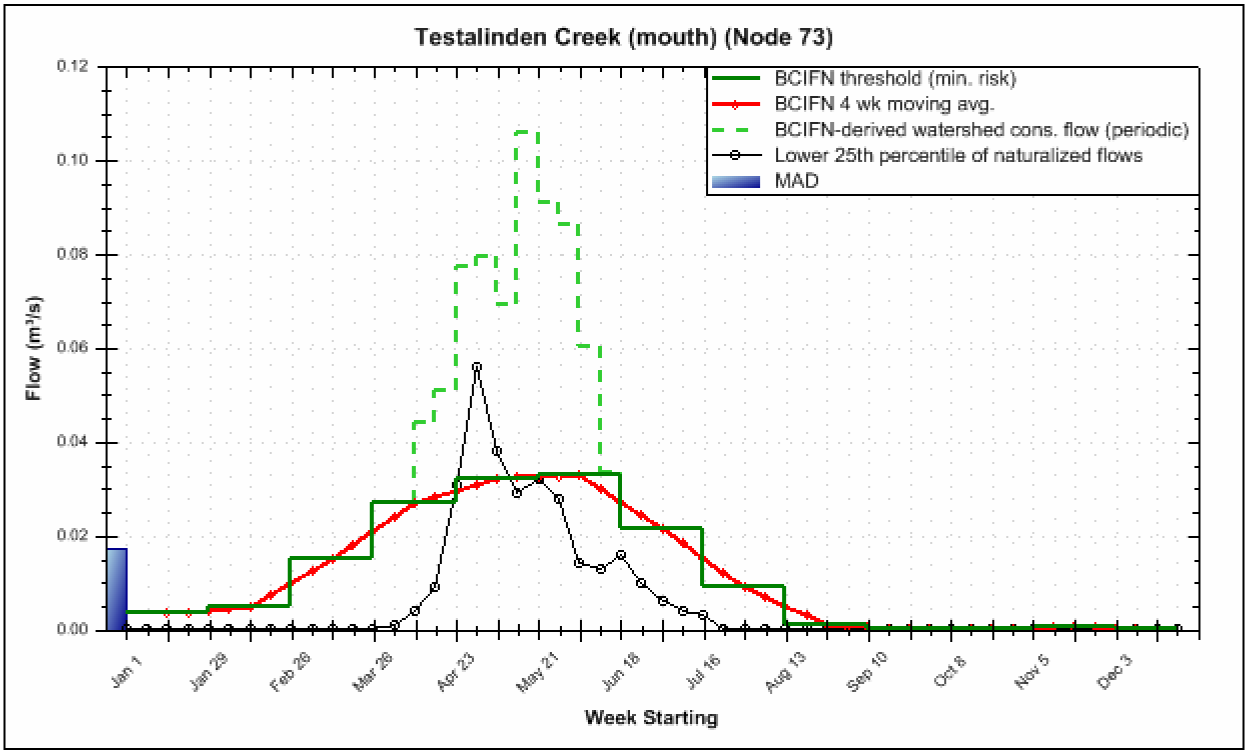


Figure B.34. Wolfcub Creek (node 71) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).



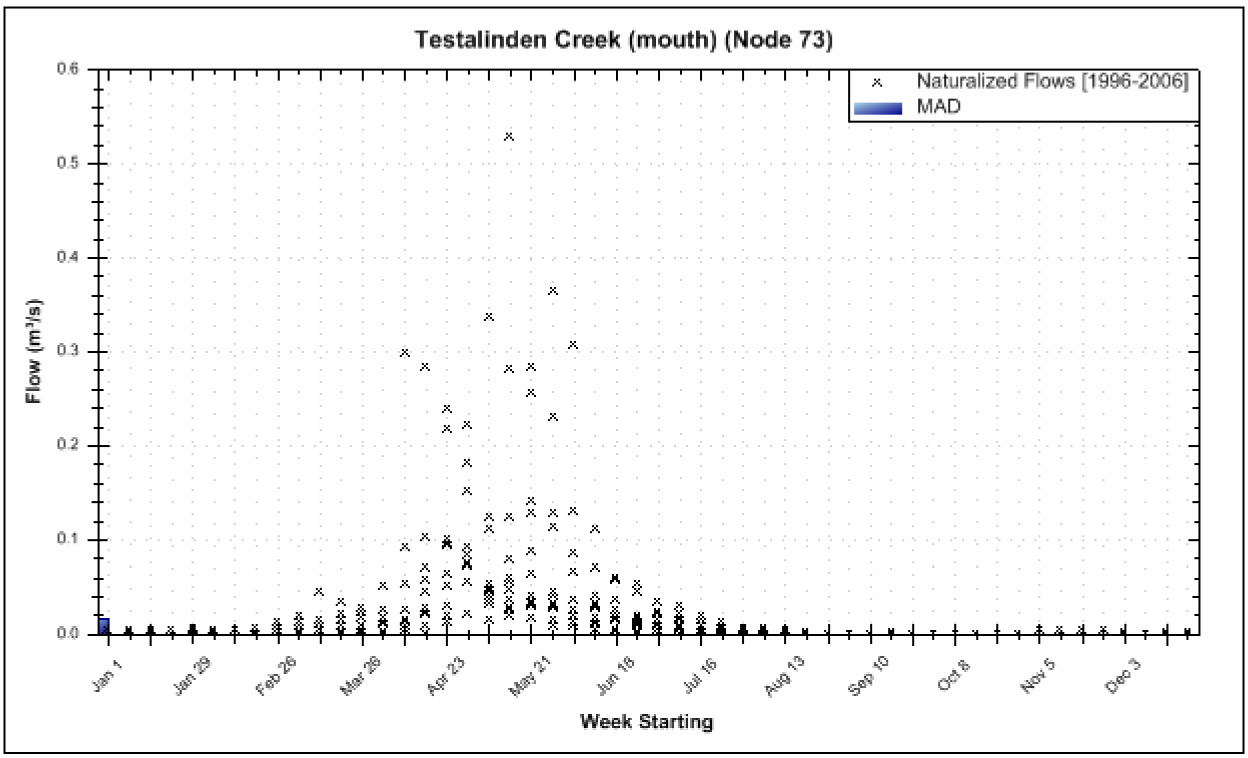
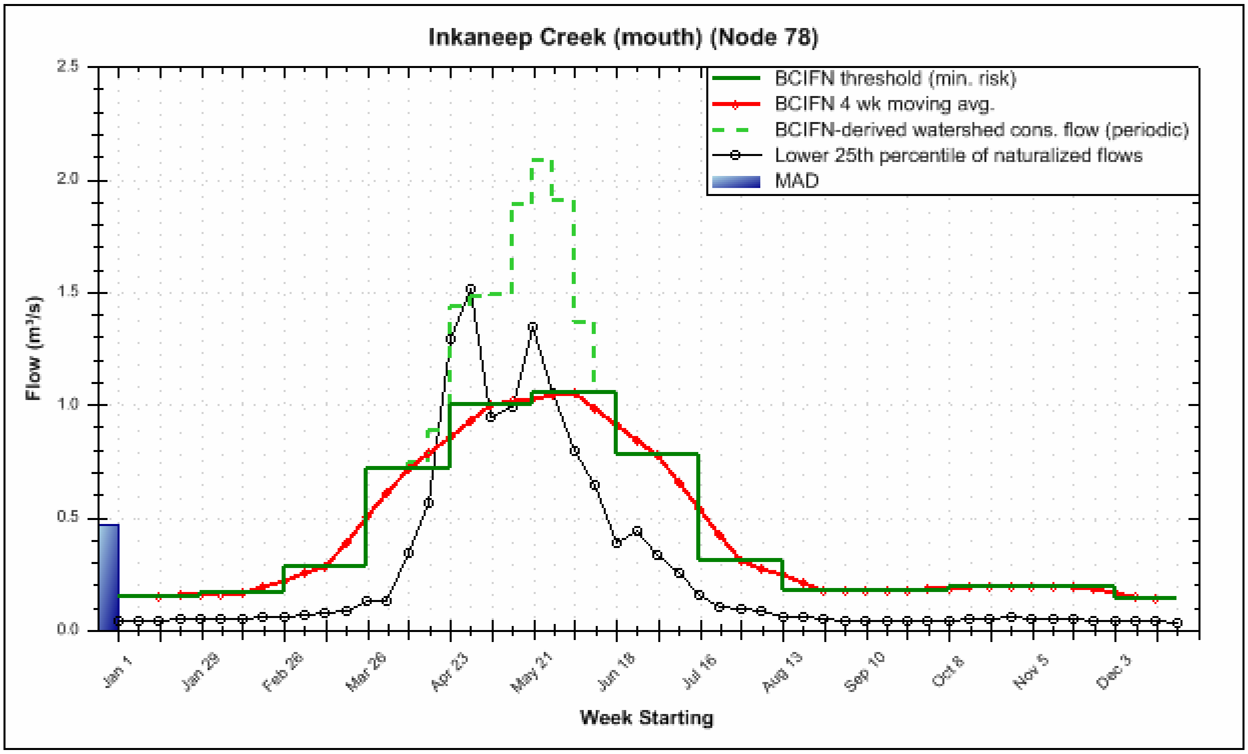


