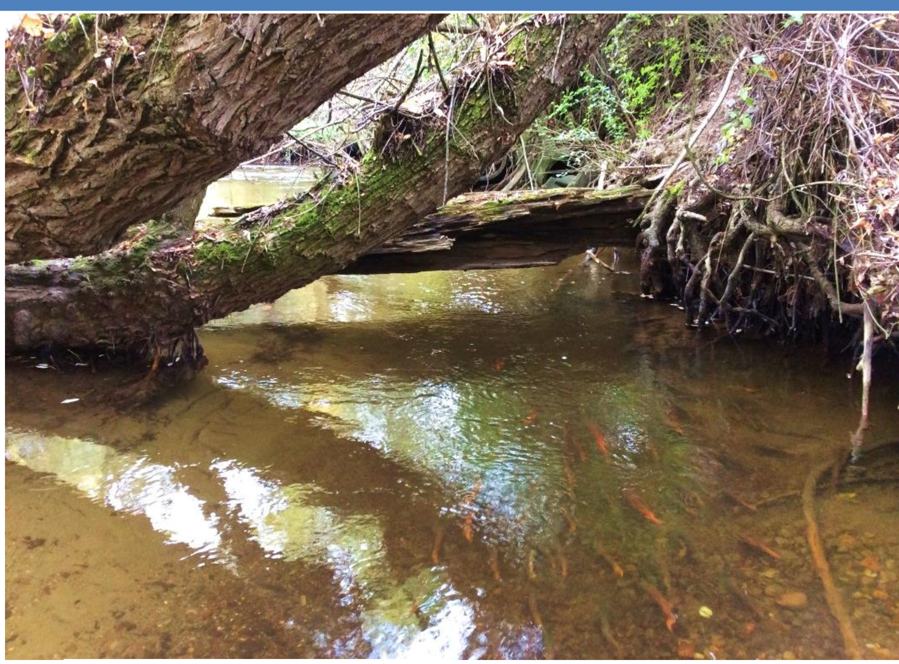
2020

Environmental Flow Needs Assessment in the Okanagan Basin



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- Rich McCleary, FLNRORD,
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EXECUTIVE SUMMARY

The need to develop Environmental Flow Needs (EFNs) for Okanagan streams was prioritized with the implementation of the British Columbia *Water Sustainability Act* in 2016. Subsequently, the Okanagan Basin Water Board (OBWB), Okanagan Nation Alliance (ONA) and B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) implemented an EFN-setting project for the Okanagan. Phase I consisted of a collaborative process that developed a robust methodology for EFN setting specific to Okanagan streams, and the acquisition of information needed to customize the methods for each stream. This report, representing Phase II of the Okanagan EFN project, describes the process of determining EFN regimes for 18 tributaries in the Okanagan Basin using the methods developed in Phase I.

Section 1.0 of this report provides a description of the project and study area, and also describes how streams were prioritized for EFN-development. The methodologies applied are presented in Section 2.0. EFNs were recommended for each stream using the desktop-based "Okanagan Tennant method"; additionally the field-based "Okanagan Weighted Usable Width (WUW) method" was used to further refine EFNs for ten of the 18 streams. In addition to the methods outlined in Phase I, this report evaluated the utility of an alternative model-based method called "System for Environmental Flow Analysis" (SEFA). Critical flows were also recommended for each stream using either desktop- or field-based methods depending on data availability.

The Okanagan Tennant method is a modification of the widely used Tennant method, which sets EFNs as a proportion of the Long-term Mean Annual Discharge (LTMAD) required to sustain a given species and life stage (flow standard) in a specific time period (periodicity). Okanagan Tennant EFNs are the lower of the flow standard and the median naturalized flows to ensure that EFNs are realistic and attainable in the context of the natural hydrograph. The field-based Okanagan WUW method utilizes standard WUW approaches that integrate the effect of changes in flow on wetted width, depth, and velocity with habitat suitability indices to calculate the weighted quantity of habitat available for a given species and life stage of fish. The Okanagan WUW method focuses the assessment of flow-related habitat changes within the range of historical or expected flows between the critical flows at the lower and the median naturalized flows at the upper end. Okanagan WUW Analysis was found to be useful for EFN setting particularly in streams with unusual flow patterns or heavily modified channels. The method characterizes local variations in channel and flow conditions that influence fish habitat in greater depth than the Okanagan Tennant method.

Critical flows represent the streamflow below which catastrophic consequences to fish populations may occur. In the absence of field data, critical flows were recommended as a proportion of LTMAD. Where WUW data was available, critical riffle analysis was completed to recommend critical flows that maintain certain minimum depths or widths.

A summary of relevant background information as well as recommended EFNs and critical flows are provided for each stream in Sections 3.1 to 3.18. Further stream-specific data such as maps, descriptions of field sites, hydrometric and water temperature data, WUW curves, detailed weekly EFNs, and percentile flow data are located in Appendices B1-B18. EFNs varied widely between streams depending on stream size, local fish populations, channel and flow conditions. EFNs for spring-spawning species such as Rainbow and Steelhead were generally achievable in most streams due to naturally high flows during freshet that produce near optimum conditions. However, EFNs for most other species that rear or spawn

in the summer and fall season were constrained by naturally low flows. Most affected are stream-rearing juvenile fish such as Rainbow, Steelhead and Chinook, as well as early fall spawning species including spring Chinook and some Kokanee stocks. Spring Chinook in particular are extremely vulnerable to low flows due to their large body size, mid-summer migration timing and long holding period. Key spring Chinook tributaries in the southern Okanagan routinely experience very low flows or even dry streambed, likely totally preventing spawner access or success. Later fall spawning species such as Sockeye generally benefit from slightly increased flows following fall rain events, but EFNs are heavily constrained by naturally low flows nonetheless. All of those species and life stages would benefit from flows greater than the EFN which provide increased WUW.

Streamflow datasets required for the EFN analyses were developed for this project by Associated (2019). The EFN setting approach relies heavily on estimated naturalized streamflow data, which is inherently uncertain due to a scarcity of historic and current hydrologic data. Estimation of naturalized and residual (after water use and management) flows is complicated by a lack of accurate water use and diversion information. Most of the study streams have naturally low flows during summer and winter low flow periods. Water use during the summer has noticeable impacts on streamflows in many streams and is an obstacle to meeting EFNs, and in some cases, critical flows. If water storage and releases as well as water use were maximized under current licences, a large number of the study streams would dry up entirely for a large part of the summer. This over-allocation should be addressed in the future.

Section 4.0 contains a review of EFN setting methods and data sources; a summary of EFN and critical flow setting approaches, uncertainties, and recommendations for each stream; as well as a complete list and summary of EFNs and critical flows for all streams. Further, recommendations are made for EFN setting in the Okanagan and in general, and knowledge gaps are identified. The report concludes with an outline of next steps. Key recommendations are: a general call for increased hydrometric monitoring for improved naturalized flow estimation, monitoring of EFN implementation, and to develop a better understanding of flow regulation and water use impacts; field confirmation of several specific EFNs; analysis of existing stream temperature data to inform EFN setting; development of habitat suitability index curves for spring Chinook spawning in small streams; and development of EFNs for anadromous salmonids in Okanagan Lake tributaries with the recent establishment of fish passage.

OKANAGAN TRANSLATIONS

Okanagan Place Names and other translations (Okanagan-English Translation)	
akskʷəkʷant	Inkaneep Creek
akɬxʷminaʔ	Shingle Creek
nʔastqʷitkʷ	Naswhito Creek
nx̌ʷəntkʷitkʷ	Columbia River
nˤaylintən	McIntyre Dam area
kłusxənitkʷ	Okanagan Lake
q̓awsitkʷ	Okanagan River
t̓íwcən	Skaha Lake
snʕax̌əlqaxʷiyaʔ	Vaseux Creek
suwiẇs	Osoyoos Lake
sx̌ʷəx̌ʷnikʷ	Okanagan Falls
siwɬkʷ	Water
captikʷl	Collection of teachings about Syilx/Okanagan laws, customs, values, governance structures and principles that, together, define and inform Syilx/Okanagan rights and responsibilities to the land and culture. These stories provide instruction on how to relate to and live on the land.

Okanagan Species Names (Okanagan-English Translation)	
kəkni or kəkn̓i	Kokanee Salmon
kisúʔ	Coho Salmon
sk’lwist	Summer or fall Chinook Salmon
ntitiyx or ntytyix	Spring Chinook Salmon
qʷəyqʷəyʕaćaʔ	Steelhead Trout
sćwin	Sockeye Salmon
xʷuminaʔ	Rainbow Trout
miməlt	Whitefish

Translations provided by Richard Armstrong, Penticton Indian Band. Indigenous Peoples of the Okanagan are the exclusive owners of their cultural and intellectual properties.

ACRONYMS

Acronym	Description
ANOVA	Analysis of Variance
BMI	Benthic Macroinvertebrate
BCIFN	B.C. Instream Flow Methodology
CABIN	Canadian Aquatic Biomonitoring Network
CEFI	Canadian Ecological Flow Index
CCT	Colville Confederated Tribes
CH	Chinook Salmon
EFN	Environmental Flow Need
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
GVW	Greater Vernon Water
HSI	Habitat Suitability Index
KO	Kokanee Salmon
LTMAD	Long-term Mean Annual Discharge (naturalized)
MOE	Ministry of Environment
OBMEP	Okanagan Basin Monitoring and Evaluation Program (ONA & Colville Confederated Tribes)
OBWB	Okanagan Basin Water Board
ONA	Okanagan Nation Alliance
OWDM	Okanagan Water Demand Model
PTAGIS	Columbia Basin PIT (Passive Integrated Transponder) Tag Information System
Q	Discharge
RB	Rainbow Trout
SEFA	System for Environmental Flow Analysis
SK	Sockeye Salmon
ST	Steelhead Trout
TEK	Traditional Ecological Knowledge
VDS	Vertical Drop Structure
WSA	Water Sustainability Act
WSC	Water Survey of Canada
WFN	Westbank First Nation
WUW	Weighted Usable Width

DEFINITIONS

Term used	Definition for the purpose of this report
Bankfull discharge	Dominant channel forming flow. Stream discharge that would fill the main channel to an elevation equal to that of the active flood plain.
Bankfull width	Stream width during bankfull discharge.
Critical Flow	Defined in Section 1 of the Water Sustainability Act (WSA), the Critical Environmental Flow Threshold (Critical Flow) is "the volume of water flow below which significant or irreversible harm to the aquatic ecosystem of the stream is likely to occur".
Environmental Flow Needs (EFN)	Defined in Section 1 of the WSA as "In relation to a stream, means the volume and timing of water flow required for the proper functioning of the aquatic ecosystem of the stream"
EFN point-of-interest	The location where streamflows are estimated for establishing EFNs (i.e., the furthest downstream transect).
Flow sensitive	Streams prone to natural flows below 20% Long-term Mean Annual Discharge (LTMAD) are considered 'flow sensitive'.
Glide	Shallow sections with little to no surface turbulence, specifically with intermediate wetted width: mean depth ratios of 21-49.
Habitat Suitability Index (HSI)	HSIs Models weight locations relative to one another considering key criteria. Fisheries HSIs typically relate velocity and depth to spawning or rearing habitats of fish using preferences for different conditions.
Flow standard	The instream presumptive flow standard (flow standard) refers to the portion of LTMAD required to sustain a given species and life stage.
Left Bank	The bank of a stream to an observer's left when facing downstream.
Long-term Mean Annual Discharge (LTMAD)	The arithmetic mean of individual naturalized mean annual discharge values at a specific point on a stream over a multi-year period.
Maximum Licensed Flow	Streamflow assuming water withdrawals and storage management are maximized under existing water licences.
Naturalized Flow	The flow that would occur naturally in the absence of flow regulation including storage reservoirs and water withdrawals.
Percentile (Pn)	The value below which a given percentage (n) of observations occurs.
Percentile Flow	The flow represented by the nth percentile of a range of flows at a specific point on a stream.
Periodicity	Timing and duration of species and life stages present in a given creek.
Pool	Deep sections with low flow velocity compared to nearby riffles, specifically with wetted width: mean depth ratios <20.
Rapid Habitat Assessment	Instream survey of fluvial habitat types.
Rating Curve	Relationship of discharge versus stage at a given point on a stream. Developed by collecting frequent discharge measurements and water surface elevations.
Residual Flow	Streamflow assuming current water withdrawals and management (net streamflow)
Riffle	Shallow stream sections where the water approaching the riffle must rise upwards and converge with water near the surface, creating a turbulent surface: specifically with a wetted width: mean depth ratio of >50.
Right Bank	The bank of a stream to an observer's right when facing downstream.
Weighted Usable Width (WUW)	The estimated width of a stream that is suitable for a specific life stage or species. Calculated using depth and velocity measurements along designated transects in conjunction with HSI curves.
Wetted width	Actual measured stream width.

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1.0 INTRODUCTION

1.1 Background

Syilx/Okanagan communities have always recognized and nurtured a strong connection towards siwɬkʷ (water). The importance of water in *Syilx/Okanagan* communities and governance is related through *captikʷl* and the natural laws. *Syilx/Okanagan* governance systems have always sustainably and respectfully managed water (syilx water declaration www.syilx.org).

Implementation of the British Columbia *Water Sustainability Act* (WSA) on February 29, 2016 created the need to develop regulatory environmental flow needs (EFNs). The WSA defines EFNs as the "*the volume and timing of stream flow required for proper functioning of the aquatic ecosystem*". According to Section 15 of the WSA, water managers must consider EFNs in new non-domestic water licensing decisions for surface and groundwater if the aquifer is reasonably likely to be hydraulically connected to a stream. The WSA defines the critical environmental flow threshold ("critical flow") as "*the volume of stream flow below which significant or irreversible harm to the aquatic ecosystem is likely to occur*". Sections 86-88 of the WSA give the province the ability to restrict water withdrawals if streamflow drops below the EFN, or to completely stop withdrawals altogether if flows drop below the critical flow (WSA 2016). The concept of EFNs is not new; however, the consideration of EFNs in water management decisions has recently increased throughout North America, along with greater recognition of the importance of ecological, cultural, and social values of rivers, and an increased demand on water resources.

The Okanagan Valley is an important farming and fruit growing region. Water demand for irrigation and domestic purposes during the naturally dry summer climate competes with the streamflow needs of the aquatic ecosystem. Considerable efforts to define EFNs in the Okanagan have been ongoing since the 1970s. However, EFN development has been hampered by a lack of stream-specific available information to describe an appropriate EFN flow regime (Associated 2016). While various terms have been used to recommend "minimum flows" in Okanagan streams, no previous work has specifically recommended critical flows as defined by the WSA. Koshinsky (1972) first defined minimum flow requirements for Okanagan streams that contained suitable flow regimes to support a fishery, using substrate and stream channel morphology data. Shepherd & Ptolemy (1999) outlined the importance of developing an efficient method for setting EFNs in the Okanagan, based on the compilation of recommendations from previous studies conducted since the 1970s. In 2001, Northwest Hydraulic Consultants (NHC) defined EFNs for 21 tributaries of kłusxənitkʷ (Okanagan Lake) by using the B.C. modified Tennant Method. Their proposed values ranged from 20% of the long-term mean annual discharge (LTMAD) for winter (Oct-March) to 200% in May (NHC 2001). These targets are currently being used to set default EFNs in the Okanagan by provincial fisheries staff. ESSA and Solander (2009) defined instream flow needs (now called EFNs) for the Okanagan Basin Water Board (OBWB) supply and demand project using the B.C. Instream Flow Methodology (BCIFN), which is based on percentile flows. This method did not provide any comparison between flows and fish presence (periodicity) or habitat function, and routinely provided EFNs higher than median flows outside of the freshet period. The more detailed, field-based weighted usable width (WUW) method has previously been used in the Okanagan for water-use planning in Trout Creek (NHC 2005; Water Management Consultants 2005) and Mission Creek (Epp 2008, 2009, 2010; Water Management Consultants 2010).

Previously recommended EFNs have often been considerably higher than possible naturally, particularly in dry years. This project aims to derive science-based EFN flow regimes, and to study the relationship between flows and habitat function more closely. Defining robust and defensible EFNs within the Okanagan Basin is necessary to avoid water allocation conflicts with fish and aquatic ecosystems. The semi-arid climate and hydrology regime of the Okanagan Basin can stress local indigenous fish populations even with their unique coping strategies. High water demand for both agriculture and domestic consumption exacerbates the stress on aquatic species, in particular during the summer when water usage is high and natural streamflow is low. Pressure on water resources in the Okanagan will continue to increase due to a growing population, an increasingly variable flow regime, and a longer growing season due to climate change (Rae 2005).

Accordingly, OBWB, the Okanagan Nation Alliance (ONA), and the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) implemented an EFN-setting project for the Okanagan. The EFN Phase I report (Associated 2016) developed and recommended methods for determining the EFNs of Okanagan streams, and provided information for customized EFN-setting plans for 18 specific tributaries in the Okanagan Basin. The development of methods began in late 2015 by the consulting team from Associated Environmental Consultants (Associated), and was supplemented with input by technical experts within the project team (OBWB, ONA, and FLNRORD), as well as other external experts. Implementation of the methods and development of EFN flow regimes and critical flows for 18 Okanagan streams is described in this report (Phase II). EFN development has been a collaborative process; contributions from steering committee members and contributors to this report and/or support in collecting the data are described inTable 1-1.

Table 1-1: Contributors to this report

Name	Organization	Contribution
Elinor McGrath	ONA Fisheries	Study design and implementation; WUW analysis; reporting; Technical Advisory committee
Joe Enns	ONA Fisheries, past employee	Study design and implementation; Technical Advisory committee
Natasha Neumann	FLNRORD, formerly OBWB consultant	Hydrologist, QA/QC of Aquarius data; percentile flow analysis; Technical Advisory committee
Rich McCleary	FLNRORD – Stewardship	Steering committee and flow sensitivity assessments
Ron Ptolemy	Ministry of Environment and Climate Change Strategy	Technical Advisory committee and EFN setting guidance
Ryan Whitehouse	FLNRORD – Ecosystems	SEFA analysis, Technical Advisory committee
Molly Teather	ONA Fisheries, now at FLNRORD	Field data collection; reporting
Samantha Davis	ONA Fisheries	Report drafting and critical flow analysis
Adam O’Dell	ONA Fisheries, now at DFO	WUW analysis
Karilyn Alex	ONA Fisheries	Report review and Tennant analysis
Field technicians	ONA Fisheries and the Nations member Bands	Field data collection and guidance

1.2 Objectives

The goal of the Okanagan EFN Project was to produce defensible, transparent and robust EFN values for Okanagan streams. The scope was limited to providing technical recommendations. The specific objectives of Phase II of the EFN project were to;

1. accumulate and assess previously collected data from parallel studies that may be applicable to the study;
2. establish hydrometric stations, where applicable, to gather adequate hydrometric data to inform the EFN development;
3. determine the level of field intensity required and delineate study sites to be sampled for the streams chosen;
4. collect field data on fish habitat characteristics over a range of flows;
5. apply the "Okanagan Tennant Method" outlined in Phase I to set recommended EFNs for all 18 tributaries;
6. apply the "Okanagan WUW Method" outlined in Phase I to set recommended EFNs for ten of the 18 tributaries; and
7. recommend critical flows for each species and life-stage of concern in all 18 tributaries.

1.3 Study Area

The Okanagan Basin is a transboundary basin, spanning the Canada-U.S. border. The watershed runs from north to south, starting near Vernon, B.C. (Figure 1-1) and crossing the border at Osoyoos, B.C. The Okanagan River flows into the nx̌ʷəntkʷitkʷ (Columbia River) at Brewster, Washington State. The Canadian portion of the Okanagan Basin spans 8,000 km^2, and is long and narrow and deeply incised in the interior plateau of southern B.C. (Merritt et al. 2006). Elevation ranges from 270 meters above sea level in the southern valley to 2100 meters above sea level on the plateaus (Merritt et al. 2006). The main tributaries generally originate from elevations around 1500 meters, and drop steeply through narrow valleys before crossing alluvial fans and entering kłusxənitkʷ (Okanagan Lake) or q̓awsitkʷ (Okanagan River).

The study area covers a diverse set of ecosystems from three broad types including basins, plateaus and mountains and has been classified based on the British Columbia Ecoregion Classification System (DeMarchi 2011). The main valley is split near t̓iwcən (Skaha Lake) into the Northern Okanogan Basin and Southern Okanogan Basin Ecosections. The watersheds on the east side of the Okanagan valley originate in the Northern Okanagan Highland Ecosection. On the west side of valley, and north of Trout Creek, headwaters lie within the Western Okanagan Upland Ecosection, whereas those watersheds south of Trout Creek originate within the Okanagan Range Ecosection.

The Okanagan Basin has a semi-arid continental climate, consisting of a dry and hot summer with colder winters. Annual precipitation shows a bimodal distribution: there is a winter peak driven by storms from the Pacific Ocean, and another caused by convective summer storms (Merritt et al. 2006). The hydrological regime is snowmelt-dominated, with about three quarters of the annual runoff occurring from April to July (NHC 2001), and low flows occurring from late summer to winter. Flow in most tributaries is regulated for water storage or flood control purposes.

The Okanagan Basin is currently the most northern and upstream extent that is accessible by anadromous salmon populations in the Columbia River system. According to Traditional Ecological Knowledge (TEK), the Okanagan Basin once supported Pacific salmon species including (Rae 2005):

- sćwin – Sockeye Salmon (*Oncorhynchus nerka*) – currently present;
- ntitiyx – spring Chinook Salmon (*Oncorhynchus tshawytscha*) – currently present;
- sk'lwist – summer Chinook Salmon (*Oncorhynchus tshawytscha*) – currently present;
- qʷəyqʷəyʕaċaʔ – Steelhead (*Oncorhynchus mykiss*) – currently present; and
- kisúʔ – Coho Salmon (*Oncorhynchus kisutch*) – extirpated but low numbers have been returning.

The Basin also supports native non-anadromous salmonid species including (Rae 2005):

- kəkni – Kokanee Salmon (*Oncorhynchus nerka*) – currently present;
- xʷuminaʔ – Rainbow Trout (*Oncrorhynchus mykiss*) – currently present;
- miməlt – Whitefish –currently present;
  - Mountain Whitefish (*Prosopium williamsoni*) and
  - Pygmy Whitefish (*Prosopium coulterii*).

In addition, there have been 14 native non-salmonid species recorded and at least 14 non-native fish species introduced and observed in the Okanagan watershed (Rae 2005; Basok 2000; NPCC 2004). Several native species are listed as threatened or endangered in Canada and the United States (COSEWIC 2008; FWS 2008).

The fish species of primary interest in this report include salmonids that use the tributaries for spawning and rearing. Many of these species are culturally important to the Okanagan Nation. Species assessed in the South Okanagan included Kokanee, Rainbow, Sockeye, Steelhead, and Chinook. The Okanagan Lake Dam at the outlet of Okanagan Lake was the final migration barrier for anadromous salmonids until summer 2019, therefore, only non-anadromous species (Kokanee and Rainbow) were assessed in the north Okanagan for the purpose of this report; however, the data collected can be used to develop EFNs for other anadromous salmonid species that traditionally accessed and may once again occupy that portion of the watershed.

According to TEK, "the river channel, used to be rich in fish; Steelhead, Coho, Sockeye and King (Chinook) Salmon" (Ernst & Vedan 2000). *captikwł* (traditional legends) teach us that the natural laws of the Okanagan Basin included anadromous salmon when coyote brought them to the head of Okanagan Lake (ONA 2020). Fish passage was impeded as early as 1910 with changes to the outlet of Okanagan Lake, and in 1914 with a log weir at the site of nˤaylintən (McIntyre Dam area) (Ernst 1999). Subsequently, dams on the Okanagan River were constructed at the outlets of Okanagan Lake (Penticton Dam), Skaha Lake (Okanagan Falls Dam), Vaseux Lake (McIntyre Dam), and Osoyoos Lake (Zosel Dam in the U.S., does not impede passage) and anadromous fish populations declined drastically. As permanent fish passage was re-established at McIntyre Dam in 2009 and at Skaha Lake Control Dam at sx̌ʷəx̌ʷnikʷ (Okanagan Falls) in 2014, anadromous salmon have re-established themselves back into their territory up to the Okanagan Lake outlet dam (in Penticton). Fish passage into Okanagan Lake was established in 2019 but for the purposes of this report, EFNs for anadromous salmon were not included in tributary streams of Okanagan Lake.

Eighteen Okanagan streams were included in this project (Figure 1-1) and were chosen in collaboration between FLNRORD, OBWB and ONA. Resource limitations necessitated a ranking process to prioritize watersheds for field investigations. The following criteria were used in the ranking process:

- **Fish habitat value** – fish habitat value was determined from information contained in the stream-specific appendices of the Phase I report (Associated 2016) as well as other literature resources and traditional and local knowledge of the project partners.
- **Current Water Use Pressure** – water use pressure was determined by calculating the proportion of licensed water use to discharge on an annual basis as well as seasonally during the summer baseflow period. LTMAD values used for the calculations were taken from Summit (2009) and from Ministry of Environment (MOE; Ptolemy 2019). Estimated summer baseflows were provided by FLNRORD (2016) and estimated annual use and licensed baseflow use were contained in Associated (2016) and (Dobson 2008), respectively. Updated estimates of LTMAD and summer baseflows were later provided by Associated (2019); however, the data was not yet available at the time of the prioritization exercise.
- **Future Water Demand** – since EFNs are considered in the review of future water licence applications, those watersheds with potential for further allocation were prioritized. The number of pending licence applications (indicating high future demand) as well as any licensing restrictions (indicating that no or limited further licences would be granted) were considered. Only Equesis Creek, Shorts Creek and Vaseux Creek had no licensing restrictions on file.

Further considerations included the presence or absence of operating Water Survey of Canada (WSC) stations as well as existing Water Use Plans or Operating Plans (Table 1-2). Watersheds with Water Use Plans or Operating Plans in place were not ranked and were considered low priority for field investigations as they had previously gone through an extensive planning process; however, Mission Creek was included regardless in the Okanagan WUW Analysis due to its very high fisheries value. Lower Vernon Creek was initially included as one of the key tributaries; but was later omitted due to the complexity of its flow regime and water management, which complicated naturalized streamflow development. This report organizes the tributaries based on the EFN setting method used, then from North to South.

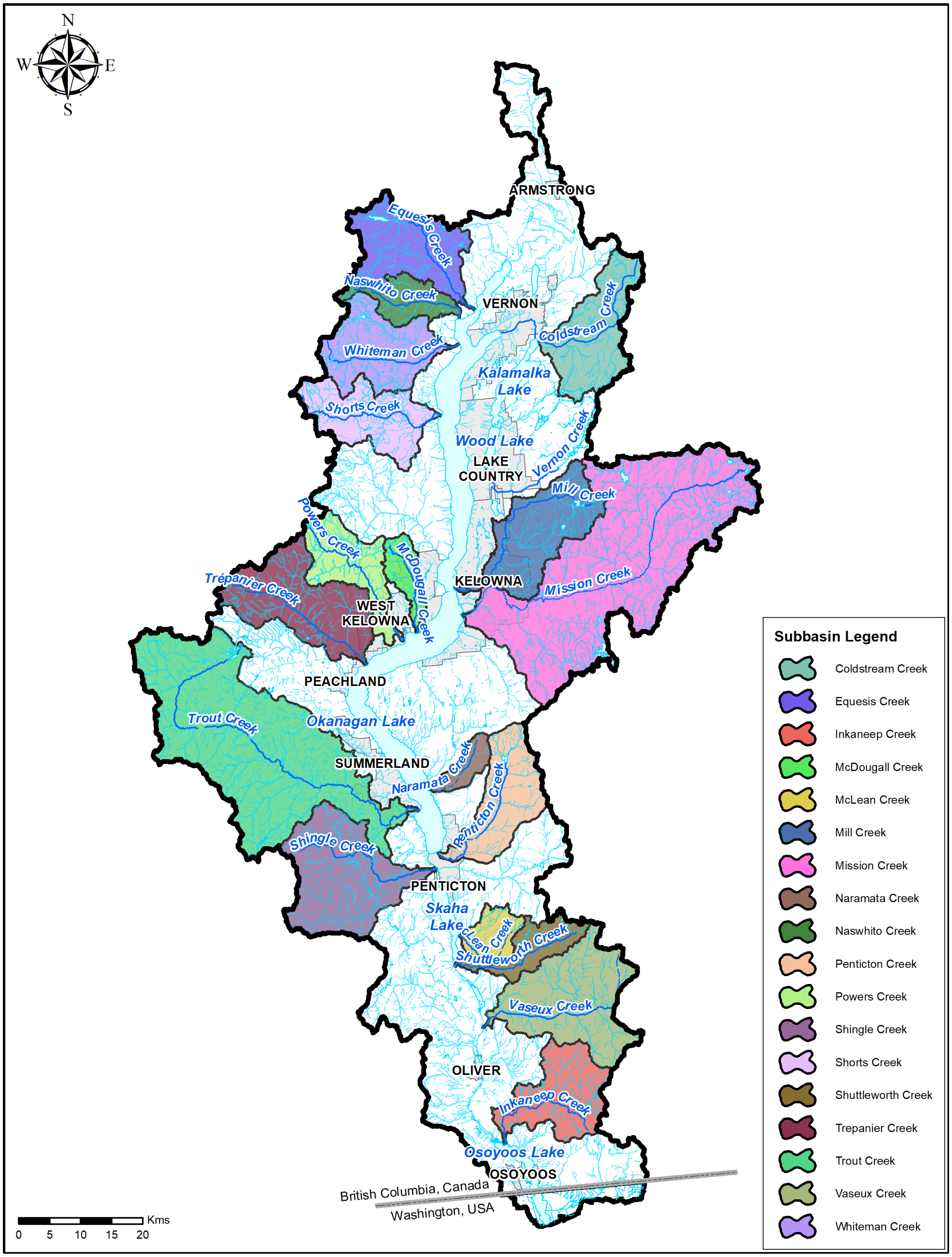


Figure 1-1: Map of the 18 study streams (Associated 2016)

Table 1-2: Criteria used for fieldwork prioritization and methods selection for EFN setting in 18 Okanagan streams

Stream	Active Water Use Plan / Operating Plan	Operating WSC hydrometric station	Fish/Fish Habitat Value	Water Use Pressure	Pending Water Licence Applications	EFN Setting Method
Coldstream Creek	No	Yes	Very High	High	4	Tennant & WUW
Equesis Creek	No	No	Very High	High	1	Tennant & WUW
Naswhito Creek	No	No	Medium	High	0	Tennant & WUW
Whiteman Creek	No	Yes	High	Low	0	Tennant & WUW
Mission Creek	Yes	Yes	a	a	a	Tennant & WUW
McDougall Creek	No	No	Medium	High	5	Tennant & WUW
Shingle Creek (upper and lower)	No	Yes	Very High	High	3	Tennant & WUW
Shuttleworth Creek	No	No	Medium	High	2	Tennant & WUW
Vaseux Creek	No	Yes	Very High	Low	0	Tennant & WUW
Inkaneep Creek	No	Yes	Very High	High	0	Tennant & WUW
Shorts Creek	No	No	Medium	Low	0	Tennant
Mill Creek	No	No	High	High	1	Tennant
Powers Creek	No	No	b	b	b	Tennant
Trepanier Creek	Yes	No	a	a	a	Tennant
Naramata Creek	No	No	Medium	High	0	Tennant
Trout Creek	Yes	No	a	a	a	Tennant
Penticton Creek	No	No	Low	Medium	0	Tennant
McLean Creek	No	No	High	N/A	1	Tennant

a not assessed due to existing Water Use Plan or Operating Plan in place

b not assessed

N/A insufficient data available to support estimate

2.0 METHODS

This report documents the process of applying the methods outlined in Phase I (Associated 2016). Methods for establishing Okanagan EFNs were developed through a comprehensive effort that included extensive collaboration with stakeholders and experts, as well as a thorough literature review of EFN setting approaches used locally and elsewhere in North America. The resulting EFN Phase I report (Associated 2016) outlined two primary methods to recommend EFNs for the study streams: an office-based exercise referred to as the "Okanagan Tennant method", which is a variation of the B.C. Modified Tennant method that was successfully used in the Okanagan in the past; and a field-based, stream-specific method requiring hydrometric and fish habitat data, called the "Okanagan WUW method". In addition, this report evaluates the utility of an alternative model-based approach called "System for Environmental Flow Analysis" (SEFA) for its ability to provide habitat information for EFN setting where gaps in the field data exist (Section 3.1.1 and Appendix C). Further, a concurrent study on biological indicators (benthic macroinvertebrates) in relation to streamflow conditions provided another alternative approach that was compared to the methods employed in this report (Section 4.3).

Initially, EFNs were determined for all 18 selected streams using the desktop Okanagan Tennant method. EFNs were further refined for 10 of the 18 streams using Okanagan WUW analyses of field data (Table 1-2). Critical flows were recommended for all streams based on a proportion of flow and further refined, where possible, using field transect data collected for the EFN analysis. The following sections describe the methods for hydrometric data collection, Okanagan Tennant analysis, Okanagan WUW analysis, critical flow analysis, and flow sensitivity assessments.

2.1 Hydrometric Data Collection

Hydrometric data is required for stream reaches of interest to establish relationships between streamflow and fish habitat conditions. Ten of the 18 study streams had active WSC hydrometric stations but only four were located in areas coinciding with prime fish bearing reaches (Associated 2016). Consequently, hydrometric stations were installed in stream reaches lacking hydrometric data. In total, 18 hydrometric stations were installed throughout seven North Okanagan (upstream of Okanagan Lake dam) EFN streams in late 2016. In the south Okanagan (tributaries to Okanagan River), three streams had previously installed hydrometric stations maintained by ONA and two new stations were installed for this project. Assistance in hydrometric station installation and training in hydrometric data collection procedures was provided by Associated.

Hydrometric stations were located in critical reaches identified for WUW field sampling based on the following considerations:

- high fish habitat value and accessibility (typically lower reaches below migration barriers);
- high water-use activities (and corresponding requirement for management decisions); and
- paired top and bottom of alluvial fan locations to estimate losses to groundwater along the fan.

Within these critical reaches, hydrometric station locations were selected based on (1) their proximity to a WUW transect for discharge measurements, (2) the presence of a pool or glide to prevent dewatering during low flows, and (3) a stable large tree or boulder to anchor the station in place. Water level was recorded using HOBO U20L-04 Water Level loggers, collecting temperature and pressure data at 15-minute intervals. Additionally, 12 atmospheric pressure stations were installed with the same equipment in proximity to the water level logger. The B.C. Resources Information Standards Committee (RISC) methods were adopted in this project (RISC 2018).

The water level loggers were suspended in metal stilling wells and using aircraft cable anchored to a locked cap. The stilling wells were anchored to boulders or trees using bolt hangers and hose clamps. A minimum of two lag bolt benchmarks were installed into nearby trees or boulders to serve as references for water level surveys. Staff plates were installed at some stations by mounting the plate on a board and bolting it to a tree or boulder at the stilling well.