Figure B.35. Testalinden Creek (node 73) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and +50% Prediction Intervals) and weekly naturalized flows (bottom).



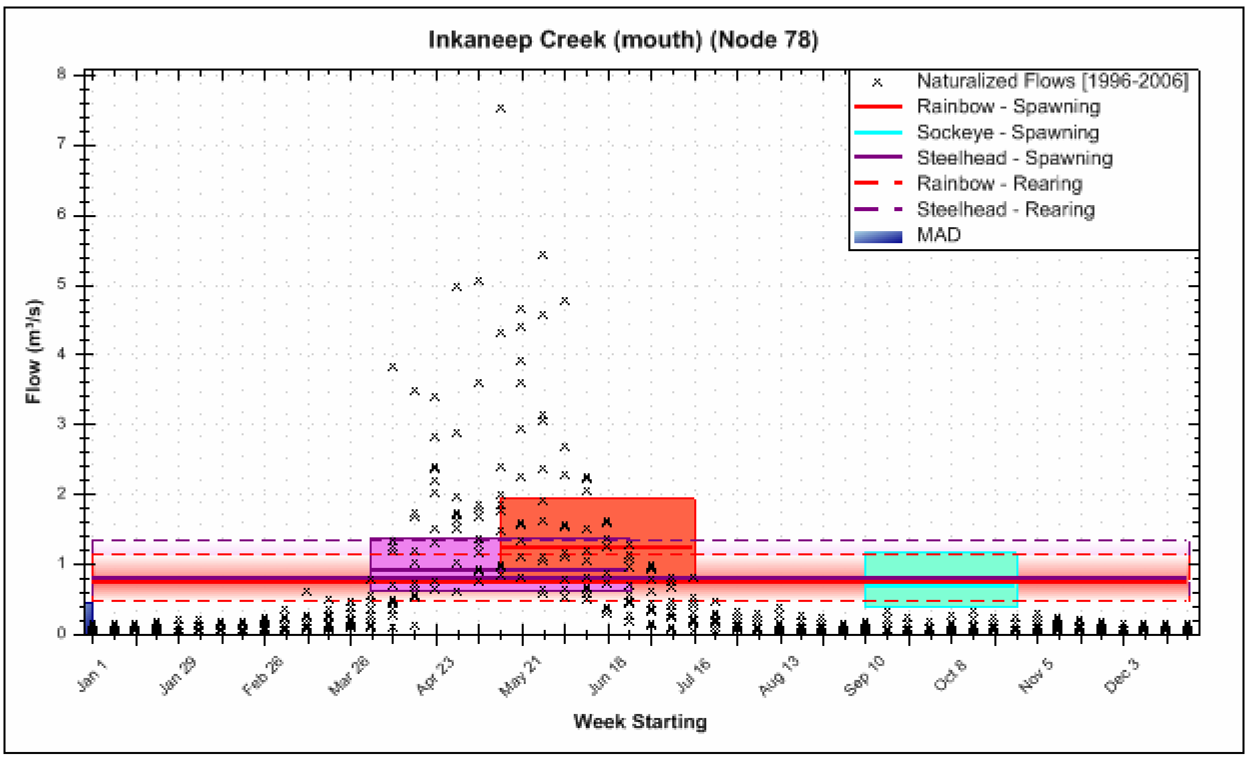


Figure B.36. Inkaneep Creek (node 78) BCIFN thresholds (minimum risk), BCIFN-derived watershed conservation flow thresholds (required only periodically), and lower 25th percentile reference line on naturalized flows (top); Hatfield and Bruce (2000) based meta-analysis of PHABIM optima for salmonid/rearing (mean and ±50% Prediction Intervals) and weekly naturalized flows (bottom).

Appendix C. Exceedance probability matrices for weekly minimum flow thresholds, conservation flow thresholds, and optimal spawning and rearing flows for salmonid species present at Okanagan Basin tributary stream nodes

Table C.1. BCIFN minimum risk flow threshold and BCIFN-derived conservation flow threshold exceedance analysis, compared to nodes with regulated historical flows. An upward pointing green arrow indicates that the probability of exceeding the flow threshold for the period of interest has increased with regulated flows, whereas a red arrow pointing down indicates the probability of exceeding the flow threshold has decreased.