At each station, discharge and water level measurements were collected during 8-10 field visits ranging from high post-freshet flows to summer low flows. Standardized field data forms, developed in collaboration with OBWB and Associated, were used to ensure consistency between field crews and visits. During each visit, hydrometric stations and hydrometric cross sections were checked for damage and disturbance such as floating debris or sediment infilling, which was remedied where possible and noted in the field records. Discharge measurements were typically collected at a nearby transect, which was carefully selected to possess characteristics conducive to high quality flow measurements, such as laminar flow, relatively uniform depth and velocity, stable banks without undercuts and little vegetation, and no in- or outflows between the station and the transect.

Two types of flow meters were used: the SonTek FlowTracker (models 1 and 2) and the Swoffer Current Velocity Meter (model 2100). The preferred instrument was the FlowTracker, which determines water velocity by measuring the change in acoustic frequency using reflections from moving particles in the flow. Measurements were conducted over 40 second intervals with a top-setting wading rod (SonTek 2007). This meter possesses built-in quality control checks that were conducted prior to each measurement. A schematic of the FlowTracker's mid-section discharge equation is provided in Figure 2-1. The Swoffer meter was used as a secondary meter when the FlowTracker was unavailable. It collects velocity measurements using a propeller that converts rotation frequency into velocity over 30 seconds with a 2 m top-setting rod (Swoffer Instruments Inc. n.d.). Discharge data collection adhered to standard procedures, including (B.C. RISC 2018; WSC 2015):

- depth and velocity measurements at a minimum of 20 panels across the wetted channel;
- panel locations were spaced 1/20th or less of the stream width apart but no less than 10 cm;
- each cross-sectional panel accounted for less than 10% of the total discharge in the measurement; and
- velocity was measured at 60% depth from the surface for water depths below 0.75 m and at 20% and 80% depth from the surface at depths above 0.75 m.

During field visits, water level measurements were collected at the hydrometric stations using one of two methods: (1) reading the water level off a staff plate (if present) or (2) surveying the water level relative to the benchmarks. Closed loop surveys were conducted with an eye level and stadia rod at an accuracy of 5 mm or less. Where water levels fluctuated notably (e.g., during high flow conditions), the stage was surveyed in twice, once upon arrival and then prior to leaving the site. Data from water level and atmospheric pressure loggers were uploaded to a portable device periodically. A field audit of data collection procedures was conducted by Associated and included review of hydrometric transect selection and set up, hydrometric measurement procedures, flow meter operation, and water level survey techniques.

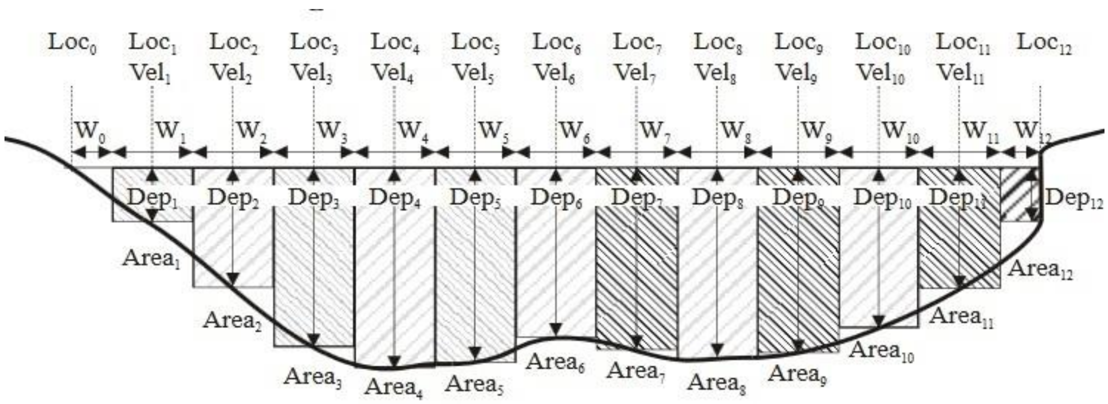


Figure 2-1: The FlowTracker's mid-section discharge equation (SonTek 2007)

All field data (water and atmospheric pressure and temperature logger data, measured discharge and water level data) were checked for errors and then entered into the OBWB AQUARIUS database. Continuous water depth records were then calculated from the water and atmospheric pressure logger data. Data correction procedures in AQUARIUS included the deletion of questionable water level records (e.g., flat lines, large spikes, frozen conditions) as well as drift correction based on water level field surveys. Rating curves relating water level and field discharge measurements were developed in AQUARIUS and then used to produce an estimated continuous discharge record from the water level logger data. Data corrections and rating curve development were completed in collaboration with an OBWB database manager who produced the rating curves and provided quality assurance and quality control.

2.2 Okanagan Tennant Analysis

One of the most common desktop methods used worldwide to set EFNs is the Tennant Method (Tennant 1976; Tharme 2003; Annear et al. 2004). This hydrologically based method assigns EFNs based on a portion of LTMAD that has been shown to sustain the biological integrity of river ecosystems in several western U.S. states (Linnansaari et al. 2013). The portion of LTMAD required to sustain a given species and life stage is termed the "instream presumptive flow standard" (flow standard). Biologists from the B.C. Fisheries Branch have modified the Tennant method to incorporate local biological and physical information for application in B.C. The "B.C. Modified-Tennant Method" has evolved over the past 30 years and continues to be updated (Ptolemy & Lewis 2002). The Okanagan Tennant method is an adaptation of the B.C. Modified Tennant method that was previously used in the Okanagan (NHC 2001, 2003, 2005).

The Tennant method has been criticized for being overly simplistic by relying on percentages of a single flow statistic (LTMAD). Rather than relying solely on flow standards, the Okanagan Tennant method defaults to the lower of the median naturalized flow for a given time period and the applicable flow standard. This adjustment is based on the premise that local aquatic populations and ecological processes have become adapted to the historic natural flow regimes, which are characterized by low and highly variable flows (Associated 2016). Defaulting to the median naturalized flows when they are lower than the flow standards means that the EFN varies from stream to stream in relation to its specific hydrology. Factors like groundwater-surface water interactions, freshet timing, bedrock influences on magnitude of base flows, and weather pattern differences are reflected in the observed streamflow patterns and are inherent in the resulting EFN values.

A flowchart outlining the steps for setting Okanagan Tennant EFNs is provided in Appendix A. The general steps below were implemented during Phase II of this project. Remaining steps, including the comparison of percentile flows under various water abstraction scenarios, will be implemented in a future phase of this project when the production of the underlying data is complete. Okanagan Tennant EFNs were developed for all 18 study streams.

1. **Literature review** – relevant information is summarized in the results section for each stream (Section 3.1 to 3.18).
2. **Define area and reach of interest** – information on stream prioritization is provided in Section 1.3 (B1 to B18).
3. **Adopt fish periodicity** – detailed fish periodicity information was compiled for the study streams based on the literature and local knowledge (Section 2.2.1).
4. **Calculate LTMAD** – estimates of naturalized LTMAD and weekly flows were developed for the EFN point-of-interest in each study stream by Associated and are provided in a separate report (Associated 2019).
5. **Choose time steps** – monthly time steps from November to March and weekly time steps from April to October were chosen by the project team
6. **Flow Standards** – flow standards were reviewed and adjusted by the project team to reflect local conditions. Flow standards used to set Okanagan Tennant EFNs are provided in Section 2.2.2.
7. **Set Okanagan Tennant EFNs** – EFNs for each time step were set as the lower of the highest flow standard or the median naturalized weekly flow for a given time step. Note in some streams the residual flow was used instead of the naturalized flow if there is a history of flow augmentation. Okanagan Tennant EFNs are provided in Sections 3.1 to 3.18 and Appendices B1 to B18 (stream-specific Appendices).
8. **Compare to previous studies** - Okanagan Tennant EFNs were compared to previous EFN recommendations as well as to fish, fish habitat and naturalized flow data, where available, and adjusted where needed (Sections 3.1 to 3.18).

2.2.1 Fish Periodicity

Periodicity information consists of identifying which ecosystem, species and life stages are of interest in a given creek, as well as their timing and duration. Fish periodicity information for the study streams was compiled from local knowledge as well as the literature. For some species and life stages, timing is relatively rigid and the requirement for suitable flows extends to a specific set of weeks in a given year (e.g., Kokanee spawning). For others, providing suitable flows for a specific duration within a general time window is sufficient. This allows the timing of EFNs to vary as a result of hydrological variation between years (e.g. channel maintenance freshet flows).

The timing of species and life stages was reviewed and agreed upon by the project team. Fish species and life stages of interest in the study streams are presented in Table 2-1 where “Y” denotes yes for presence of expected fish species. General timing information is provided in Table 2-2 and stream-specific fish periodicity information is found in Appendices B1 to B18. Periodicity information contained within this report represents the most comprehensive collection of periodicity assembled for the Okanagan, and supersedes that of which is contained in the Phase I report.

Additional explanations for the periodicity tables include:

- Key to Rainbow parr rearing is the optimization of riffles for insect production; therefore the periodicity for riffle optimization and insect production is equal to that for Rainbow rearing (Reiser & Bjornn 1979; Stalnaker & Arnette 1976).
- Anadromous salmon have not been included in tributaries of Okanagan Lake pending confirmation of re-introduction past Okanagan Lake dam.
- Kokanee spawn timing varies by stream and stream-specific information is provided in Table 2-3.
- Although not assessed in the COSEWIC (2017) report on Okanagan Summer Chinook Salmon, spring Chinook use tributaries for spawning according to TEK assessments (Ernst & Vedan 2000) and recent field observations and PIT-tag detections, and have therefore been included in this assessment. Further, ONA efforts to rebuild the stock are underway. Spring Chinook return to the Okanagan valley earlier than summer/fall Chinook and therefore have extraordinarily long holding periods.
- Short-term durations are provided for juvenile fish migration as well as ecosystem flows. For example, juvenile Sockeye require a 15-day mean duration at freshet flows for 75% emergence, as determined through Sockeye emergence records over the past 18 years (CNAT 2018).
- Ramping (up and down) of flows are important to ecosystem and fish function at all times of the year. These ramping flows are not determined within the EFNs but they should be set stream-specific within licensing allocations.
- The timing and duration for flows after freshet peak is based on the needs of endangered Cottonwood ecosystems as prescribed by Richter & Richter (2000).
- Additional flow-dependent ecosystem processes, such as wetland inundation, side channel linkage, sediment flushing and channel maintenance were also incorporated based on Leopold et al. (1964). This occurs during high flow freshet periods and timing is based on the freshet as determined in the naturalized flow assessment (Associated 2019).
- The duration times provided in Table 2-2 do not take into account changes to hydrographs resulting from of climate change.

Note for the purpose of this report that:

- Rainbow Trout parr rearing is referred to as Rainbow rearing,
- Chinook Salmon fry rearing is referred to as Chinook rearing, and
- Rainbow and Steelhead Trout juveniles are referred to as *O. mykiss* where they co-occur as they have similar juvenile rearing requirements and timing in tributary streams.

Table 2-1: Ecosystem and expected fish species and life stages in the study streams

Species/ system	Life stage/ specifics	Coldstream	Equesis	Naswhito	Whiteman	Mission	McDougall	Shingle (lower)	Shingle (upper)	Shuttleworth	Vaseux	Inkaneep	Shorts	Mill	Powers	Trepanier	Naramata	Trout	Penticton	McLean	Comments
Rainbow	Adult migration Spawning Incubation Rearing Juvenile migration Overwintering	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	Need rain events to trigger migrations and parr rearing is a sensitive life stage. Large bodied and smaller resident sized Rainbow exist in all tributaries.
Kokanee	Adult migration Spawning Incubation Juvenile migration	y	y	y	y	y	y	y					y	y	y	y	y	y	y	y	Need rain events to trigger migrations into the tributaries. Body sizes can vary significantly by stock.
Steelhead	Adult migration Spawning Incubation Rearing Juvenile migration Overwintering							y	y	y	y	y								y	Not included in tributaries of Okanagan Lake until re-introductions are confirmed and TEK consulted.
Chinook (summer)	Rearing							y		y	y	y								y	Summer Chinook spawn in the mainstem Okanagan River but use the tributaries for rearing.
Chinook (spring)	Adult migration Spawning Incubation Rearing Juvenile migration Overwintering							y	y	y	y	y									Culturally sensitive species to the Syilx as it is one of the 4 food Chiefs; not included in tributaries of Okanagan Lake until re-introductions are confirmed and TEK consulted.
Sockeye	Adult migration Spawning Incubation Juvenile migration							y		y	y										Not included in tributaries of Okanagan Lake until re-introductions are confirmed.
Ecological Flows	Flow ramping Cottonwood ecosystem flows Wetland, side channel linkage, flushing and channel maintenance	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y	Important ecosystem functions for all streams. Flow ramping up and down needs to occur for all flow changes throughout the year.

Table 2-2: General timing and duration (periodicity) of species and life stages for all study streams

Species/ system	Life stage/ specifics	Timing		Duration	Reference
		Start	End	(days)	
Rainbow	Adult migration	15-Apr	10-Jul	entire	Wightman (1975)
	Spawning	20-May	10-Jul		Roberge et al. 2002; Wightman (1975)
	Incubation	1-Jun	15-Jul	entire	Ptolemy pers. comm. 2017; CNAT 2018; Becker & Neitzel 1983
	Rearing	1-Apr	31-Oct	entire	Ptolemy pers. comm. 2017; based on water temperatures
	Juvenile migration	1-May	15-Jul	15	Ptolemy pers. comm. 2017; CNAT 2018 (15 days mean for 75% emergence at freshet flows)
	Overwintering	1-Nov	31-Mar	entire	Ptolemy pers. comm. 2017
Kokanee	Adult migration	25-Aug	8-Oct	entire	Webster 2015a and 2015b
	Spawning[1]	1-Sep	20-Oct	entire	Webster 2008 to 2016; Dill 1991; Long & Tonasket 2005a; Walsh & Weins 2006; Wodchyc et al. 2007; Mathieu & Kozlova 2009; Mathieu & Squakin 2009; Louie & Benson 2011; Bussanich et al. 2013; Benson et al. 2013; Benson & Bussanich 2014; Benson et al. 2016; Benson & Bussanich 2016; Yaniw & Benson 2017; Yaniw & Benson 2018; Yaniw & Benson in prep. 2019a; Yaniw & Benson in prep 2019b; ONA 2012
	Incubation	1-Sep	31-Mar	entire	Webster 2016
	Juvenile migration	1-Apr	31-May	15	McGrath et al. 2012; McGrath et al. 2014; Webster 2016; 15 days mean for 75% emergence at freshet flows (CNAT 2018)
Steelhead	Adult migration	1-Apr	25-Jun	entire	Ptolemy pers. comm. 2017; Long et al. 2006; Folks et al. 2009; Benson & Squakin 2008; Arterburn et al. 2007; Upper Shingle Creek specific based on mid elevation freshet (April 16 to June 25)
	Spawning	1-Apr	25-Jun	entire	Arterburn 2013; Upper Shingle Creek specific based on mid elevation freshet (April 16 to June 25)
	Incubation	1-Apr	15-Jul	entire	Ptolemy pers. comm. 2017; Long et al. 2006; Folks et al. 2009; Benson & Squakin 2008; Arterburn et al. 2007
	Rearing	1-Apr	31-Oct	entire	Ptolemy pers. comm. 2017; Arterburn et al. 2007
	Juvenile migration	8-Apr	20-Jun	15	Arterburn 2013
	Overwintering	1-Nov	31-Mar	entire	Ptolemy pers. comm. 2017
Chinook (summer)	Rearing	1-Apr	29-Apr	entire	Davis 2010; Davis 2009; Davis et al 2008; Davis et al. 2007
Chinook (spring)	Adult migration	1-Jul	17-Sep	entire	PIT tag recoveries (http://www.ptagis.org), Sockeye enumeration unpublished data 2000-2017
	Spawning	27-Aug	30-Sep	entire	Peven (2003); DFO pers. comm. cited in Epp, 2014; Davis 2010; Davis 2009; Davis et al. 2008; Davis et al. 2007; CCT 2004; Snow et al. 2018
	Incubation	27-Aug	8-Mar	entire	Peven (2003); DFO pers. comm. cited in Epp, 2014; Davis 2010; Davis 2009; Davis et al. 2008; Davis et al. 2007.
	Rearing	1-Apr	31-Oct	entire	Ptolemy pers. comm. 2017; based on water temperatures
	Juvenile migration	14-Apr	30-Jun	15	Davis 2010; Davis 2009; Davis et al. 2008; Davis et al. 2007; COSEWIC 2006; CNAT 2018
	Overwintering	1-Nov	31-Mar	entire	Ptolemy pers. comm. 2017
Sockeye	Adult migration	1-Jul	15-Sep	entire	PIT tag recoveries (http://www.ptagis.org); CNAT 2018; Davis et al. 2009; Audy & Benson 2011; Benson & Audy 2012; Bussanich et al. 2012
	Spawning	16-Sep	31-Oct	entire	CNAT 2018 (18 years of data); Davis et al. 2009; Audy et al. 2011; Benson & Audy 2012; Bussanich et al. 2012
	Incubation	16-Sep	31-Mar	entire	CNAT 2018 (18 years of data); SECL 2002; Lawrence 2003; Lawrence 2004
	Juvenile migration	31-Mar	25-May	15	CNAT 2018 (18 years of data); Lawrence 2003; Lawrence 2004; Tonasket 2007; Hyatt et al. 2009; Benson 2010
Ecological Flows	Ramping up and down	Jan	Dec	all year	Flow ramping should occur at all times of the year.
	Cottonwood Ecosystem flows	freshet	31-Jul	entire	Richter & Richter 2000; Scott et al. 1996; Amlin & Rood 2001; Mahoney & Rood 1998, general ecosystem flows NHC 2001. Start date determined from the end of freshet dates set from the naturalized hydrograph
	Wetland, side channel linkage, flushing and channel maintenance flow	1-Apr	30-Jun	15	Jones et al 2015, Leopold et al. 1964;

1 General period for all streams, with any stream-specific information presented in Table 2-3

Table 2-3: Stream-specific spawning time period refinements for Okanagan Kokanee stocks

Stream	Start date	End date	Peak spawning date	References
Coldstream Creek	22-Sep	23-Oct	9-Oct	Webster 2008 to 2017; Dill 1991
Equesis Creek	10-Sep	10-Oct	26-Sep	
Naswhito Creek	12-Sep	7-Oct	23-Sep	
Whiteman Creek	8-Sep	5-Oct	20-Sep	
Mission Creek	31-Aug	5-Oct	18-Sep	
McDougall Creek	Westbank First Nation notes Kokanee were once there, none recently enumerated, default to average dates (1-Sept to 20-Oct)			
Lower Shingle Creek	25-Sep	1-Nov	15-Oct	Long & Tonasket 2005b; Walsh & Weins 2006; Wodchyc et al. 2007; Mathieu & Kozlova 2009; Mathieu & Squakin 2009; Louie & Benson 2011; Benson et al. 2013; ONA 2012
Upper Shingle Creek	none			Rivard-Sirois et al. 2012; Rivard-Sirois & Audy 2010
Shuttleworth Creek	none			
Vaseux Creek	none			
Inkaneep Creek	none			
Shorts Creek	18-Sep	26-Oct	unknown	Webster 2008 to 2016; Dill 1991; Ward 2018 pers. comm. (FLNRORD)
Mill Creek	17-Sep	13-Oct	30-Sep	
Powers Creek	4-Sep	3-Oct	17-Sep	
Trepanier Creek	4-Sep	4-Oct	21-Sep	
Naramata Creek	17-Sep	10-Oct	unknown	
Trout Creek	1-Sep	20 Oct	unknown	
Penticton Creek	6-Sep	7-Oct	23-Sep	
McLean Creek	cut off by culverts, no Kokanee observed in recent years, default to average dates (1-Sept to 20-Oct)			

2.2.2 Flow Standards

Flow standards for use in this project were based on information supplied by FLNRORD staff as well as the literature and are listed in Table 2-4. Notably, flow standards for ecological flows were added with the intention to preserve key ecological functions such as riparian recruitment (Richter & Richter 2000; Scott et al. 1996; Amlin & Rood 2001; Mahoney & Rood 1998), wetland inundation, floodplain connections, side channel linkage, invertebrate drift, gravel bed flushing, and channel maintenance (Hynes 1970; Leopold et al. 1964). Flow standards represent the portion of LTMAD required to sustain a given ecosystem, species and life stage and are presented as percent of LTMAD (%LTMAD).

Additional explanations for flow standard tables include:

- Flow standards for large bodied salmonids were calculated for each stream (Table 2-5) according to the following formula (Ptolemy & Lewis 2002; Annear et al. 2002):

  $$\text{large bodied salmonid flow standard} = 148 * \text{LTMAD}^{-0.36}$$

- Endangered Cottonwood are the key species in Okanagan riparian ecosystems (Lea 2008). Ramp down rates of 2.5 cm per day (Mahoney & Rood 1998) are needed for maintenance and recruitment of Cottonwoods post freshet (Richter & Richter 2000; Scott et al. 1996; Amlin & Rood 2001). The ecosystem flow standard of 100% described in NHC (2001) along with the flow standard for channel maintenance met these ramp down rates. However, more research is needed to confirm the validity of this flow standard specifically for Cottonwood needs and to monitor its effectiveness.
- In stream channels running through erodible materials, general geometry relationships known as regime equations have been derived that describe the relationships between channel-forming discharge, slope and cross section (Leviavsky 1955). The flood stage where the stream reaches bankfull discharge is the dominant channel forming flow (Newbury 2010, Leopold et al. 1964). This bankfull discharge is described as the annual flood discharge (Q) and occurs at the 66th percentile ($Q_{66\%}$) from a flood exceedance assessment (Leopold et al. 1964; Kellerhals & Church 1989) also known as the 1.5-year freshet flow. These bankfull discharges also maintain average rates of sediment transport, bank-full widths and depths, pool-riffle ratios, and the average rates of bank migration, (Leopold et al. 1964) thus stable bed and bank erosion. Annual flood flows were calculated for each creek and tend to vary in practise due to water storage or diversion. Flow standards were calculated from the LTMAD determined by Associated (2019) and the stream-specific $Q_{66\%.}$ annual flood (Table 2-6). Freshet flow standards, by design, may not be met every year, and are not expected to occur at the same time each year.
- For all Okanagan tributaries it is important to note that rain events create significant pulses in flows that many species (e.g., spawning Kokanee and spawning Rainbow) key into for entering the stream and use for particular life stage needs. In most cases rain events cannot be controlled but in highly regulated systems they need to be allowed.

Table 2-4: Flow standards used for calculating the Okanagan Tennant EFNs

Species	Life stage	Flow standards (% LTMAD)	Reference
Rainbow	Adult migration - large bodied	$148*LTMAD^{-0.36}$ Table 2-5	Ptolemy & Lewis 2002; Annear et al. 2002
	Adult migration - small bodied	100%	Ptolemy pers. comm. 2019
	Spawning	40%	NHC 2001
	Incubation	20%	Ptolemy & Lewis 2002
	Rearing	20%	Ptolemy & Lewis 2002;
	Juvenile migration	50%	NHC 2001
	Overwintering	20%	Ptolemy & Lewis 2002; NHC 2001
Kokanee	Adult migration	20%	Ptolemy & Lewis 2002
	Spawning	20%	Ptolemy & Lewis 2002; NHC 2001
	Incubation	20%	Ptolemy & Lewis 2002; NHC 2001
	Juvenile migration	50%	Ptolemy & Lewis 2002; Ptolemy pers. comm. 2019
Steelhead	Adult migration	$148*LTMAD^{-0.36}$ Table 2-5	Ptolemy & Lewis 2002; Annear et al. 2002
	Spawning	143%	Ptolemy pers. comm. 2019
	Incubation	20%	Ptolemy &Lewis 2002
	Rearing	20%	Ptolemy pers. comm. 2019
	Juvenile migration	50%	Ptolemy & Lewis 2002
	Overwintering	20%	Ptolemy & Lewis 2002
Chinook (summer)	Rearing	20%	Ptolemy pers. comm. 2019
Chinook (spring)	Adult migration	$148*LTMAD^{-0.36}$ Table 2-5	Ptolemy & Lewis 2002; Ptolemy pers. comm. 2019
	Spawning	143%	Ptolemy pers. comm. 2019
	Incubation	20%	Ptolemy & Lewis 2002
	Rearing	20%	Ptolemy & Lewis 2002
	Juvenile migration	50%	Ptolemy & Lewis 2002
	Overwintering	20%	Ptolemy & Lewis 2002
Sockeye	Adult migration	25%	Based on Coho similar sized bodies. Ptolemy & Lewis 2002
	Spawning	40%	Based on Coho similar sized bodies. Ptolemy & Lewis 2002
	Incubation	20%	Ptolemy & Lewis 2002
	Juvenile migration	50%	Ptolemy & Lewis 2002
Ecological Flows	Freshet ramp up	ramp up of 2.5cm/hr	Knight Piesold Ltd. 2005
	Cottonwood Ecosystem freshet ramp down flows	100%	Richter & Richter 2000; Scott et al. 1996; Amlin & Rood 2001; Mahoney & Rood 1998 (ramp down of 2.5cm per day), general ecosystem flows NHC 2001 met ramp down rates
	Wetland, side channel linkage, flushing and channel maintenance flow	Table 2-6	ONA flood exceedance based on $Q_{66\%}$ channel maintenance flows (Leopold et al. 1964).

Table 2-5: Large bodied salmonid adult migration flow standards

Stream	**LTMAD used in analysis** (m^3/s)	**Flow standards**[1] (%LTMAD)
Coldstream Creek	0.748	164
Equesis Creek	0.700	168
Naswhito Creek	0.363	213
Whiteman Creek	1.092	143
Mission Creek	6.352	76
McDougall Creek	0.132	307
Shingle (lower) Creek	0.641	174
Shingle (upper) Creek	0.272	236
Shuttleworth Creek	0.436	200
Vaseux Creek	1.285	135
Inkaneep Creek	0.362	213
Shorts Creek	1.014	147
Mill Creek	0.744	165
Powers Creek	0.643	174
Trepanier Creek	1.283	135
Naramata Creek	0.157	288
Trout Creek	2.174	112
Penticton Creek	1.159	140
McLean Creek	0.167	282

1 based on the formula $148 \times LTMAD^{-0.36}$ (Ptolemy & Lewis 2002)

Table 2-6: Freshet flow standards calculated for each stream

Stream	**Watershed area** (km^2)	**$Q_{66\%}$** (m^3/s)	**LTMAD** (m^3/s)	**Flow standard** (%LTMAD)	**Source**
Coldstream Creek	206	5.4	0.748	730%	08NM142 (60.6 km^2)
Equesis Creek	204	7.7	0.700	1100%	Lukey & Alex 2018
Naswhito Creek	87	3.3	0.363	910%	Lukey & Alex 2018
Whiteman Creek	203	7.7	1.092	710%	Lukey & Alex 2018
Mission Creek	831	55.4	6.352	870%	08NM116 (795 km^2)
McDougall Creek	54	1.0	0.132	730%	no peak flow data, scaled based on Trout Creek
Shingle (lower) Creek	299	9.7	0.641	1510%	Rivard-Sirois 2013
Shingle (upper) Creek	118	3.8	0.272	1410%	scaled from Lower Shingle results
Shuttleworth Creek	90	2.6	0.436	600%	Burge 2011
Vaseux Creek	294	11.2	1.285	870%	record too short, scaled from Whiteman Creek
Inkaneep Creek	227	8.6	0.362	2380%	record too short, scaled from Whiteman Creek
Shorts Creek	186	7.1	1.014	700%	record too short, scaled from Whiteman Creek
Mill Creek	224	14.9	0.744	2000%	based on mission 08NM116 (795 km^2)
Powers Creek	145	6.4	0.643	990%	no peak flow data, scaled from Trepanier Creek
Trepanier Creek	260	11.4	1.283	890%	based on stn 08NM041 (182 km^2)
Naramata Creek	42	0.76	0.157	480%	no hydrometric records, scaled from Trout Creek
Trout Creek	747	13.5	2.174	620%	Eyjolfson & Alex 2018
Penticton Creek	180	11.0	1.159	950%	Mould 2017; highly modified flood regime
McLean Creek	63	1.1	0.167	680%	no peak flow data, scaled from Trout Creek

2.2.3 Percentile Flow Analysis

Methods recommended in Phase I of this project required the development of several streamflow datasets, including naturalized, residual and maximum licensed flows. Naturalized flows are the flow that would occur naturally in the absence of flow regulation including storage reservoirs and water withdrawals. Residual flows are the actual flows that occur at a specific point on a stream as recorded by streamflow measurements and reflect water withdrawals and management at the time. Maximum licensed flows refer to the flows that would occur at a specific point on a stream if all water withdrawals and storage management were maximized under existing water licences. Naturalized, residual and maximum licensed flow datasets for the study streams were provided by Associated (2019). The naturalized flow datasets are complete, 11 of 18 residual flow datasets were provided and nine of 18 maximum licensed flow datasets were provided. The naturalized flows are an integral component of the Okanagan Tennant Analysis (Section 2.2) and are also used in the WUW analysis (Section 2.3).

Calculation of percentile flows from the flow datasets was required for two tasks described in the Phase I report: assessing the impact of flows below the EFN, and allowing EFNs to vary naturally during drier years. Percentiles of most interest to FLNRORD were the 1-in-5 year low flow (P20) and the 1-in-2 year low flow (P50). These percentiles, along with the median, minimum and maximum flows, were calculated in excel and are plotted and also provided in Table-format in the stream-specific Appendices (B1 to B18). Values are shown in units of m^3/s as well as %LTMAD. Further information on how percentile flow data is used for each task is provided below:

- **Assess impacts of flows below EFNs.** The Phase I report recommended providing a means of assessing the impact of flows below the recommended EFNs, resulting either from existing or proposed water licences. WUW curves generated for the Okanagan WUW Analysis can provide this information. For streams where only Okanagan Tennant Analysis was completed and WUW curves are not available, percentile flows are used for comparing the %LTMAD available between the naturalized and residual (current or future) hydrographs at a given return period. This provides a basic understanding of the impact of current or future allocated water use on streamflows and particularly, the frequency of low streamflows.
- **Adjusting EFNs for natural flow variation.** The Phase I report recommended that EFNs be allowed to vary naturally with weather conditions for real-time operational management purposes (not water licensing purposes). Thus, the EFN would become the lower of the EFN value derived from the methods described in Sections 2.3 and 2.3, or the naturalized real-time flow. Tables of naturalized flow percentiles indicate at which percentile the EFN would be met and also provide guidance on naturally lower EFNs during drier years. Similarly, this approach could be used to adjust EFNs upwards during wetter years to increase habitat availability and fish production that may be associated with higher than normal flows (Reiser & Bjornn 1979), particularly for those species and life-stages that are constrained by naturally low flows (e.g. summer juvenile rearing). Implementation of this approach requires caution, as real-time naturalized hydrometric station data is scarce and requires careful analysis to properly characterize flow conditions in a given year.

2.3 Okanagan Weighted Usable Width Analysis

Ten of the 18 study streams were selected for WUW analysis based on the prioritization exercise described in Section 1.3 and budget and time constraints. WUW analysis is a standard technique that has been widely used throughout B.C. and elsewhere (Thompson 1972). The method integrates the effect of changes in flow on wetted width, depth, and velocity with habitat suitability indices (HSI) to calculate the weighted quantity of habitat available for a given species and life stage of fish (Ptolemy & Lewis 2002). The Okanagan WUW method is a field-based approach that constitutes a variation of a WUW method previously used in the Okanagan. WUW is calculated using depth and velocity measurements at panels along transects located in the appropriate habitat units for the species and life stage of interest, in conjunction with HSI curves. Repeating the measurements and calculations at each transect over a range of flows and then plotting WUW vs. discharge demonstrates changes in habitat with flow.

WUW values demonstrate the greatest usable width (optimal flow) at flows that produce the preferred depth and velocity conditions for the species/life stage. Optimal flows are often higher than median naturalized flows and not realistic and attainable in the context of the natural hydrograph. The Okanagan WUW method addresses the tendency to recommend optimal flows by focusing the assessment of flow-related habitat changes within the range of historical or expected flows bound by the critical flows at the lower and the median naturalized flows at the upper end. Ultimately, EFN recommendations were made based on the Okanagan Tennant and WUW analysis, and in some cases under consideration of additional information to inform "expert judgement" (see Phase I report, Associated 2016). General steps for implementation of the method are provided in Appendix A (Associated 2016). Further information on determination of critical flows is found in Section 2.4.

2.3.1 Transect Selection

Stream reaches of interest were identified through extensive review of available literature and data such as fish habitat inventories, Sensitive Habitat Inventory and Mapping (SHIM) maps, fish enumeration reports, inventories of fish barriers, as well as the B.C. Stream Macro-Reach spatial dataset, which supplied reach gradient information for the study streams. Knowledge of local fisheries experts and TEK were used where available to guide selection of stream reaches of interest.

Transects for assessment of spawning habitat were located in glides and pool tail-outs, whereas transects for assessment of juvenile fish rearing and insect production were located in riffles. Instream habitat surveys were completed in 2016 during the summer low flow season in all stream reaches of interest to ensure that study transects would be representative of reach conditions. Rapid Habitat Assessment is a type of instream survey that involves mapping fluvial habitat features with the use of a high accuracy handheld GPS unit (Trimble GeoXT, Trimble, Inc.). While walking the stream, geographical limits of pools, glides and riffles were mapped and the maximum water depth, bankfull width, and wetted width were recorded for each. Further relevant information, such as stream modifications, fish barriers, and water diversions were noted as well. Mapping a segment of stream by habitat type (riffle, pool, glide, etc.) allows for stratified sampling by habitat type. Each habitat type is mapped for the entire reach and the proportions are calculated by length. Cross-sections are then chosen by habitat type (Jowett & Richardson 2008). The following habitat types were identified:

- Riffles: shallow sections where the water approaching the riffle must rise upwards and converge with water near the surface, creating a turbulent surface: specifically with a wetted width: mean depth ratio of >50 (Dunne & Leopold 1978);

- Pools: deep sections with low flow velocity compared to nearby riffles, specifically with W: D ratios <20 (Dunne & Leopold 1978);
- Glides: shallow sections with little to no surface turbulence, specifically with intermediate W: D ratios of 21-49 (Dunne & Leopold 1978).