Node		BCIFN Minimum Flow Threshold									Conservation Flow			
ID	Name	Freshet			Late Summer			Mid-winter			Freshet			ID
1	Vernon Creek at outlet of Kalamalka Lake	72	49	▼	36	13	▼	12	32	▲	57	37	▼	1
3	Deep Creek (mouth)	53			13			31			53			3
5	Irish Creek (mouth)	51			4			9			36			5
8	Equesis Creek (mouth)	55			9			10			38			8
10	Nashwhito Creek (mouth)	56			9			10			39			10
12	Vernon Creek (mouth); includes Zone A &	73	65	▼	29	20	▼	12	14	▲	62	53	▼	12
14	Whiteman Creek (mouth)	59			8			9			40			14
16	Shorts Creek (mouth)	59	52	▼	8	15	▲	9	0	▼	40	43	▲	16
18	Lambly Creek (mouth)	59			8			9			40			18
20	Kelowna (Mill) Creek (mouth)	51	35	▼	13	21	▲	13	2	▼	39	28	▼	20
22	Mission Creek (mouth)	68	51	▼	12	9	▼	11	4	▼	66	46	▼	22
24	Bellevue Creek (mouth)	67			11			6			40			24
25	Residual area E-5	67			11			5			40			25
26	McDougall Creek (mouth)	45			10			0			28			26
27	Residual area W-8	73			18			14			64			27
28	Powers Creek (mouth)	60	49	▼	9	23	▲	8	5	▼	40	41	▲	28
30	Trepanier Creek (mouth)	61	60	▼	10	3	▼	9	0	▼	44	41	▼	30
32	Peachland Creek (mouth)	69	45	▼	12	14	▲	11	14	▲	37	24	▼	32
34	Chute Creek (mouth)	67			11			5			40			34
36	Eneas Creek (mouth)	58			10			6			40			36
37	Residual area W-12	73			29			14			64			37
38	Robinson Creek (mouth)	66			7			0			38			38
40	Naramata Creek (mouth)	67			10			5			40			40
42	Trout Creek (mouth)	73	62	▼	8	14	▲	11	2	▼	40	50	▲	42
44	Turnbull Creek	67			7			1			38			44
46	Penticton Creek (mouth)	67			10			6			40			46
51	Shingle Creek (mouth)	58			10			10			42			51
52	Ellis Creek (mouth)	69			11			9			43			52
54	Residual area E-11	70			12			9			44			54
55	Marron River	62			10			8			33			55
60	Shuttleworth Creek (mouth)	70			11			9			44			60
66	Vaseux Creek (mouth)	72			12			9			48			66
69	Park Rill (mouth)	62			10			8			32			69
71	Wolfcub Creek (mouth)	66			10			9			44			71
73	Testalinden Creek (mouth)	60			8			6			31			73
78	Inkaneep Creek (mouth)	68			12			9			48			78

Fish Meta-Analysis Flow Exceedance Probability Matrices

For the fish meta-analysis tables below, an upward pointing arrow indicates that the probability of exceeding the flow threshold for the period of interest has increased with regulated flows, whereas a grey cell with no arrow indicates the probability of exceeding the flow threshold has decreased.

Table C.2. Rainbow spawning meta-analysis with terciles, P() = 50/75%, compared to selected nodes' historical regulated flows

Node		Rainbow Spawning												
		P() red/yellow/green using terciles				P() < 25% P() < 75% P() ≥ 75%				P() < 25% P() < 50% P() ≥ 50%				
ID	Name	Mean Optimal		Lower 50% PI		Mean Optimal		Lower 50% PI		Mean Optimal		Lower 50% PI		ID
1	Vernon Creek at outlet of Kalamalka Lake	58	35	79	44	58	35	79	44	58	35	79	44	1
3	Deep Creek (mouth)	12		33		12		33		12		33		3
5	Irish Creek (mouth)													5
8	Equesis Creek (mouth)	38		49		38		49		38		49		8
10	Nashwhito Creek (mouth)	26		45		26		45		26		45		10
12	Vernon Creek (mouth); includes Zone A & B	62	53	84	69	62	53	84	69	62	53	84	69	12
14	Whiteman Creek (mouth)	45		57		45		57		45		57		14
16	Shorts Creek (mouth)	48	43	62	55	48	43	62	55	48	43	62	55	16
18	Lambly Creek (mouth)	49		63		49		63		49		63		18
20	Kelowna (Mill) Creek (mouth)	22	17	41	28	22	17	41	28	22	17	41	28	20
22	Mission Creek (mouth)	89	78	96	85	89	78	96	85	89	78	96	85	22
24	Bellevue Creek (mouth)	43		60		43		60		43		60		24
25	Residual area E-5													25
26	McDougall Creek (mouth)	9		15		9		15		9		15		26
27	Residual area W-8													27
28	Powers Creek (mouth)	44	33	58	45	44	33	58	45	44	33	58	45	28
30	Trepanier Creek (mouth)	51	44	72	55	51	44	72	55	51	44	72	55	30
32	Peachland Creek (mouth)	27	20	45	29	27	20	45	29	27	20	45	29	32
34	Chute Creek (mouth)	40		59		40		59		40		59		34
36	Eneas Creek (mouth)	11		17		11		17		11		17		36
37	Residual area W-12	0		0		0		0		0		0		37
38	Robinson Creek (mouth)	5		17		5		17		5		17		38
40	Naramata Creek (mouth)	28		48		28		48		28		48		40
42	Trout Creek (mouth)	70	60	85	68	70	60	85	68	70	60	85	68	42
44	Turnbull Creek													44
46	Penticton Creek (mouth)	49		66		49		66		49		66		46
51	Shingle Creek (mouth)	55		76		55		76		55		76		51
52	Ellis Creek (mouth)	52		66		52		66		52		66		52
54	Residual area E-11	31		50		31		50		31		50		54
55	Marron River	6		13		6		13		6		13		55
60	Shuttleworth Creek (mouth)	40		58		40		58		40		58		60
66	Vaseux Creek (mouth)	62		73		62		73		62		73		66
69	Park Rill (mouth)													69
71	Wolfcub Creek (mouth)	13		23		13		23		13		23		71
73	Testalinden Creek (mouth)													73
78	Inkaneep Creek (mouth)	35		57		35		57		35		57		78

Table C.3. Rainbow rearing across 4 periods of interest, where red/yellow/green is split based upon terciles, with selected nodes' historical regulated flows