Post-fieldwork data processing involved dividing the streams into reaches based on the habitat type length proportions and average conditions during the rapid assessment. Habitat types evaluated in this approach were limited to glides and riffles to correspond with available HSI curves. The mean wetted widths and depths were calculated for riffles and glides by reach, along with a 95% confidence interval for each. Subsequently, riffles and glides that were representative of average reach conditions (i.e., had widths and depths within the 95% confidence interval) were re-visited to further assess their suitability as WUW transects. The following considerations were made in the WUW transect selection process:

- **Access**: transects with reasonable and consistent access were prioritized to ensure efficient use of time.
- **Safety:** site conditions are safe under all flow conditions and no other hazards (e.g., livestock, dogs, leaning trees) exist.
- **Habitat type:** Transects of a suitable habitat unit for the species and life stage of interest were selected (i.e., glides for spawning, riffles for rearing). Substrate conditions in the transect were also visually assessed to ensure they appeared suitable for life stage/species needs (i.e. spawning sized gravel for Kokanee). It was attempted to locate riffle and glide transects in close proximity to allow simultaneous measurement. Where known, documented spawning locations were selected.
- **Bank and site stability:** stable channels were prioritized to ensure consistent transect conditions over the course of the study. Transects with active bank erosion or showing signs of livestock activity or high public use were avoided.
- **Discharge measurement:** For glides, is the transect suitable for discharge measurement under a range of flows (i.e., relatively uniform, laminar, homogenous flow conditions, no debris, boulders or undercut banks, stable perpendicular flow angle)?
- **Hydrometric monitoring**: Is there a suitable spot for a hydrometric station nearby?

The number of transects and the required field intensity level for each creek were determined by the quality of the habitat and fish production from a given stream, the total length of stream reaches of interest, uniformity of stream habitat conditions, budget, as well as the necessity to be able to complete a full round of measurements on a given creek in one day. The number of transects installed per stream ranged between two and six. At almost all of the measurement locations, hydraulically linked riffle (rearing) and glide (spawning) transects were installed. The selected transects were marked by hammering flagged rebar pins into the banks above the high water mark. For each transect set, a minimum of two benchmarks were installed in nearby trees and boulders with lag bolts and anchor bolts to enable surveying of the transect. In total, 63 WUW transects were installed.

2.3.2 WUW Field Data Collection

Field data collection commenced in late summer of 2016 and continued to spring of 2018. In general, 8-10 measurements were taken at each transect. The cross-sectional profile of transects can change considerably from year to year, especially after a sizeable freshet as observed in 2017. Transect changes often lead to changes in the WUW vs. flow relationship, which reduces consistency in multi-year studies. Therefore, the bulk of the data was collected between June and September of 2017. Field visits were timed to commence immediately post-freshet, when channel forming flows had receded and the streams were wadeable, and continued through the lowest flows of the 2017 summer season (generally in early September). Information from real-time hydrometric stations was used to determine the most beneficial timing of field measurements over a representative range of streamflows. A small number of transects experienced such major channel changes during the 2017 freshet that they had to be abandoned and new transects were installed in June 2017 to replace them.

During each measurement, a 50 m tape was stretched across the stream and anchored to the rebar pins used to flag the transect. Measurement locations were always recorded from the left bank headpin to provide consistency between visits. Field measurement of WUW data is similar to discharge measurement described in Section 2.1 and consists of measuring depth and velocity at over 20 panels at each transect. The SonTek FlowTracker was used for measurement in the glide transects to concurrently produce high-quality discharge measurements. A Swoffer velocity meter was used for measurement in riffle transects. It has a larger sample volume than the FlowTracker, and was deemed more suitable for determining average panel velocities in highly variable and sometimes turbulent riffle conditions, which should be avoided while using the FlowTracker (SonTek 2016). As described in Section 2.1, velocity readings were taken at 60% of the water depth from the surface for depths below 0.75 m, and at 20% and 80% for depths above 0.75 m (WSC 2015). General information was gathered at each transect, including changes in channel condition that would affect the transect hydraulics. Transect photos looking up and downstream from the center of the transect were taken during each visit to provide a visual record.

The timing of visits proved challenging in several streams where high freshet flows were immediately followed by very low flows (e.g., Vaseux Creek, Shuttleworth Creek). Where data gaps were identified, additional visits were conducted pre-freshet in 2018 to reduce the likelihood of transect changes during the subsequent freshet. However, in Inkaneep Creek, a large landslide occurred on April 9, 2018 upstream of the sampled reach rendering it inaccessible. This left an incomplete data set for the entire creek and the shape of the WUW was be difficult to discern. An effort was made to model the shape of the curves with available transect survey. The modeling effort included combining all field data collected to create depth and velocity profiles for 5 cm wide cross-sectional cells. As well, for each cell, profiles were created for calculated cross-sectional area and discharge. Surveying and depth data were used to create a rating curve and cross-sectional bed profile. The trajectories of each cell to increase in cross-sectional area and discharge were plotted by total cross-sectional area and total discharge calculated per visit. These relationships were used to calculate hypothetical depth and velocities for discharge ranges using simple discharge and area formulas. Outputs were then cross-referenced with the available rating curve points. Modeled outputs for depths and velocities were overlaid on measured WUW values. This method was only used on glide transects as depth data and surveyed water surface elevations proved difficult to reconcile in riffle transects (non-laminar flow).

2.3.3 Analytical Methods

The relationship between WUW and streamflow illustrates how the amount of useable habitat changes over a range of flows. This information is then used to further refine the Okanagan Tennant EFNs and to recommend stream-specific EFNs. Streamflow information at the transects was collected as part of each measurement. The following sections describe how WUW was calculated (Section 2.3.3.1) and how the WUW vs. flow relationships were established (Section 2.3.3.2).

2.3.3.1 *Calculation of WUW*

The depth and velocity field data from each transect measurement were transferred to a series of Excel workbooks. The WUW at each panel *(j)* is calculated by multiplying the width of the panel by the probability of use *(p)* for a given fish species and life-stage. The WUW of a transect at a given discharge is the sum of all panel WUWs, where *n* = the total number of panels:

$$WUW\ (m) = \sum_{j=1}^{n} p_j * panel\ width_j$$

The probability of use is provided by HSI curves for each species and life stage. The curves define probability of use values (0 to 1) separately for water depth and velocity, which are then multiplied to produce a composite probability for each panel (*j):*

$$p_j = p_{depth} *\ p_{width}$$

While it is ideal to create HSI curves specific to a species and region, the timeline and budget of this project did not allow for a complete Okanagan HSI curve study. The following HSI curves valid for B.C. were supplied by the B.C. Ministry of Environment and Climate Change Strategy (Ptolemy pers. comm. 2017):

- Juvenile Rainbow rearing (fry and parr life stages);
- Juvenile Steelhead rearing;
- Juvenile Salmon rearing (Coho and Chinook);
- Generic insect production for use in rearing (riffle) transects;
- Kokanee spawning;
- Rainbow spawning;
- Chinook spawning;
- Coho spawning; and
- Steelhead spawning.

The supplied HSI curves were originally developed for Water Use Plans by a team of B.C. specialists. Informal validation of the curves was based on spawner enumerations in the context of meso-habitat conditions over several years of reach-level surveys in other B.C. watersheds. Review of the supplied HSI curves by the project team led to several adjustments of the curves for the Okanagan, discussed in greater detail below. The final HSI curves used in this project are provided in Appendix D. No further field validation of the HSI curves was possible due to the extensive field effort that would be required.

Adjustment of the HSI curve for Chinook spawning were made to reflect the smaller body size of the spring-run Chinook found in Okanagan River tributaries compared to the larger-bodied summer-run Chinook that the initial HSI curves were provided for. Further, summer-run Chinook typically spawn in large river mainstems where depths and velocities differ substantially from those in the smaller streams typically used by spring-run Chinook. For this project, HSI curves developed for spring-run Chinook in the Nicola River (approximately 100 km from the study area) were used (Triton 2009). While the Nicola River is larger than our study streams, it was considered the best available information.

The initial set of HSI curves did not include curves for Sockeye spawning and none were readily available from the literature. As a result, HSI curves for this project were constructed from habitat data collected during Sockeye spawner enumerations in the Okanagan River over several years. The mainstem Okanagan River is larger than the study streams and generally has greater water depths, which results in some uncertainty regarding the suitability of HSI curves in smaller streams. However, no Sockeye spawning habitat data was available from smaller tributaries and this information was considered the best available data.

Due to extensive spawning habitat loss from diking and channelization of the Okanagan River, Sockeye spawning areas become saturated quickly in high run years. Preferences for depth and velocity for Sockeye redd locations are difficult to determine if the choice of locations is density-dependent. Therefore, only data from 2001, 2002, and 2003 were included because these were not years of high spawner abundance.

Only data from the two most natural reaches of the Okanagan River were included in HSI curve development: a "natural" reach between McIntyre Dam and the Highway 97 Bridge near Oliver; and a "semi-natural" reach extending from the Highway 97 Bridge downstream to Vertical Drop Structure (VDS) 13 just north of Oliver. The reaches were chosen because they exhibited varieties of depths and velocities with higher heterogeneity of habitat types, and they had a larger quantity of spawning area meaning that locations were not confined by other factors.

Frequency analysis of depth and velocity measurements at observed Sockeye redds was conducted to determine preference. Data was analyzed in Excel by performing the following steps (Bovee & Cochnauer 1977):

1. The depth and velocity data was split into bins of 0.1 m and 0.1 m/s, respectively, over the observed range of data.
2. The number of individual redds in each bin was tallied.
3. For each parameter, the bin with the highest tallied number of redds (greatest frequency) was considered the optimum and assigned a probability of use = 1.0.
4. The probability of use for all other bins was calculated by dividing the number of redds in the bin by the number of redds in the "optimum" bin.
5. The probabilities of use were plotted for each of the bins.
6. Probability of use was then calculated for each 0.01 m or 0.01 m/s increment by straight-line interpolation between bins. This produced continuous probability of use curves for depth and velocity over a range of 0 to 4.0 m or m/s, respectively, corresponding to those provided by the B.C. Ministry of Environment and Climate Change Strategy.

The range, shape, and optimum conditions of the resulting Sockeye HSI curves were compared to the only available reference curves which are from Sockeye in the Cedar River, WA (WDFW 2004), as well as the initially provided spawning curves for Kokanee (same species though smaller-bodied) and Coho (similar body size). Following discussion within the project team, the Sockeye depth HSI curve was finalized without further adjustments; the Sockeye velocity HSI curve was finalized after the ascending limb was adjusted slightly to match that of the Coho HSI curve. All HSI curves adopted for the Okanagan EFN project are provided in Appendix D.

2.3.3.2 *WUW Curve Fitting*

Definition of the WUW vs. flow relationships for each applicable species / life stage involved fitting nonlinear regression models to the combined transect data from the appropriate habitat units. In riffle transects, flow is often turbulent and is obstructed by substrate resulting in an inaccurate total calculated discharge. Therefore, flow values from adjacent glide transects were used in all of the WUW analysis.

All spawning assessments utilized data from glide transects. Juvenile rearing assessments utilized data from riffle and glide transects but separate WUW curves were fit to each. Insect production assessments utilized data from riffle transects. Curve fitting was completed in the software R (R Core Team 2015) using the packages *nlstools* (Baty et al. 2015) and *investr* (Greenwell and Schubert Kabban 2014). Plots were produced in base R and with the package *ggplot2* (Wickham 2016). The following procedure was followed for each species / life stage and stream:

1. **Visually inspect data** for each transect by plotting WUW vs. flow.
2. **Fit curve to each transect** separately to assess likely WUW peaks, data gaps, or curve fitting problems.
3. **Standardize WUW between transects**. WUW values were standardized between transects of a given stream to account for between-site differences in channel size (Booker 2016). Standardization significantly removed scatter from the composite WUW curve fitted to all transects and better illustrated the relative decline of WUW with decreasing flows (the shape and slope of the WUW curve). Standardization procedures were automated in R and involved scaling each WUW observation as a proportion of the peak WUW value for each transect:

$$\%\, Max\, WUW = \frac{WUW}{Peak\, WUW}$$

   The resultant % Maximum WUW values lie between 0% and 100%. Where transect curves fit to the data in step two revealed that no measured data points coincided with the peak, the WUW values for a given transect were scaled relative to the peak of the fitted curve. This was necessary for Rainbow spawning WUW analysis in Naswhito and Whiteman creeks, Sockeye spawning in Shuttleworth Creek, and *O. mykiss* parr and Chinook fry rearing in Inkaneep Creek.

4. **Fit composite curve**. A composite curve was then fit to all transects in a given stream with the %Maximum WUW values as dependent variable and discharge as the independent variable. Curves were non-linear and had to possess certain characteristics: initial rise followed by a peak; typically, decay of WUW at higher flows; no negative values, WUW=0 at Discharge=0. Review of the habitat-flow and general ecological modelling literature (Bolker 2008) resulted in the selection of lognormal curves and Ricker curves as the most suitable curves to model the WUW vs. flow relationship. Both are defined over the range of positive values, are right-skewed and show initial exponential growth followed by decay at higher values of the independent variable. Example applications of the lognormal function to habitat-flow relationship modelling can be found in Lewis et al. (2004) and Turner et al. (2016).

   For some species and life stages with higher flow requirements (e.g., Steelhead spawning), WUW values were zero in the lower range of flows; therefore, the curve had to be offset from the origin and shifted to the right. For that reason, the additional option of using the Ricker function was explored. The Ricker curve typically goes through the origin but was modified to allow for an offset from the origin by adding the term b, a constant that is subtracted from the independent variable (discharge). The origins of the Ricker function lie in stock-recruitment modelling for fisheries management purposes (Ricker 1958). It has since become a standard choice for hump-shaped ecological patterns that are skewed to the right (Bolker 2008) as typically observed in habitat-flow relationships. Example applications of a standard and an adjusted Ricker curve for defining habitat-flow relationships are found in Lamouroux and Jowett (2005) and Booker (2016).

WUW vs. flow relationships for each study stream and each species/life stage of interest were thus estimated using one of the following forms:

Lognormal curve: $\% \, Max \, WUW_{avg} = \frac{a}{Q * b * \sqrt{2\pi}} * e^{-\frac{(\ln(Q)-c)^2}{2b^2}}$

Ricker curve: $\% \, Max \, WUW_{avg} = a(Q-b)^c * e^{-dQ}$

Where Q = discharge (m^3/s) and
a, b, c, and d are non-linear regression parameters estimated by the software

5. **Plot results and select best fit.** Both curve types were fit to the data and the best was selected based on standard model selection procedures such as visual inspection of the fit (e.g., peak coincides with data, offset from origin is properly represented, plot of fitted vs. observed values shows good agreement), low residual sum of squares, and lack of pattern and normality of the residuals. Further, an Analysis of Variance (ANOVA) was applied to the model fits to indicate whether one warranted selection over the other. Curve fitting procedures and goodness of fit assessment outputs were automated through the use of functions in R to ensure consistent procedures between streams and analysts.

   Upon inspection of the fitted WUW curves, it became evident that WUW peaks for Rainbow fry rearing often aligned with flows below the lowest measured data point due to the shallow depth and low velocity preferences of fry. This resulted in difficulty in defining the lower end of the WUW curve or prevented fitting of the curves entirely. As a result, final EFNs were not recommended for Rainbow fry rearing. Rainbow fry rearing habitat is not as limited by low flows as that of Rainbow parr, which have higher depth and velocity preferences (see HSI curves in Appendix D). This is supported by life history information for Okanagan Lake tributary streams, which indicates that parr habitat is limiting with respect to Rainbow production (Andrusak et al. 2006). Thus, Rainbow fry flow needs are likely sufficiently met by EFNs recommended for Rainbow parr rearing.

6. **Recommend Final EFNs**. Changes in WUW with flow were examined with a focus on the flow range between critical flows and the Okanagan Tennant EFN. Final recommended EFNs were either reduced from the Okanagan Tennant EFN, where changes in habitat (indicated by WUW) were deemed acceptable or left unchanged where they were not. In a small number of cases, Okanagan Tennant EFNs produced very low WUWs (i.e., <10%) despite the documented presence of fish populations. Frequently, the underlying naturalized flow estimates used to set Okanagan Tennant EFNs were considered uncertain in those cases. As a result, final recommended EFNs were adjusted upward as informed by the WUW curves and additional stream-specific information.

   Additional information considered to recommend EFNs included: spatial availability of habitat; the relative importance of a watershed to fish populations or system productivity; fish population estimates and their temporal variation; spawner enumerations and key locations; water temperature and temperature related issues; presence of barriers to fish passage such as falls or culverts; the effects of previous habitat alteration on stream productivity; and history of water management and flow augmentation.

Summer water temperatures were an additional consideration for EFN setting for juvenile fish rearing EFNs as well as spring Chinook migration and spawning. Both occur during the summer and coincide with peak water temperatures. It has been well documented that temperatures of approximately 21-22°C present migration barriers to most adult salmonids (McCullough 1999). Upper lethal temperatures for most juvenile salmonids fall within the range of 21-26°C but juveniles are generally limited in distribution to reaches with temperatures below 22-24°C. Optimum temperatures at which maximum growth is achieved are much lower, around 15°C (McCullough 1999). Thus, temperatures below 20°C were considered favourable for juvenile salmonid rearing (Koshinsky 1972a).

Final EFNs for a given period were recommended under consideration of fish periodicity for all species of interest. Priority was given to the species and life stage with the highest flow requirements, as higher flows than required for some species/life stages are on balance usually better than lower than required flows for others (Associated 2016). Further details on the specific method used to recommend EFNs for each stream are provided in Sections 3.1 to 3.18.

The Phase I report (Associated 2016) recommended calculating a WUW Index that scaled the WUW between the critical flow (Index = 0, see Section 2.4) and the Okanagan Tennant EFN flow (median naturalized flow or flow standard) (Index = 1). The WUW Index thus shows the change in WUW over a range of flow conditions that are typical for the time period. When examining changes in WUW between critical and median naturalized flows it became apparent that the WUW Index would frequently scale WUW over a very small range (e.g., 5-10% WUW), particularly during the summer and fall low flow season. Calculation of the WUW Index was not considered particularly informative for EFN setting in those cases, particularly where the range would fall within the confidence bands of the WUW curve. It was considered more informative to view the absolute change in WUW than to produce a scaled index over such a small WUW range. WUWs had already been scaled relative to their peak to standardize between transects during WUW curve fitting. The resulting WUWs between 0% and 100% made it easy to assess relative changes between two points on the WUW curve without calculation of the WUW Index.

Nonetheless, the WUW Index is useful for comparison of impacts between naturalized, residual and maximum licensed hydrographs. Residual and maximum licensed datasets are not yet available for all streams and the WUW Index percentile plots, as described in the Phase I report, should be prepared when all datasets are complete. An example plot is provided in Section 4.1 (Figure 4-1).

2.4 Critical Flow Analysis

The EFN setting procedures described in Section 2.3 require evaluation of habitat changes between the critical flow and the final recommended EFNs. Critical flow is defined in the WSA (Section 1.1). For our study, critical flows were generally intended to represent a point below which catastrophic consequences to fish populations may occur.

In the absence of stream-specific information, a common approach employed regionally is to apply a value of 5% LTMAD as a critical flow for juvenile fish rearing and 10% LTMAD for Kokanee spawning (McCleary pers. comm. 2019). Habitat information collected for WUW analysis in some streams during this study (Table 1-2) was used to further refine the critical flows where possible. Critical flow analytical methods were based on the *Standard Operating Procedure for Critical Riffle Analysis for Fish Passage in California*,

California Department of Fish and Wildlife [CDFW] (2017) and Thompson (1972). This methodology involves choosing critical riffles that are shallow and sensitive to changes in streamflow that may limit stream connectivity and impede fish migration, and are within reaches that are typically used for spawning. The method was applied to the riffle transects surveyed for WUW analysis, as well as few additional wide and shallow riffles at the mouth of streams that were deemed as possible barriers to migration during low flows. Most of the WUW transects are located mid-riffle, providing "average" riffle conditions, as opposed to conditions at the most shallow or sensitive portion of each riffle.

2.4.1 Critical Flow Criteria

Critical flows were determined by species and life stage based on a number of criteria related to riffle width retention for rearing life stages and minimum passage depths for adult life stages. Criteria were developed through review of literature and discussion within the project team. For parr rearing and insect production from riffles, it was recommended that at least 60% of the riffle area remain wetted (Ptolemy pers. comm. 2016; Thompson 1972; Neuman & Newcombe 1977). The wetted proportion of each riffle was calculated relative to the wetted width at a flow of 100% LTMAD in order to provide a point of reference and facilitate comparison between streams. For adult migration, passage depth criteria were defined based on minimum passage depths in riffles, which are typically the most shallow areas of a stream (Reiser & Bjornn 1979). A minimum of 25% of the wetted transect width (relative to wetted width at 100% LTMAD) must meet minimum depth requirements that vary depending on body size of the fish (Table 2-7; CDFW 2017, Thompson 1972).

In Tennant-only streams where no WUW data was collected, critical flows were set according to the %LTMAD-based approach described above, using 5% LTMAD as a critical flow for juvenile fish rearing and 10% LTMAD for Kokanee spawning. Further, case studies of Rainbow spawning success in Mission Creek (Wightman 1975) and 83 Mile Creek (Cartwright 1968) indicate that critical flows of 50% LTMAD are appropriate for Okanagan streams (Table 2-7). This approach was also applied in some WUW streams where the critical riffle analysis criteria could not be applied for a variety of reasons (e.g., depth criteria produced implausibly high flows, no data points at or near critical flows). Detailed information on the approach taken is discussed for each stream in sections 3.1 to 3.18.

Table 2-7: Critical flow setting criteria for Okanagan tributaries

Species/Life stage	Critical flow criteria	
	Where WUW data available	Tennant only streams*
Juvenile rearing	wetted width ≥ 60% width at 100% LTMAD	5% LTMAD
Insect production from riffles	wetted width ≥ 60% width at 100% LTMAD	5% LTMAD
Spring Chinook spawning	≥25% of transect width >=0.24 m depth	20% LTMAD (adult migration) 10% LTMAD (spawning)
Steelhead & adfluvial Rainbow spawning	≥25% of transect width >=0.18 m depth	50% LTMAD
Sockeye spawning	≥25% of transect width >=0.18 m depth	10% LTMAD
Kokanee spawning	≥25% of transect width >=0.12 m depth	10% LTMAD
Juvenile overwintering	n/a	5% LTMAD

**See Table 1-2 for EFN-setting methods used for each stream.*

2.4.2 Critical Riffle Analytical Methods

Critical riffle analysis for streams with WUW data was completed for each riffle transect in Excel according to the steps below. The resultant critical flows were then averaged for each criterion for all study riffles in a stream to produce stream- or each-specific critical flow recommendations.

- **Determine wetted width at 100% LTMAD** (provided by Associated 2019). Wetted width was plotted against discharge and a curve was fit to the data, from which wetted width at 100% LTMAD was calculated.
- **Parr rearing and insect production**. The proportion of wetted width, relative to that at 100% LTMAD, was calculated for each measured discharge (i) as:

$$\%wetted\ width_i = \frac{wetted\ width_{\ i}}{wetted\ width\ at\ 100\%\ LTMAD}$$

  The % wetted width was plotted against discharge and a curve fit to the data. The discharge at which wetted width declined below 60% was then calculated by inverse prediction.

- **Chinook spawning**. For each transect measurement, the proportion of the transect width meeting the minimum passage depth of 0.24 m was calculated according to the following equation:

$$\%\ transect \geq 0.24\ m = \frac{\sum panel\ widths \geq 0.24\ m\ depth}{wetted\ width\ at\ 100\%\ LTMAD}$$

  The % transect $\geq$ 0.24 m was plotted against discharge and a curve fit to the data. The discharge at which the % transect > 0.24 m depth declined below 25% was then calculated by inverse prediction. Where the resulting critical flow was implausibly high (i.e., much greater than naturalized flows), critical flow was either set based on a proportion of LTMAD (20% LTMAD during migration and 10% LTMAD during spawning) or to the weekly naturalized flows if the passage depth analysis indicated that no passage was possible at the %LTMAD critical flows. Stream-specific information and uncertainty in the naturalized flow estimates were carefully considered and are discussed in the results, where applicable.

- **Sockeye, Steelhead, Rainbow spawning**. For each transect measurement, the proportion of the transect width meeting the minimum passage depth of 0.18 m was calculated according to the following equation:

$$\%\ transect \geq 0.18\ m = \frac{\sum panel\ widths \geq 0.18m\ depth}{wetted\ width\ at\ 100\%\ LTMAD}$$

  The % transect $\geq$ 0.18 m was plotted against discharge and a curve fit to the data. The discharge at 25% transect width was then calculated by inverse prediction. Where this critical flow was implausibly high (i.e., much greater than naturalized flows), critical flow was set to 10% LTMAD.

- **Kokanee spawning.** For each transect measurement, the proportion of the transect width meeting the minimum passage depth of 0.12 m was calculated according to the following equation:

$$\%\ transect \geq 0.12\ m = \frac{\sum panel\ widths \geq 0.12\ m\ depth}{wetted\ width\ at\ 100\%\ LTMAD}$$

The % transect $\geq$ 0.12 m was plotted against discharge and a curve fit to the data. The discharge at 25% transect width was then calculated by inverse prediction. The average of that discharge for all study transects in a given stream produced the depth-based critical flow. Where this critical flow was implausibly high (i.e., much greater than naturalized flows), critical flow was set to 10% LTMAD.

A summary of the critical flow methods are given in Table 2-7. The above metrics were calculated for each riffle transect on a stream, where applicable (e.g., Chinook spawning was only assessed in those streams where Chinook occur). The results were then compared between transects and final recommended critical flows for each species/life stage were developed under careful consideration of the following:

- transect geometry (e.g., was the transect wide and shallow or narrow and deep);
- transect location relative to the reaches of interest for a given species/life stage (e.g., a transect near the mouth typically received higher priority than one located at the upstream extent of the spawning area);
- plausibility of the critical flows compared to naturalized flow conditions;
- stream-specific knowledge of fish populations (e.g., streams with a greater proportion of large-bodied Kokanee may require higher critical flows for passage);
- comparison to the WUW curves; and
- comparison to summer 30-day naturalized low flows at 1:5 year, 1:10 year, and 1:20 year return periods (Appendix B1 to B18, critical flows).

2.5 Flow Sensitivity Assessment

From an extensive review of habitat-flow studies that had been completed in British Columbia, it was evident that flows of 20% LTMAD are required to conserve adequate summer and winter rearing flows for juvenile fish and to maintain insect production in riffle habitats (Ptolemy & Lewis 2002). Water extractions from streams prone to natural flows below this 20% LTMAD threshold have the potential to interfere with EFNs (Ptolemy & Lewis 2002) and as a result, streams that experience flows below this threshold are considered 'flow sensitive' in the EFN Policy (FLNRORD & MOE 2016). This concept was applied in a project to identify and map the flow sensitivity status of land units (eco-sections) for both the summer and winter seasons (White & Ptolemy 2011a, 2011b). Standard low flow frequency analyses that utilize a 30-day or 60 day duration are well suited for assessing seasonal flow quantities for the purpose of environmental flow assessment (e.g., Beecher et al. 2010) and for establishing 'flow sensitive' status. For this Okanagan EFN study, a 1-in-2 year 30-day (4-week) duration was used for determining summer and winter flow sensitive status. Time periods for summer flows are July 1 to September 30 and winter flows run from November 1 to March 31. The specific methodology for calculating the 1-in-2 year 30-day flow is described in the methods section of the report on the development of the streamflow datasets (Associated 2019). During the process of developing Okanagan EFNs, the Province began developing guidelines and processes for determining flow sensitivity in streams. The purpose of adding this assessment, which is outside of the Okanagan Tennant and WUW method, is for comparing results and processes.

3.0 RESULTS

This section presents recommended EFNs for 18 Okanagan streams developed using the methods described in Section 2.0. Each subsection outlines watershed characteristics relevant to EFN setting and summarizes available literature. Stream-specific data considered in the EFN setting process is described and the recommended EFNs are presented in summary tables and figures. Additional stream-specific information is provided in Appendices B1 to B18, including:

- transect locations, descriptions and photos;
- habitat mapping;
- discharge and water temperature records;
- stream-specific flows and periodicity information;
- detailed weekly Okanagan Tennant, WUW and final recommended EFNs;
- WUW curves;
- critical flow assessments; and
- percentile flow data.

3.1 Coldstream Creek

Coldstream Creek is a tributary of Kalamalka Lake, which then flows into Okanagan Lake through Vernon Creek. Coldstream Creek flows from the east side of the Okanagan Basin to its confluence with Kalamalka Lake in the District of Coldstream just east of Vernon, B.C. The Coldstream Creek watershed is approximately 206 km^2 (Associated 2016). Coldstream Creek flows from its relatively steep headwaters onto the valley floor near the community of Lavington. It traverses the low gradient valley floor for a considerable distance before discharging into Kalamalka Lake. An alluvial aquifer (3266) underlies the valley floor from Lavington to the Kalamalka Lake confluence (Associated 2017). A summary of creek characteristics is provided in Table 3-1 and additional stream-specific data is provided in Appendix B1.

The lower reaches of Coldstream Creek flow through agricultural and urban areas and common impacts such as bank modifications, bank erosion from livestock access, riparian clearing, and water quality problems have been identified (Ecoscape 2010, Larratt Aquatic 2011). Nonetheless, its low gradient, pool-riffle morphology, suitable spawning substrate, and relatively abundant riparian vegetation observed during habitat surveys (Table B1-1, Appendix B1) contribute to its status as one of the most prolific Kokanee spawning streams in the Okanagan (Aqua Resource Management Inc. 2001). The creek is accessible to Kokanee and Rainbow spawners from Kalamalka Lake between the mouth and a barrier posed by an old spillway weir at Coldstream Ranch, approximately 7 km upstream. A further barrier, the culverts below the Highway 6 crossing immediately upstream of Coldstream Ranch, were replaced in 2012 by wider culverts that allow for fish passage. The stream is further known to support resident Rainbow and non-salmonid fish species (Associated 2016).

Study transects in Coldstream Creek were located downstream of the fish barrier at Coldstream Ranch. All four paired riffle and glide transects (eight total) were situated in the section of the creek that contains nearly all Kokanee spawning activity on an annual basis (Figure B1-2, Appendix B1). This section extends between the mouth of the creek to several enhancement weirs installed in Coldstream Park (Webster 2014).

Coldstream Creek (along with Mill Creek) has the highest base flows of any of the study streams and experiences significant groundwater inflows in the valley-bottom reaches (Associated 2019). Past reports have indicated the favorable flow regime to be the greatest asset of fish production in the creek (Wightman & Taylor 1978). One hydrometric station was installed in 2016 to collect hydrometric data for this project. The station is situated at McClounie Road and has collected data since 2016 to the present. Further information on the Coldstream Creek hydrometric station is provided in Appendix B1.

At present, there are 40 points of diversion in the watershed and four pending water licence applications (Associated 2019) and the stream is currently fully recorded for irrigation unless supported by storage (FLNRORD 2016). Greater Vernon Water (GVW) is the main water supplier with developed water storage at King Edward Lake Reservoir. There are no known inter-basin water transfers to or from Coldstream Creek (Associated 2016). Under natural conditions, Coldstream Creek is not 'flow sensitive' during summer and winter with naturalized flows above 20% LTMAD (Table 3-2).

Table 3-1: Coldstream Creek description

Drainage Area	206 km^2
Median Elevation	1040 m
WSC station	08NM142 (Active) – Coldstream above Municipal Intake (1967-present) 08NM124 (Historic) – Coldstream near Lavington (1959-1979) 08NM154 (Historic) – Coldstream at the Mouth (1969-1970) 08NM179 (Historic) – Coldstream above Kalavista Diversion (1970-1982)
ONA station	08NM589 – Coldstream Creek near McClounie Road (2016-2018)
LTMAD	0.748 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, non-salmonid fish (MOE 1982)
Land use	Agriculture and urban development in lower reaches. Forestry and recreation in upper reaches (Associated 2016)

Okanagan Tennant EFNs for Coldstream Creek were developed in accordance with the methods outlined in Section 2.2. Naturalized flow data was provided by Associated (2019) with an estimated data quality rating of B (data error between 10% and 25%); residual and maximum licensed flow estimates were not available at the time of reporting. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. Contrary to most other study streams, naturalized flows in Coldstream Creek are much greater than flow standards during the non-freshet period, as were residual flows measured during this project and historically. Therefore, WUW information from the study transects was used to adjust the Okanagan Tennant EFNs upward. The recommended EFNs are intended to maintain current levels of fish production in Coldstream Creek by protecting flow conditions that local populations have become adapted to. A summary of the recommended EFNs is provided in Table 3-3, including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-1, Figure 3-2, and Appendix B1, and flow sensitives in Table 3-2. Critical flows were calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in Coldstream Creek is provided at the end of this section.

Table 3-2: Flow sensitivities in Coldstream Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.360	48%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.248	33%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-3: EFN summary table for Coldstream Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m^3/s)	Recommended EFN (m^3/s)				Critical flow	
		Median (m^3/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production[a]	April 1 – Oct 31	0.150	20%	0.250	0.250	33%	0.250	0.543	0.075	10%
Rainbow spawning	20-May – 10-Jul	1.06	142%	1.00	0.100	133%	0.704	1.00	0.419	56%
Kokanee spawning	22-Sep – 23-Oct	0.150	20%	0.250	0.250	33%	0.250	0.250	0.164	22%
Rainbow overwintering	Nov 1 – March 31	0.150	20%	n/a	0.250	33%	0.250	0.295	0.075	10%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