Node		Rainbow Rearing																				
		P() red/yellow/green split using terciles																				
		All Year				Freshet				Late Summer						Mid-winter						
ID	Name	Mean	Optimal	Lower 50% PI		Mean	Optimal	Lower 50% PI		Mean	Optimal		Lower 50% PI			Mean	Optimal		Lower 50% PI			ID
1	Vernon Creek at outlet of Kalamalka Lake	29	23	40	32	75	53	85	60	26	13		50	17		6	15	▲	9.1	27	▲	1
3	Deep Creek (mouth)	33		56		58		82		4			25			31			64			3
5	Irish Creek (mouth)																					5
8	Equesis Creek (mouth)	18		23		74		87		0			0			0			0			8
10	Nashwhito Creek (mouth)	16		19		71		77		0			0			0			0			10
12	Vernon Creek (mouth); includes Zone A &	38	30	59	40	82	74	99	78	24	18		60	25		20	20		35	32		12
14	Whiteman Creek (mouth)	19		25		80		93		0			0			0			0			14
16	Shorts Creek (mouth)	21	16	27	20	86	81	93	88	0	1.5	▲	0	4.1	▲	0	0		2	0		16
18	Lambly Creek (mouth)	21		27		88		93		0			0			0			4			18
20	Kelowna (Mill) Creek (mouth)	20	13	31	21	65	44	85	57	2	2.5	▲	7.1	11	▲	2	0.8		17	2.3		20
22	Mission Creek (mouth)	38	33	49	43	100	96	100	98	16	13		29	30	▲	5	1.1		11	3.2		22
24	Bellevue Creek (mouth)	17		20		83		93		0			0			0			0			24
25	Residual area E-5																					25
26	McDougall Creek (mouth)	7		11		31		43		0			0			0			0			26
27	Residual area W-8																					27
28	Powers Creek (mouth)	19	15	24	20	81	68	97	77	0	1.1	▲	0	3.3	▲	0	0		0	0.9	▲	28
30	Trepanier Creek (mouth)	21	16	25	19	93	76	99	84	0	0		0.6	0.5		0	0		0	0		30
32	Peachland Creek (mouth)	14	9.7	20	17	63	42	78	53	0	0		4.5	2		0	0		0	3.4	▲	32
34	Chute Creek (mouth)	17		20		83		92		0			0			0			0			34
36	Eneas Creek (mouth)	6		10		31		48		0			0			0			0			36
37	Residual area W-12	0		0		0		0		0			0			0			0			37
38	Robinson Creek (mouth)	4		6.1		23		33		0			0			0			0			38
40	Naramata Creek (mouth)	13		18		69		88		0			0			0			0			40
42	Trout Creek (mouth)	24	19	29	23	98	78	100	84	0	5.6	▲	2.6	10	▲	0	0		0	0		42
44	Turnbull Creek																					44
46	Penticton Creek (mouth)	19		22		91		95		0			0			0			0			46
51	Shingle Creek (mouth)	17		23		83		97		0			1.3			0			0			51
52	Ellis Creek (mouth)	20		23		92		95		0			0.6			0			0			52
54	Residual area E-11	16		22		72		92		0			0			0			0			54
55	Marron River	5		8.7		21		37		0			0			0			0			55
60	Shuttleworth Creek (mouth)	18		22		84		92		0			0			0			0			60
66	Vaseux Creek (mouth)	23		27		94		99		2			4.5			0			0			66
69	Park Rill (mouth)																					69
71	Wolfcub Creek (mouth)	8		14		39		64		0			0			0			0			71
73	Testalinden Creek (mouth)																					73
78	Inkaneep Creek (mouth)	19		24		80		57		0			0			0			0			78

Table C.4. Rainbow rearing across 4 periods of interest, where red/yellow/green is split based upon P() = 25%/75%, with selected nodes' historical regulated flows

Node		Rainbow Rearing																				
		P() < 25%						P() < 75%							P() ≥ 75%							
		All Year				Freshet				Late Summer						Mid-winter						
ID	Name	Mean Optimal		Lower 50% PI		Mean Optimal		Lower 50% PI		Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			ID
1	Vernon Creek at outlet of Kalamalka Lake	29	*23*	40	*32*	75	*53*	85	*60*	26	*13*		50	*17*		6	*15*	▲	9.1	*27*	▲	1
3	Deep Creek (mouth)	33		56		58		82		4			25			31			64			3
5	Irish Creek (mouth)																					5
8	Equesis Creek (mouth)	18		23		74		87		0			0			0			0			8
10	Nashwhito Creek (mouth)	16		19		71		77		0			0			0			0			10
12	Vernon Creek (mouth); includes Zone A &	38	*30*	59	*40*	82	*74*	99	*78*	24	*18*		60	*25*		20	*20*		35	*32*		12
14	Whiteman Creek (mouth)	19		25		80		93		0			0			0			0			14
16	Shorts Creek (mouth)	21	*16*	27	*20*	86	*81*	93	*88*	0	*1.5*	▲	0	*4.1*	▲	0	*0*		2	*0*		16
18	Lambly Creek (mouth)	21		27		88		93		0			0			0			4			18
20	Kelowna (Mill) Creek (mouth)	20	*13*	31	*21*	65	*44*	85	*57*	2	*2.5*	▲	7.1	*11*	▲	2	*0.8*		17	*2.3*		20
22	Mission Creek (mouth)	38	*33*	49	*43*	100	*96*	100	*98*	16	*13*		29	*30*	▲	5	*1.1*		11	*3.2*		22
24	Bellevue Creek (mouth)	17		20		83		93		0			0			0			0			24
25	Residual area E-5																					25
26	McDougall Creek (mouth)	7		11		31		43		0			0			0			0			26
27	Residual area W-8																					27
28	Powers Creek (mouth)	19	*15*	24	*20*	81	*68*	97	*77*	0	*1.1*	▲	0	*3.3*	▲	0	*0*		0	*0.9*	▲	28
30	Trepanier Creek (mouth)	21	*16*	25	*19*	93	*76*	99	*84*	0	*0*		0.6	*0.5*		0	*0*		0	*0*		30
32	Peachland Creek (mouth)	14	*9.7*	20	*17*	63	*42*	78	*53*	0	*0*		4.5	*2*		0	*0*		0	*3.4*	▲	32
34	Chute Creek (mouth)	17		20		83		92		0			0			0			0			34
36	Eneas Creek (mouth)	6		10		31		48		0			0			0			0			36
37	Residual area W-12	0		0		0		0		0			0			0			0			37
38	Robinson Creek (mouth)	4		6.1		23		33		0			0			0			0			38
40	Naramata Creek (mouth)	13		18		69		88		0			0			0			0			40
42	Trout Creek (mouth)	24	*19*	29	*23*	98	*78*	100	*84*	0	*5.6*	▲	2.6	*10*	▲	0	*0*		0	*0*		42
44	Turnbull Creek																					44
46	Penticton Creek (mouth)	19		22		91		95		0			0			0			0			46
51	Shingle Creek (mouth)	17		23		83		97		0			1.3			0			0			51
52	Ellis Creek (mouth)	20		23		92		95		0			0.6			0			0			52
54	Residual area E-11	16		22		72		92		0			0			0			0			54
55	Marron River	5		8.7		21		37		0			0			0			0			55
60	Shuttleworth Creek (mouth)	18		22		84		92		0			0			0			0			60
66	Vaseux Creek (mouth)	23		27		94		99		2			4.5			0			0			66
69	Park Rill (mouth)																					69
71	Wolfcub Creek (mouth)	8		14		39		64		0			0			0			0			71
73	Testalinden Creek (mouth)																					73
78	Inkaneep Creek (mouth)	19		24		80		57		0			0			0			0			78