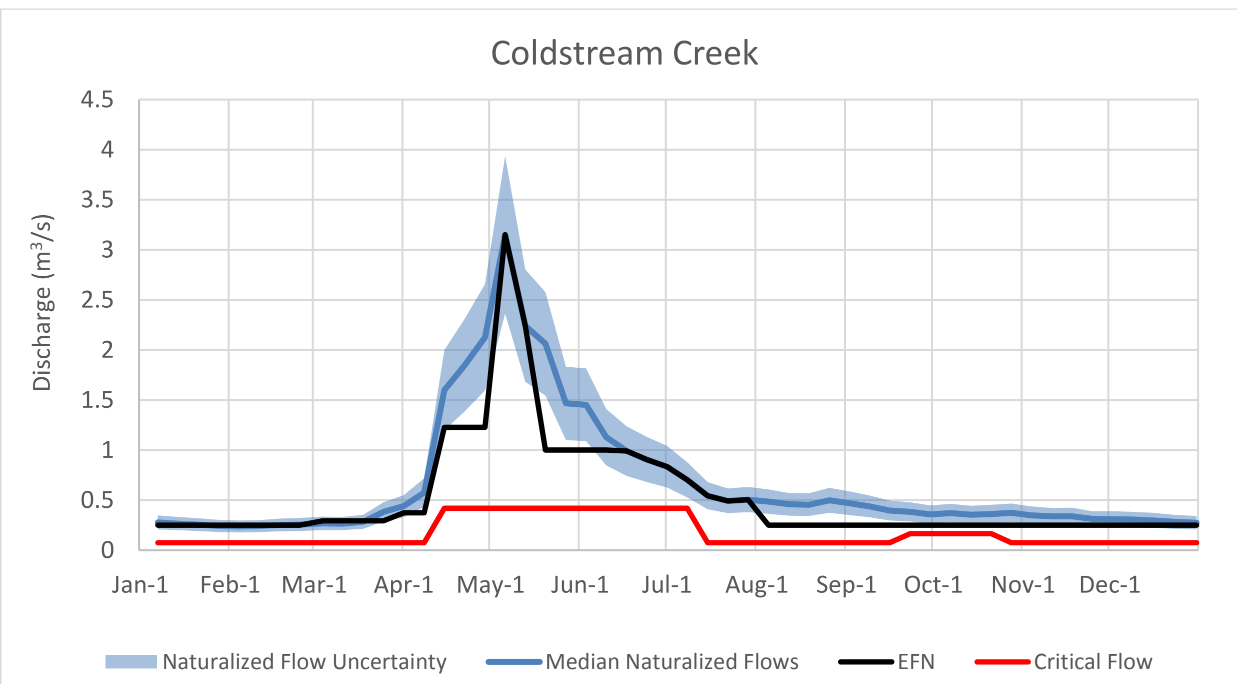


Figure 3-1: Weekly EFNs, critical flow and streamflows in Coldstream Creek

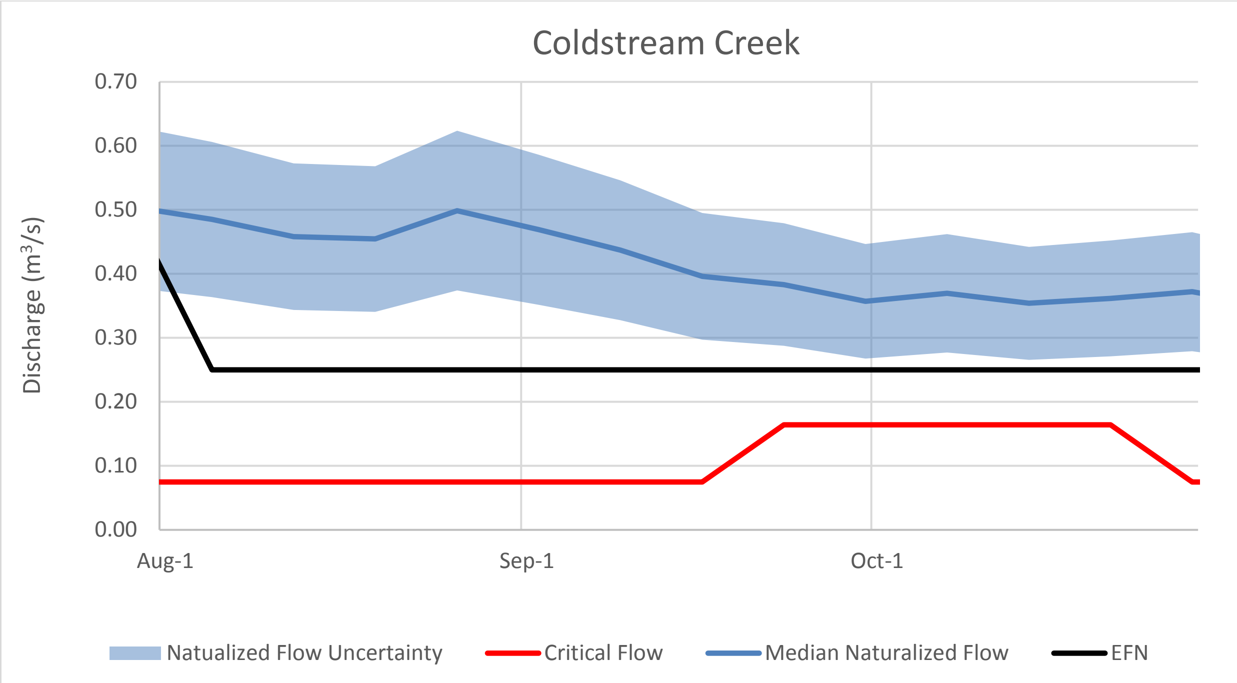


Figure 3-2: Weekly EFNs, critical flow and streamflows during the summer and fall period in Coldstream Creek

Rainbow parr rearing

The recommended EFN for Rainbow Parr Rearing is 0.250 m^3/s (33% LTMAD), which maintains approximately 80% of maximum WUW in glides and 40% in riffles (Figure B1-5, Appendix B1). The recommended EFN is near the lowest late summer flows observed at the ONA hydrometric station between 2016-2018 (Figure B1-3, Appendix B1), indicating that the EFN is generally achieved under current water use conditions even during dry years (2017 and 2018). Photos of habitat conditions in Coldstream Creek at the recommended EFN flows are provided in Plate 3-1.

The recommended critical flow for Rainbow parr rearing is 0.075 m^3/s (10% LTMAD; Table B1-3, Appendix B1). While riffle analysis indicates that 60% of maximum wetted width is maintained at flows of approximately 0.055 m^3/s (7% LTMAD), no measurements were collected below 0.250 m^3/s and there is considerable uncertainty in this estimate. 10% LTMAD is recommended as the critical flow as opposed to the 5% LTMAD routinely applied by FLNRORD, to reflect the naturally high baseflows in Coldstream Creek and consistency with the results of the riffle analysis. Koshinsky (1972) recommended 0.17 - 0.20 m^3/s as a minimum flow for incubation, rearing and fry migration, which is lower than the EFN but higher than the critical flow recommendation.

The recommended EFN is approximately equal to the lowest median weekly flow observed at WSC station 08NM179 (Coldstream Creek above Kalavista Diversion, operational from 1970-1982) for the summer and fall low flow period (mid-July to late September). The recommended EFN also maintains approximately 45% of maximum insect production WUW (Figure B1-6, Appendix B1) and is likely sufficient to maintain the relatively cool water temperatures (daily maximum <16°C) observed at the ONA hydrometric station between 2016 and 2018, which are favorable to Rainbow rearing (Figure B1-4, Appendix B1).

Rainbow spawning

The recommended EFN for Rainbow spawning is 1.00 m^3/s (134% LTMAD, Figure B1-7, Appendix B1), which maintains maximum (~100%) Rainbow spawning WUW while also maximizing Rainbow parr rearing WUW during freshet. The recommended EFN is slightly lower than the median naturalized flows during the spawning period and residual flows are generally above the EFN from late April to mid-June (Appendix B1, Figure B1-3), indicating that the EFN can be met during most years. Photos of habitat conditions in Coldstream Creek at the recommended EFN flows are provided in Plate 3-2.

The recommended critical flow for Rainbow spawning is 0.419 m^3/s (56% LTMAD, Table B1-3, Appendix B1) based on the passage depth criterion (Table 2-7).

Kokanee spawning

Coldstream Creek is one of the primary Kokanee producing streams in the Okanagan Valley and therefore protecting spawning flows in this stream is vital. The recommended EFN for Kokanee spawning is 0.250 m^3/s (33% LTMAD), which maintains near maximum WUW (~90%; Figure B1-8, Appendix B1). Flows observed at the ONA hydrometric 2016-2018 during the Kokanee spawning period were between 0.3 and 0.5 m^3/s (Figure B1-3, Appendix B1) and indicate that the EFN is achievable under current water use conditions even during dry years (2017 and 2018). Median daily flows observed at WSC station 08NM179 (Coldstream Creek above Kalavista Diversion, operational from 1970-1982) during the Kokanee spawning season ranged from 0.27-0.33 m^3/s, which is also above the EFN. Minimum passage depth for Kokanee (0.12 m over $\geq$25% of riffle width) was achieved at all riffle transects at the recommended EFN. Photos of habitat conditions in Coldstream Creek at the recommended EFN flows are provided in Plate 3-1. The recommended EFN is similar to the minimum spawning flow of 0.23 m^3/s suggested by Koshinsky (1972).

The recommended critical flow for Kokanee spawning is 0.164 m^3/s (22% LTMAD; Table B1-3, Appendix B1) based on the passage depth criterion (Table 2-7). Although no measurements were collected below 0.250 m^3/s and there is some uncertainty related to this value, it is well below the summer 1 in 20-year return period 30-day Naturalized Low Flow (Table B1-4, Appendix B1) and is therefore highly likely to be exceeded.

Plate 3-1: Coldstream Creek habitat conditions at flows near the recommended Rainbow parr rearing and Kokanee spawning EFNs (0.250 m³/s)


Glide 2 at 0.308 m^3/s (41% LTMAD)


Glide 3 at 0.282 m^3/s (38% LTMAD)


Riffle 2 at 0.308 m^3/s (41% LTMAD)


Riffle 3 at 0.282 m^3/s (38% LTMAD)

Plate 3-2: Coldstream Creek habitat conditions at flows near the recommended Rainbow spawning EFN (1.00 m³/s)


Glide 3 at 0.909 m^3/s (122% LTMAD)


Glide 2 at 1.01 m^3/s (135 % LTMAD)

3.1.1 SEFA analysis trial in Coldstream Creek

During this study, it was identified that the SEFA program may provide utility in modelling habitat information for those streams where WUW field data was lacking. In Coldstream Creek, flows remained high during the study season and low flow WUW data could not be obtained, leading to greater uncertainty in the WUW curve at lower flow rates. Critical riffle analysis required extrapolation beyond the range of observed data, which led to increased uncertainty. SEFA analysis was completed to assess whether the model could provide further information on habitat condition at lower flows. The SEFA model requires fewer field transect measurements than WUW analysis, but incorporates detailed transect elevation surveys and substrate data that are then used to model habitat conditions over the range of flows.

The WUW analysis in Coldstream Creek was based on 11 field measurements of depth and velocity at eight transects as described in Section 2.3.2. The SEFA analysis used the station, velocity, and depth data from two of the WUW field measurements (high and moderate flows) as well as detailed cross-sectional elevation surveys and substrate data from each transect. Ideally, a third flow measurement at low flows would be incorporated but was unavailable for reasons mentioned above. The modelling parameters differed slightly between SEFA and WUW: for Rainbow parr rearing EFNs, SEFA only utilized information on invertebrate production from riffles whereas WUW analysis also used parr rearing HSIs applied to riffles and glides. Critical flow analysis used the same parameters between the two modelling approaches (passage depth for Kokanee and riffle width for parr rearing). A description and full results of the SEFA analysis completed for Coldstream Creek is presented in Appendix C.

SEFA produced similar, though not identical, information on the habitat-flow relationships as the WUW analysis. Kokanee spawning WUW peaked at higher flows and declined slightly more rapidly than the curve produced by the WUW analysis; however, differences in the lower flow range were very small. The SEFA model showed maximum habitat suitability at 0.52 m^3/s (70% LTMAD) with a rapid decrease below 0.15 m^3/s (20% LTMAD). The WUW curve peaked at slightly lower flows of approximately 0.37 m^3/s (Figure B1-8, Appendix B1). The recommended EFN from the WUW analysis was 0.250 m^3/s (33% LTMAD) and this value would also be supported by the SEFA analysis. For critical flows, the SEFA model recommended that 0.22 m^3/s (30% LTMAD) should be the minimum flow to maintain at least 25% riffle width deep enough for passage. In contrast, the critical riffle analysis recommended a critical flow of 0.164 m^3/s (22% LTMAD) though uncertainty was high for lack of low flow measurements. Overall, EFN recommendations would be similar in this case though critical flow recommendations based on SEFA would be higher.

Similarly, for Rainbow parr rearing, SEFA predicted a slightly more rapid decline in insect production with dropping flows though EFN recommendations would likely be similar. SEFA predicted that wetted riffle widths drop off considerably below 0.11 m^3/s (15% LTMAD) and decline to approximately 50% of bankfull wetted width at 0.052 m^3/s (7% LTMAD); this is quite similar to the results of the critical riffle analysis (Table B1-2, Appendix B1) which indicated that 60% of bankfull wetted width is maintained at 0.055 m^3/s. As a result, critical flow recommendations would be similar between the two models.

The SEFA model is a promising program for EFN investigations but like all models, the relevance of the outputs relies heavily on the selection of the data inputs. It is possible that model results at low flows would have been more informative if low flow field surveys had been obtained. With the data inputs listed above, the SEFA model provided similar though not identical information to support EFN and critical flows setting. Application of the SEFA model is most useful where field surveys can be obtained over the full range of flows (low, moderate, and high) but resource constraints prevent the number of field visits typically required for full WUW analysis (8-10).

Using SEFA to extrapolate beyond the measured range to fill in gaps in field data is less certain. Running the SEFA analysis for a dataset with a complete range of WUW observations and excluding the low flow observation; then comparing SEFA-modelled habitat suitability at low flows and critical passage flows to those derived from WUW and critical riffle analyses would provide further information on SEFA's suitability for this purpose. However, extrapolation beyond the range of measured data generally introduces a high degree of uncertainty.

Several advantages and disadvantages of the SEFA model compared to WUW analysis are listed below:

Advantages:

- Less fieldwork – streams only need to be visited 3 times per season (high, medium and low flows). This simplifies field planning and reduces the frequency of visits.
- Gathering more data (substrate, surveying, gradient) on the transect allows for more options in future analysis, such as analyses in programs like HEC-RAS, which could be used for stream engineering projects. WUW data is somewhat limited to EFN analysis with few options for other uses.

Disadvantages:

- More intensive fieldwork – the requirement for detailed transect surveys and substrate measurements adds significant time and some additional expertise required during field visits. This limits the number of transects that can be surveyed in one day.
- Manning's Roughness values have a large influence on modeled flow velocities, particularly at low flows which are often most critical to EFN setting. Manning's Roughness values cannot be adjusted within the SEFA model. In SEFA trials completed for several EFN streams, SEFA-modeled velocities were very different from measured velocities. This results in differing habitat suitability estimates between SEFA and WUW analysis. Further comparison between modeled and measured velocities are advised before applying the SEFA model for EFN setting.

3.2 Equesis Creek

Equesis Creek is a tributary to Okanagan Lake, flowing from the west side of the Okanagan Basin into the northwest arm of Okanagan Lake south of Vernon, B.C. over a total length of 27 km (Wildstone Resources Ltd. 1997). The Equesis Creek watershed is approximately 204 km^2 (Associated 2016) and has several lakes in its headwaters including Pinaus Lake, which had an outlet dam built in 1922 to control downstream flows. A summary of creek characteristics is found in Table 3-4 and additional stream-specific data is provided in Appendix B2.

In the lower reaches, Equesis Creek flows over an alluvial fan that has merged with the Naswhito Creek fan. Water losses and gains across the fan are unknown. The lower reaches of Equesis Creek (downstream of Westside Road) flow through agricultural fields and bank modifications, bank erosion from unrestricted livestock access, and riparian clearing were identified during habitat surveys for this project. Severe downcutting of the streambed and associated bank erosion was observed in the lower 2 km. Further, extensive flooding and sediment deposition during the 2017 and 2018 freshets resulted in dredging work near the mouth. The lower reaches of Equesis Creek have some impairment due to channelization, but have medium to good quality riparian vegetation (Eyjolfson & Dunn 2016). The reach upstream of Westside Road shows moderate development impacts and areas of erosion, with some unscreened water intakes (Eyjolfson & Dunn 2016). The intermediate and upper reaches of Equesis Creek mostly traverse forested lands with some agricultural use.

Equesis Creek is an important spawning and rearing area for fluvial and adfluvial Rainbow, and an important producer of Kokanee (Wightman & Taylor 1978). The entire length of Equesis Creek is of suitable gradient for spawning (Anonymous 1969), and it was ranked #3 for fisheries production capacity in tributaries to Okanagan Lake (Wightman & Taylor 1978). Several irrigation weirs were documented as barriers to fish passage in previous reports (Anonymous 1969; Wightman & Taylor 1978). Habitat surveys for this project revealed that several of them have either been removed, altered or deteriorated to a point where they have become passable. The irrigation weir immediately below Westside Road has become partially passable and Kokanee were documented to spawn in the reaches upstream (Louis 2012). The largest of the barriers, an irrigation dam located 4.8 km from the mouth (Eyjolfson & Dunn 2016), was identified to block Kokanee and Rainbow adult migrations. However, this dam was impacted by high flows during the 2018 freshet and is now partially passable (Louis pers. comm. 2019). Annual Kokanee spawner enumerations generally find the majority of spawning activity occurs below Westside road. Annual spawner reports make note of a higher proportion of large-bodied Kokanee in Equesis Creek than adjacent Naswhito and Whiteman Creeks during some years (Louis 2016). Rainbow spawning activity likely extends much further upstream.

A total of three glide and three riffle transects were established in Equesis Creek in August of 2016 (Figure B2-3, Appendix B2). All transects were located downstream of the irrigation dam fish barrier 4.8 km from the mouth and mostly within the documented Kokanee spawning reaches below Westside Road. One paired glide riffle transect was situated upstream of Westside Road. The lowermost transects (1 and 2) near the mouth had to be moved following the 2017 freshet due to extensive channel changes at the original locations.

Equesis Creek has relatively high flows during the non-freshet period due to flow augmentation from storage in Pinaus Lake (Associated 2019). The Okanagan Indian Band holds several storage licences on Pinaus Lake that are managed for downstream irrigation users and releases are also jointly managed with FLNRORD to supplement natural streamflows for fish when needed (Dobson 2008). There are no active

WSC hydrometric stations on Equesis Creek though historical data exists. Three hydrometric stations were installed in 2016 to collect hydrometric data for this project (Figure B2-3, Appendix B2). The station near the mouth had to be moved further upstream post-2017 freshet due to extensive flooding and sediment deposition in the area. A real-time station installed just downstream of Westside Road continues to operate presently. A third station was installed upstream of Westside Road. At present, there are 67 points of diversion within the watershed and two pending water licence applications (Associated 2019); however, the actual volume extracted is unknown. A conservation licence is in place but is very small (0.002 m^3/s) (Associated 2019). Equesis Creek is 'flow sensitive' during summer and winter when naturalized flows are below 20% LTMAD (Table 3-5).