Table C.5. Rainbow rearing across 4 periods of interest, where red/yellow/green is split based upon P() = 25%/50%, with selected nodes' historical regulated flows

Rainbow Rearing

P() < 25% | P() < 50% | P() ≥ 50%

Node		All Year				Freshet				Late Summer						Mid-winter						
ID	Name	Mean	Optimal	Lower	50% PI	Mean	Optimal	Lower	50% PI	Mean	Optimal		Lower	50% PI		Mean	Optimal		Lower	50% PI		ID
1	Vernon Creek at outlet of Kalamalka Lake	29	*23*	40	*32*	75	53	85	*60*	26	*13*		50	*17*		6	*15*	▲	9.1	*27*	▲	1
3	Deep Creek (mouth)	33		56		58		82		4			25			31			64			3
5	Irish Creek (mouth)																					5
8	Equesis Creek (mouth)	18		23		74		87		0			0			0			0			8
10	Nashwhito Creek (mouth)	16		19		71		77		0			0			0			0			10
12	Vernon Creek (mouth); includes Zone A &	38	*30*	59	*40*	82	*74*	99	*78*	24	*18*		60	*25*		20	*20*		35	*32*		12
14	Whiteman Creek (mouth)	19		25		80		93		0			0			0			0			14
16	Shorts Creek (mouth)	21	*16*	27	*20*	86	*81*	93	*88*	0	*1.5*	▲	0	*4.1*	▲	0	*0*		2	*0*		16
18	Lambly Creek (mouth)	21		27		88		93		0			0			0			4			18
20	Kelowna (Mill) Creek (mouth)	20	*13*	31	*21*	65	*44*	85	*57*	2	*2.5*	▲	7.1	*11*	▲	2	*0.8*		17	*2.3*		20
22	Mission Creek (mouth)	38	33	49	*43*	100	*96*	100	*98*	16	*13*		29	*30*	▲	5	*1.1*		11	*3.2*		22
24	Bellevue Creek (mouth)	17		20		83		93		0			0			0			0			24
25	Residual area E-5																					25
26	McDougall Creek (mouth)	7		11		31		43		0			0			0			0			26
27	Residual area W-8																					27
28	Powers Creek (mouth)	19	*15*	24	*20*	81	68	97	*77*	0	*1.1*	▲	0	*3.3*	▲	0	*0*		0	*0.9*	▲	28
30	Trepanier Creek (mouth)	21	*16*	25	*19*	93	*76*	99	*84*	0	*0*		0.6	*0.5*		0	*0*		0	*0*		30
32	Peachland Creek (mouth)	14	*9.7*	20	*17*	63	*42*	78	53	0	*0*		4.5	*2*		0	*0*		0	*3.4*	▲	32
34	Chute Creek (mouth)	17		20		83		92		0			0			0			0			34
36	Eneas Creek (mouth)	6		10		31		48		0			0			0			0			36
37	Residual area W-12	0		0		0		0		0			0			0			0			37
38	Robinson Creek (mouth)	4		6.1		23		33		0			0			0			0			38
40	Naramata Creek (mouth)	13		18		69		88		0			0			0			0			40
42	Trout Creek (mouth)	24	*19*	29	*23*	98	*78*	100	*84*	0	*5.6*	▲	2.6	*10*	▲	0	*0*		0	*0*		42
44	Turnbull Creek																					44
46	Penticton Creek (mouth)	19		22		91		95		0			0			0			0			46
51	Shingle Creek (mouth)	17		23		83		97		0			1.3			0			0			51
52	Ellis Creek (mouth)	20		23		92		95		0			0.6			0			0			52
54	Residual area E-11	16		22		72		92		0			0			0			0			54
55	Marron River	5		8.7		21		37		0			0			0			0			55
60	Shuttleworth Creek (mouth)	18		22		84		92		0			0			0			0			60
66	Vaseux Creek (mouth)	23		27		94		99		2			4.5			0			0			66
69	Park Rill (mouth)																					69
71	Wolfcub Creek (mouth)	8		14		39		64		0			0			0			0			71
73	Testalinden Creek (mouth)																					73
78	Inkaneep Creek (mouth)	19		24		80		57		0			0			0			0			78

Table C.6. Kokanee spawning meta-analysis with terciles, P() = 50%/75%, compared against selected nodes' historical regulated flows

Node		Kokanee Spawning																		
		P() red/yellow/green using terciles						P() < 25% P() < 75% P() ≥ 75%						P() < 25% P() < 50% P() ≥ 50%						
ID	Name	Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			ID
1	Vernon Creek at outlet of Kalamalka Lake	26	11		66	18		26	11		66	18		26	11		66	18		1
3	Deep Creek (mouth)	0			16			0			16			0			16			3
5	Irish Creek (mouth)																			5
8	Equesis Creek (mouth)	0			0			0			0			0			0			8
10	Nashwhito Creek (mouth)	0			0			0			0			0			0			10
12	Vernon Creek (mouth); includes Zone A & B	21	16		70	29		21	16		70	29		21	16		70	29		12
14	Whiteman Creek (mouth)	0			0			0			0			0			0			14
16	Shorts Creek (mouth)	0	1	▲	0	5	▲	0	1	▲	0	5	▲	0	1	▲	0	5	▲	16
18	Lambly Creek (mouth)	0			0			0			0			0			0			18
20	Kelowna (Mill) Creek (mouth)	0	5	▲	14	28	▲	0	5	▲	14	28	▲	0	5	▲	14	28	▲	20
22	Mission Creek (mouth)	14	14		29	32	▲	14	14		29	32	▲	14	14		29	32	▲	22
24	Bellevue Creek (mouth)																			24
25	Residual area E-5																			25
26	McDougall Creek (mouth)																			26
27	Residual area W-8	0			0			0			0			0			0			27
28	Powers Creek (mouth)	0	1	▲	0	2	▲	0	1	▲	0	2	▲	0	1	▲	0	2	▲	28
30	Trepanier Creek (mouth)	0	0		3	1		0	0		3	1		0	0		3	1		30
32	Peachland Creek (mouth)	0	0		9	13	▲	0	0		9	13	▲	0	0		9	13	▲	32
34	Chute Creek (mouth)	0			0			0			0			0			0			34
36	Eneas Creek (mouth)	0			0			0			0			0			0			36
37	Residual area W-12	0			0			0			0			0			0			37
38	Robinson Creek (mouth)	0			0			0			0			0			0			38
40	Naramata Creek (mouth)	0			0			0			0			0			0			40
42	Trout Creek (mouth)	0	4	▲	0	9	▲	0	4	▲	0	9	▲	0	4	▲	0	9	▲	42
44	Turnbull Creek	0			0			0			0			0			0			44
46	Penticton Creek (mouth)	0			0			0			0			0			0			46
51	Shingle Creek (mouth)	0			0			0			0			0			0			51
52	Ellis Creek (mouth)	0			1			0			1			0			1			52
54	Residual area E-11	0			1			0			1			0			1			54
55	Marron River																			55
60	Shuttleworth Creek (mouth)																			60
66	Vaseux Creek (mouth)																			66
69	Park Rill (mouth)																			69
71	Wolfcub Creek (mouth)																			71
73	Testalinden Creek (mouth)																			73
78	Inkaneep Creek (mouth)																			78

Table C.7. Sockeye spawning and steelhead spawning/rearing meta-analysis where red/yellow/green split based upon P() = 25% and 50%/75%

Node ID	Node Name	Sockeye Spawning (P() < 25%, P() < 75%, P() ≥ 75%) Mean Optimal	Sockeye Spawning (P() < 25%, P() < 75%, P() ≥ 75%) Lower 50% PI	Sockeye Spawning (P() < 25%, P() < 50%, P() ≥ 50%) Mean Optimal	Sockeye Spawning (P() < 25%, P() < 50%, P() ≥ 50%) Lower 50% PI	Steelhead Spawning (P() < 25%, P() < 75%, P() ≥ 75%) Mean Optimal	Steelhead Spawning (P() < 25%, P() < 75%, P() ≥ 75%) Lower 50% PI	Steelhead Spawning (P() < 25%, P() < 50%, P() ≥ 50%) Mean Optimal	Steelhead Spawning (P() < 25%, P() < 50%, P() ≥ 50%) Lower 50% PI
66	Vaseux Creek (mouth)	2	8	2	8	81	87	81	87
78	Inkaneep Creek (mouth)	0	0	0	0	62	78	62	78

Steelhead Rearing, P() < 25%, P() < 75%, P() ≥ 75%:

Node ID	Node Name	All Year Mean Optimal	All Year Lower 50% PI	Freshet Mean Optimal	Freshet Lower 50% PI	Late Summer Mean Optimal	Late Summer Lower 50% PI	Mid-winter Mean Optimal	Mid-winter Lower 50% PI
66	Vaseux Creek (mouth)	23	29	94	99	2	5.2	0	0
78	Inkaneep Creek (mouth)	18	24	77	94	0	0	0	0

Steelhead Rearing, P() < 25%, P() < 50%, P() ≥ 50%:

Node ID	Node Name	All Year Mean Optimal	All Year Lower 50% PI	Freshet Mean Optimal	Freshet Lower 50% PI	Late Summer Mean Optimal	Late Summer Lower 50% PI	Mid-winter Mean Optimal	Mid-winter Lower 50% PI	ID
66	Vaseux Creek (mouth)	23	29	94	99	2	5.2	0	0	66
78	Inkaneep Creek (mouth)	18	24	77	94	0	0	0	0	78

Table C.8. Chinook spawning and rearing meta-analysis with P() = 50%/75%, compared against selected nodes' historical regulated flows

Chinook Spawning:

Node ID	Node Name	P() < 25%, P() < 75%, P() ≥ 75% Mean Optimal			Lower 50% PI			P() < 25%, P() < 50%, P() ≥ 50% Mean Optimal			Lower 50% PI		
22	Mission Creek (mouth)	22	*10*		40	*37*		22	*10*		40	*37*	
28	Powers Creek (mouth)	0	*0*		2	*0*		0	*0*		2	*0*	
30	Trepanier Creek (mouth)	0	*0*		0	*0*		0	*0*		0	*0*	
42	Trout Creek (mouth)	0	*7*	▲	0	*14*	▲	0	*7*	▲	0	*14*	▲

Chinook Rearing:

Node ID	Node Name	P() < 25%, P() < 75%, P() ≥ 75% Mean Optimal			Lower 50% PI			P() < 25%, P() < 50%, P() ≥ 50% Mean Optimal			Lower 50% PI			ID
22	Mission Creek (mouth)	38	*38*		65	*76*	▲	38	*38*		65	*76*	▲	22
28	Powers Creek (mouth)	25	*41*	▲	62	*86*	▲	25	*41*	▲	62	*86*	▲	28
30	Trepanier Creek (mouth)	35	*15*		65	*32*		35	*15*		65	*32*		30
42	Trout Creek (mouth)	38	*17*		85	*30*		38	*17*		85	*30*		42

Table C.9. Coho spawning meta-analysis with P() = 50%/75%, compared against selected nodes' historical regulated flows

		Coho Spawning												
		P() < 25%			P() < 75%		P() ≥ 75%	P() < 25%			P() < 50%		P() ≥ 50%	
	Node													
	ReportID	55	235		115	295		75	235		135	295		
	ThresholdBadOk	25.0	25.0		25.0	25.0		25.0	25.0		25.0	25.0		
	ThresholdOkGood	75.0	75.0		75.0	75.0		50.0	50.0		50.0	50.0		
ID	Name	Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			ID
22	Mission Creek (mouth)	16	7		38	30		16	7		38	30		22
28	Powers Creek (mouth)	0	0		1	0		0	0		0	0		28
30	Trepanier Creek (mouth)	0	0		0	0		0	0		0	0		30
42	Trout Creek (mouth)	0	6	▲	0	10	▲	0	6	▲	0	10	▲	42

Table C.10. Coho rearing across 4 periods of interest, where red/yellow/green is split based upon P() = 25%/75%, with selected nodes' historical regulated flows

		Coho Rearing																								
		P() < 25%								P() < 75%								P() ≥ 75%								
	Node	All Year						Freshet						Late Summer						Mid-winter						
ID	Name	Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			ID
22	Mission Creek (mouth)	48	42		67	67		100	98		100	100		27	29	▲	50	64	▲	10	3		38	24		22
28	Powers Creek (mouth)	26	21		39	34		97	81		100	89		0	3	▲	10	27	▲	0	1	▲	8	4		28
30	Trepanier Creek (mouth)	26	19		42	28		99	84		100	96		2	1		23	6		0	0		6	0		30
42	Trout Creek (mouth)	29	24		47	36		100	84		100	90		3	11	▲	29	24		0	0		20	3		42

Table C.11. Coho rearing across 4 periods of interest, where red/yellow/green is split based upon P() = 25%/50%, with selected nodes' historical regulated flows

		Coho Rearing																								
		P() < 25%								P() < 50%								P() ≥ 50%								
	Node	All Year						Freshet						Late Summer						Mid-winter						
ID	Name	Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			Mean Optimal			Lower 50% PI			ID
22	Mission Creek (mouth)	48	42		67	67		100	98		100	100		27	29	▲	50	64	▲	10	3		38	24		22
28	Powers Creek (mouth)	26	21		39	34		97	81		100	89		0	3	▲	10	27	▲	0	1	▲	8	4		28
30	Trepanier Creek (mouth)	26	19		42	28		99	84		100	96		2	1		23	6		0	0		6	0		30
42	Trout Creek (mouth)	29	24		47	36		100	84		100	90		3	11	▲	29	24		0	0		20	3		42

Appendix D. Hazard coded ("traffic light") maps of optimal fish flow threshold exceedance probabilities for Okanagan Basin tributary nodes

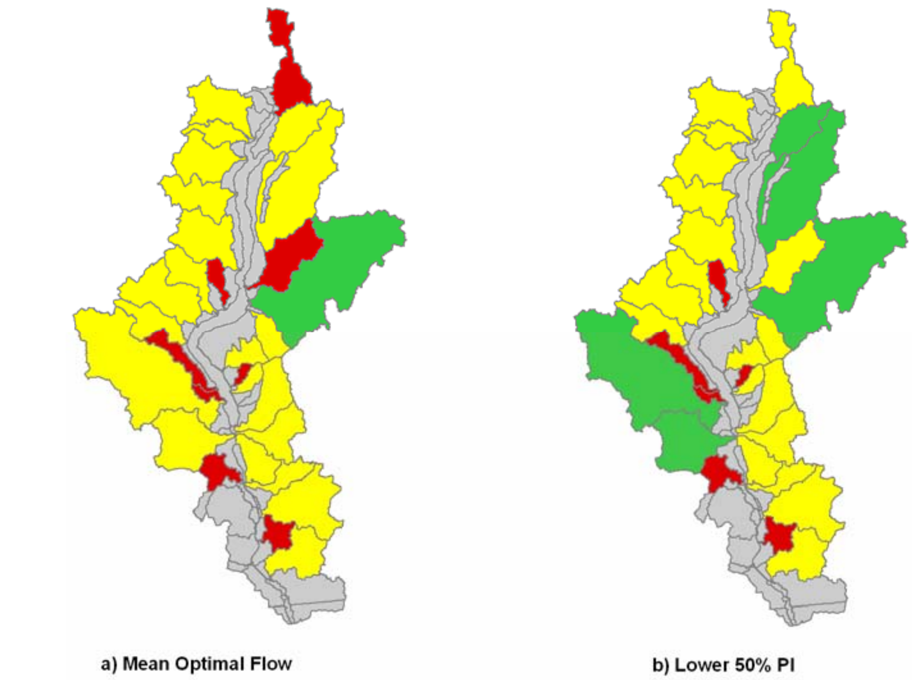


Figure D.1. Rainbow spawning meta-analysis map, where red/yellow/green split based upon P() = 25%/75%, comparing mean optimal flow to lower 50% PI

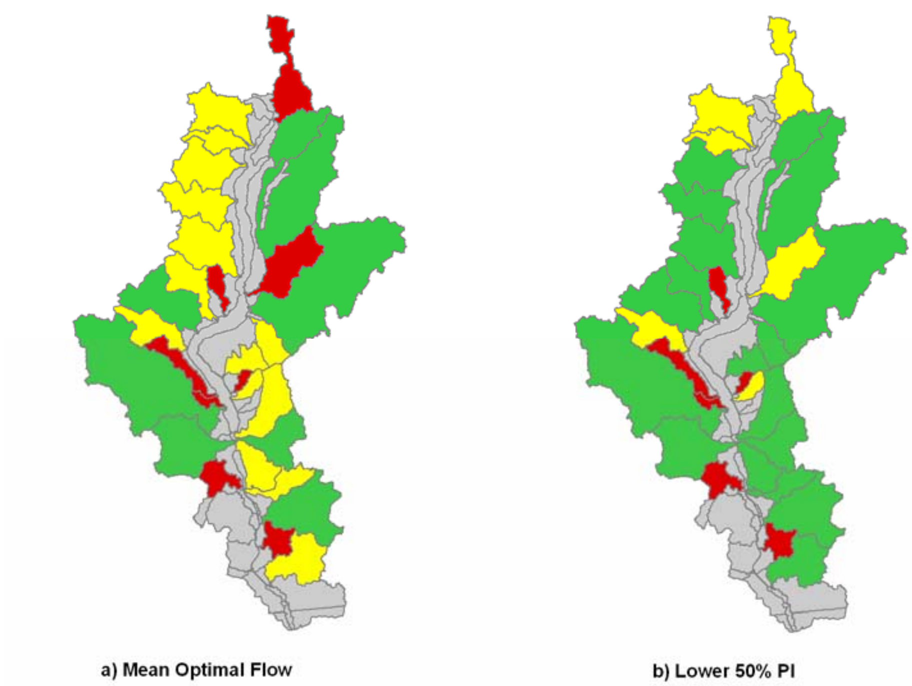


Figure D.2. Rainbow spawning meta-analysis map, where red/yellow/green split based upon P() = 25%/50%, comparing mean optimal flow to lower 50% PI

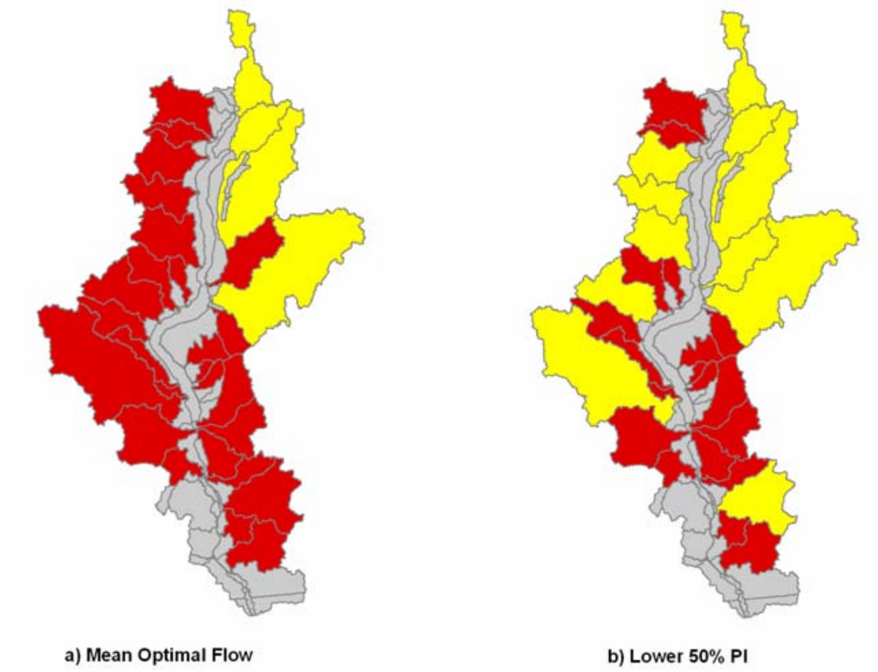


Figure D.3. Rainbow rearing meta-analysis map, where red/yellow/green split based upon P() = 25%/75%, comparing mean optimal flow to lower 50% PI

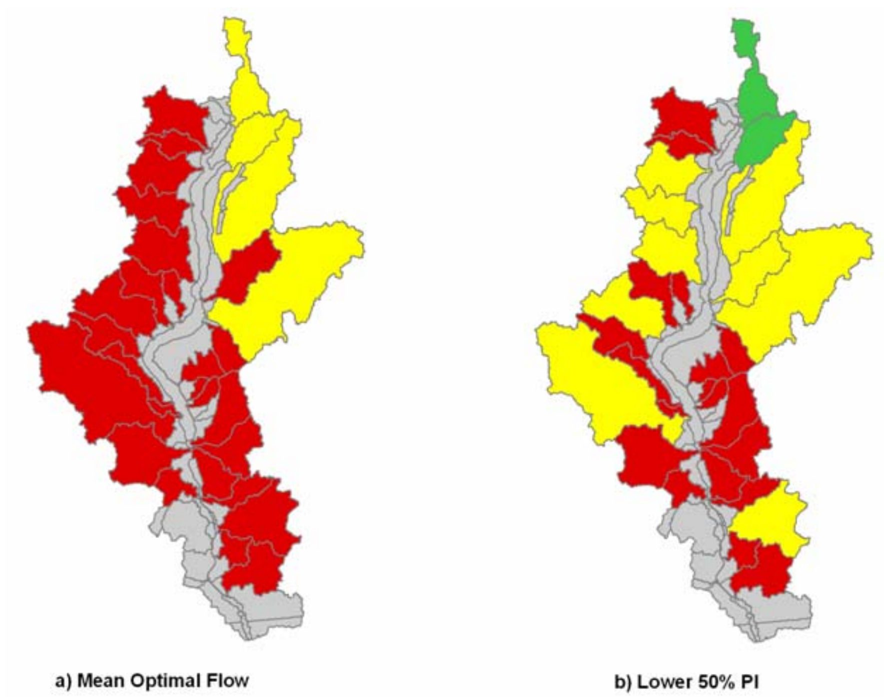


Figure D.4. Rainbow rearing meta-analysis map, where red/yellow/green split based upon P() = 25%/50%, comparing mean optimal flow to lower 50% PI

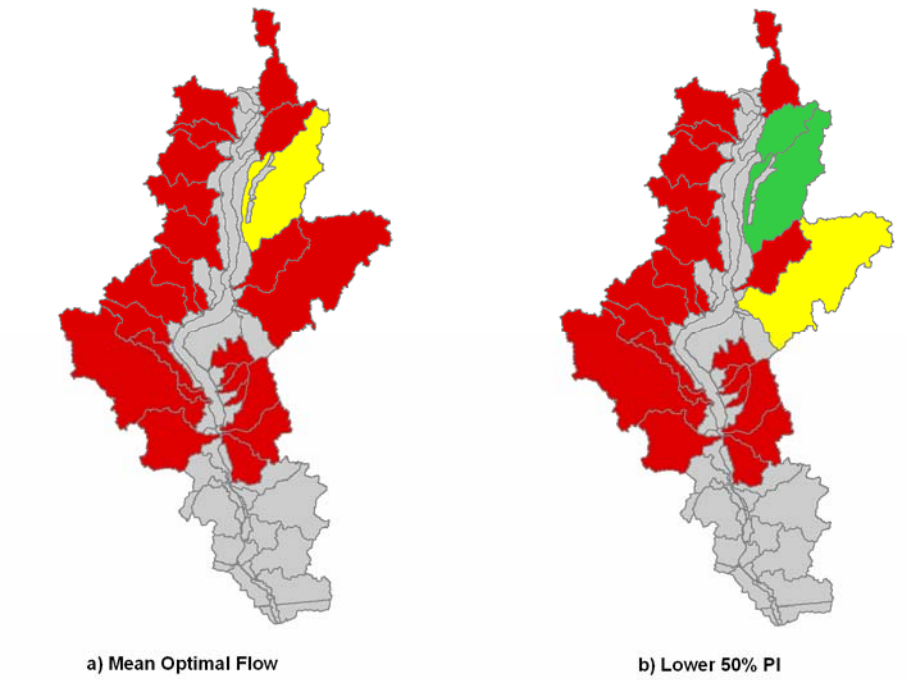


Figure D.5. Kokanee spawning meta-analysis map, where red/yellow/green split based upon P() = 25%/75%, comparing mean optimal flow to lower 50% PI

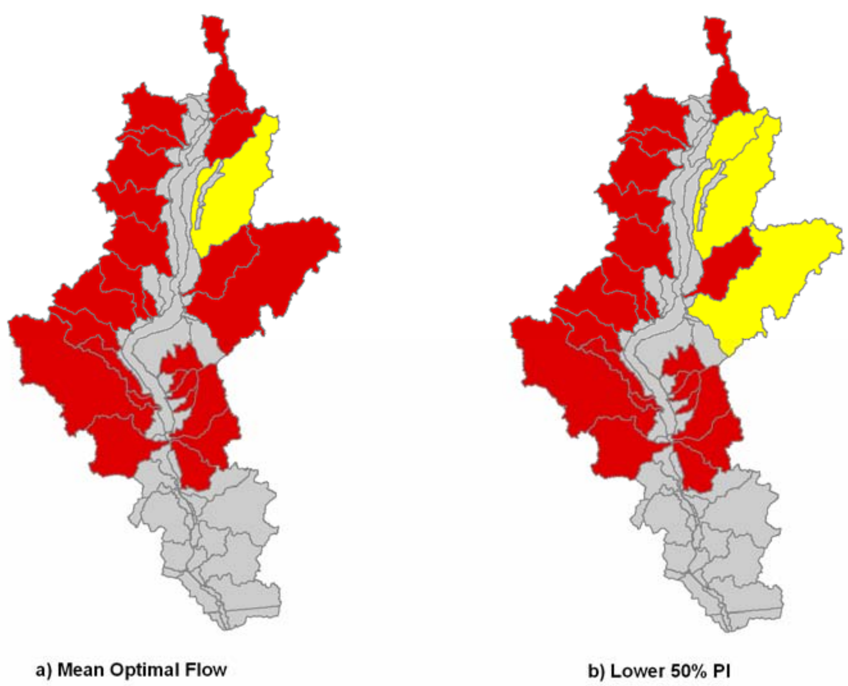


Figure D.6. Kokanee spawning meta-analysis map, where red/yellow/green split based upon P() = 25%/50%, comparing mean optimal flow to lower 50% PI.