Table 3-4: Equesis Creek description

Drainage Area	203.5 km^2
Median elevation	1173 m
WSC station	There are no active WSC stations in the Equesis drainage area. Historic records are available from: 08NM176 – Ewer Creek near the Mouth (1971-1986) 08NM024 – Equesis Creek near Vernon (1921-1926) 08NM161 – Equesis Creek near the Mouth (1969-1982)
ONA station	08NM707 – Equesis Hydromet 1a at Victoria Road (2017-2018) 08NM161-HDS – Equesis Hydromet 2 at Westside Road (2017-present) 08NM585 – Equesis Hydromet 3 at Bonneau Road (2016-2017)
LTMAD	0.700 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, Prickly Sculpin, and Yellow Perch (ESSA & Solander 2009)
Land use	Forestry, agriculture. Lower reach flows through Okanagan Indian Reserve No. 1 (Associated 2016)

Naturalized, residual and maximum licensed flow data were provided by Associated (2019), with an estimated data quality rating of B for naturalized flows (data error between 10% and 25%), and a rating of D for residual and maximum licensed flows (data error greater than 50%). The naturalized LTMAD and summer low flow estimates were considered relatively low for the watershed and channel size. Estimated maximum licensed flows indicate that the stream would be dry from late July to mid-September if licensed withdrawal and storage volumes were maximized (Figure 3-4).

Okanagan Tennant EFNs for Equesis Creek were developed in accordance with the methods outlined in Section 2.2. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. However, flows in Equesis Creek are augmented by releases from Pinaus Lake and residual flows are typically greater than flow standards during the non-freshet period. Local fish populations have adapted to this flow augmentation and therefore, final EFN setting in Equesis Creek was based on residual rather than naturalized flows. Accordingly, WUW information from the study transects was used to adjust the Okanagan Tennant EFNs. A summary of the recommended EFNs is provided in Table 3-5, including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-3, 3-4 and Appendix B2 and naturalized flow sensitives in Table 3-5. The recommended EFNs are intended to maintain current levels of fish production in Equesis Creek by protecting flow conditions that local populations have become adapted to. Critical flows were calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in Equesis Creek is provided at the end of this section.

Table 3-5: Flow sensitivities in Equesis Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.059	8%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.046	7%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-6: EFN summary table for Equesis Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m^3/s)	Recommended EFN (m^3/s)				Critical flow	
		Median (m^3/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.140	20%	0.17	0.170	24%	0.163	0.505	0.035	5%
Rainbow spawning	May 20 – Jul 10	1.18	168%	1.100	1.10	157%	0.706	3.39	0.380	54%
Kokanee spawning	Sep 10 – Oct 10	0.132	19%	0.177	0.177	25%	0.170	0.198	0.070	10%
Rainbow overwintering	Nov 1 – March 31	0.121	17%	n/a	0.137	20%	0.134	0.173	0.035	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

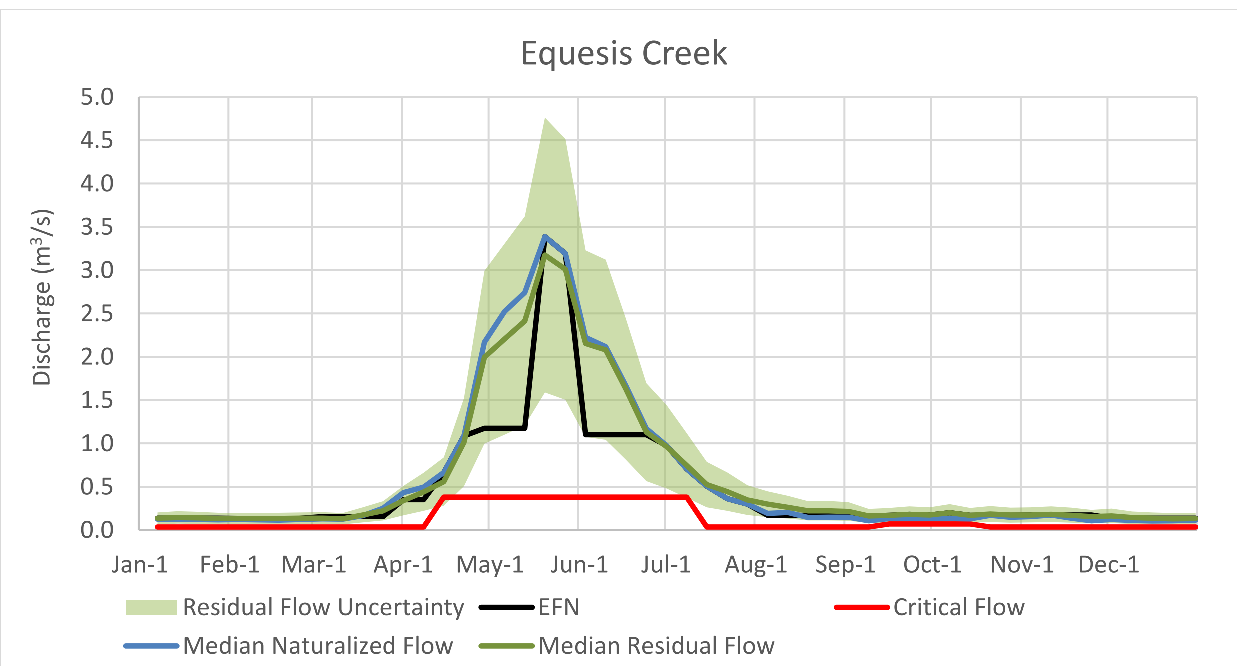


Figure 3-3: Weekly EFN, critical flow and streamflows in Equesis Creek

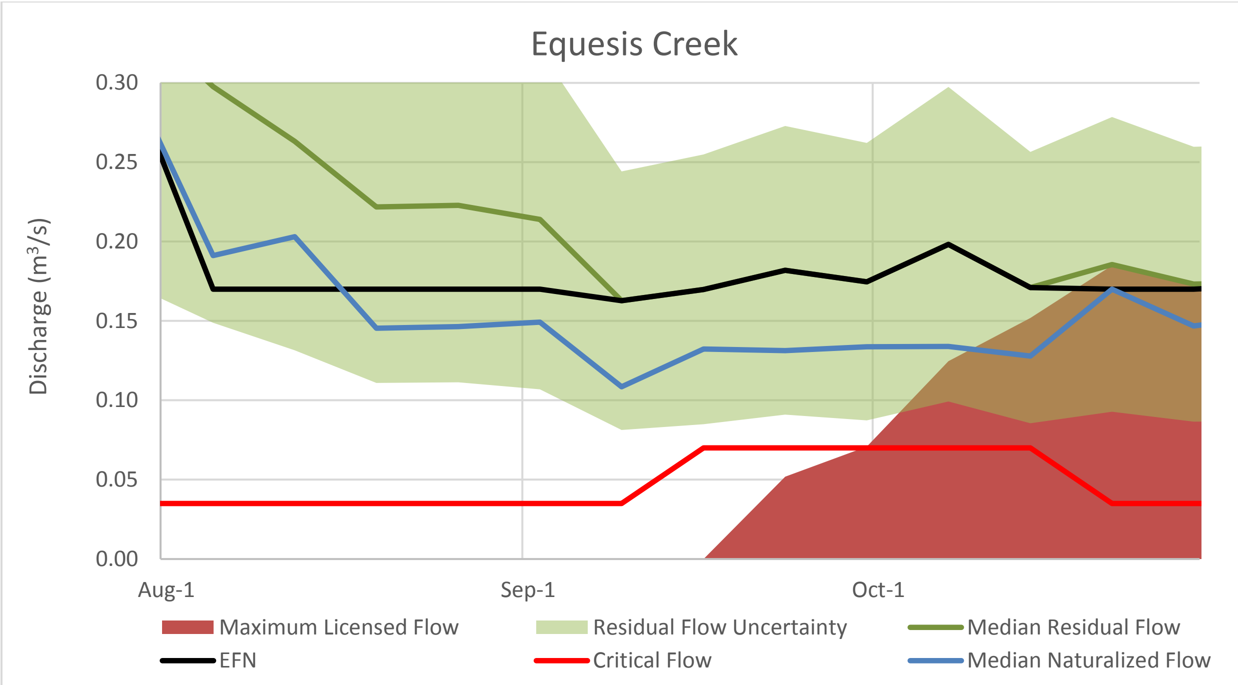


Figure 3-4: Weekly EFN, critical flow and streamflows during the summer and fall period in Equesis Creek

Rainbow parr rearing

Due to consistently high streamflows in Equesis Creek during the study period, no low flow WUW measurements could be obtained. Therefore, the low flow portion of the WUW curve has greater uncertainty than in other streams, as indicated by the wider confidence bands (Figure B2-11, Appendix B2). The recommended EFN for Rainbow Parr rearing is 0.170 m^3/s (24% LTMAD). While naturalized flows indicate a slightly lower Okanagan Tennant EFN (~0.140 m^3/s, Table 3-6), fish populations in the creek have adapted to an augmented residual flow regime and any reductions would lead to losses in productivity, as indicated by the rapid decline of the WUW curve. The recommended EFN maintains approximately 45% of maximum Rainbow parr rearing WUW (Figure B2-11, Appendix B2) and 25% of insect production WUW (Figure B2-12, Appendix B2). It is near the lowest of the weekly residual flow estimates provided by Associated (2019), confirming that the recommended EFN is generally achievable under residual flow conditions. Further, residual flows recorded at the hydrometric stations from 2016-2018 were greater than 0.2 m^3/s (Figures B2-4 to B2-6, Appendix B2), indicating that the recommended EFN can be met with relative certainty under current water use and release operations. Historically, the lowest residual median weekly flows at the WSC hydrometric station 08NM161 (1969-1982) was slightly below the recommended EFN at 0.124 m^3/s, but discharge was generally above ~0.2 m^3/s (Figure B2-7, Appendix B2). Photos of habitat conditions in Equesis Creek at the recommended EFN flows are provided in Plate 3-3.

Historic EFN recommendations for Rainbow rearing in Equesis Creek have ranged from 0.075 m^3/s (11% LTMAD) (Shepherd & Ptolemy 1999) to 0.75 m^3/s (ESSA & Solander 2009) but were not based on field observations. WUW curves indicate that a flow of 0.075 m^3/s would provide <20% of maximum parr rearing WUW. Koshinsky (1972) recommended a minimum incubation flow of 0.17-0.23 m^3/s, which is similar to the recommended EFN.

The recommended critical flow for Rainbow parr rearing is 0.035 m^3/s (5% LTMAD, Table 3-6). While riffle analysis indicates that 60% of maximum wetted width is maintained at flows of approximately 0.107 m^3/s (15% LTMAD; Table B2-2, Appendix B2), no measurements were collected below 0.21 m^3/s and there is considerable uncertainty in this estimate. Further measurements at low flows should be obtained to confirm the critical flow recommendation.

Water temperatures in Equesis Creek recorded at the ONA hydrometric stations were generally favorable to Rainbow rearing (maximum 16°C recorded in mid-July), which was likely aided by the relatively high streamflows throughout the summer period (Figures B2-8 to B2-10, Appendix B2).

Rainbow spawning

The recommended EFN for Rainbow Spawning is 1.10 m^3/s (157% LTMAD), which is just below the Okanagan Tennant flow standard (168% LTMAD) and below the median weekly naturalized flows during the Rainbow spawning period (Figure B2-13, Appendix B2). This EFN maintains high WUW (> 90% of maximum) while also maintaining approximately 90% of Rainbow parr rearing WUW. Photos of habitat conditions in Equesis Creek at the recommended EFN flows are provided in Plate 3-4.

The recommended critical flow for Rainbow spawning is 0.380 m^3/s (54% LTMAD, Table B2-2, Appendix B2) based on the passage depth criterion (Table 2-7).

Kokanee spawning

The recommended EFN for Kokanee spawning is 0.177 m^3/s (25% LTMAD; Table 3-6), which is equivalent to the median estimated residual flows during the Kokanee spawning period (Associated 2019). While naturalized flows are slightly lower during the same period (~0.132 m^3/s, 19% LTMAD), fish populations in Equesis Creek have adapted to the augmented flow regime and any reductions may result in losses in productivity, as indicated by the rapid decline of the WUW curve (Figure B2-14, Appendix B2). The recommended EFN maintains approximately 70% of Kokanee spawning WUW. Safe riffle passage conditions for Kokanee are achieved at 0.095 m^3/s (14% LTMAD, Table B2-2, Appendix B2), though higher flows or channel modifications may be needed to facilitate access during some years if gravel aggradation occurs at the mouth. The recommended EFN is expected to provide sufficient flows for safe riffle passage during most years. Photos of habitat conditions in Equesis Creek at the recommended EFN flows are provided in Plate 3-3.

Historic EFN recommendations for Kokanee spawning in Equesis Creek have ranged from 0.09 m^3/s (13% LTMAD; Dobson 1990b) to 0.9 m^3/s (ESSA & Solander 2009). The recommended EFN is similar to that by Shepherd & Ptolemy (1999) who recommended an EFN of 0.15 m^3/s but lower than that of Koshinsky (1972) who recommended 0.23-0.28 m^3/s.

The recommended critical flow for Kokanee spawning is 0.070 m^3/s (10% LTMAD, Table B2-3, Appendix B2) based on the LTMAD criterion (Table 2-7). While riffle analysis indicates that safe riffle passage is maintained at flows of 0.095 m^3/s (14% LTMAD; Table B2-2, Appendix B2), no measurements were collected below 0.21 m^3/s and there is considerable uncertainty in this estimate. Further measurements at low flows should be obtained to confirm the critical flow recommendation.

Recently observed residual flows during the Kokanee spawning period are typically greater than those estimated by Associated (2019). Daily flows during the Kokanee spawning period recorded at the hydrometric station near Westside Road (08NM161HDS) from 2016 to 2018 ranged from 0.25 to 0.51 m^3/s

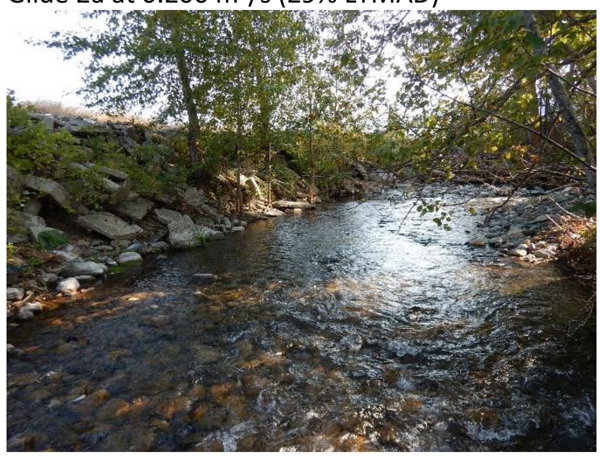
(Figure B2-5, Appendix B2). Noticeably lower flows were recorded at the hydrometric station near the mouth in 2017 (approximately 0.2 m^3/s) throughout the irrigation season, followed by a sudden increase in mid-October (Figure B2-4, Appendix B2). The reaches below Westside Road may have flows below the EFN during the summer and the Kokanee spawning period due to irrigation water withdrawals during some years. Historical median weekly residual flows from the WSC 08NM161 hydrometric station (1969-1982, also near Westside Road) ranged from 0.19 to 0.25 m^3/s. Kokanee spawning EFNs are likely to be met during most years with continued supplementation from Pinaus Lake. Maintaining spawning flows in the 0.25-0.5 m^3/s range, when possible, would maximize Kokanee spawning habitat capacity (WUW increase from 70% to 100%) and should be encouraged to maximize production from this creek.

Plate 3-3: Equesis Creek habitat conditions at flows near the recommended Rainbow parr rearing (0.170 m³/s) EFN and Kokanee spawning EFN (0.177 m³/s)

Glide 2 at 0.172 m³/s (25% LTMAD)

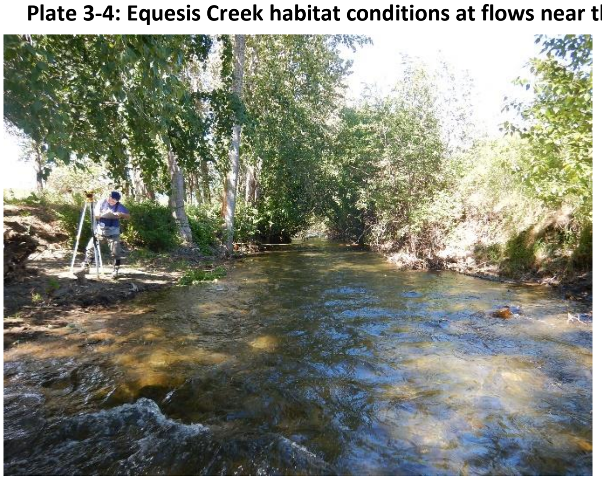
Glide 2a at 0.200 m³/s (29% LTMAD)

Riffle 2 at 0.172 m³/s (25% LTMAD)



Riffle 2a at 0.200 m³/s (29% LTMAD)

Plate 3-4: Equesis Creek habitat conditions at flows near the recommended Rainbow spawning (1.10 m³/s) EFN



Glide 2a at 1.14 m³/s (163% LTMAD)

Glide 1a at 1.30 m³/s (186% LTMAD)

3.3 nʔastqʷitkʷ - Naswhito Creek

Naswhito Creek is a tributary to Okanagan Lake, flowing from the west side of the Okanagan Basin into the northwest arm of Okanagan Lake near Vernon, B.C. over a length of approximately 13 km (Eyjolfson & Dunn 2016). The Naswhito Creek watershed is approximately 87 km^2 (Associated 2016). Naswhito Creek is not lake-headed and has no developed storage; however, several wetlands are located in the headwaters. A summary of creek characteristics is found in Table 3-7 and additional stream-specific data is provided in Appendix B3.

The lower reaches of Naswhito Creek flow over an alluvial fan that has merged with the Equesis Creek fan. Paired streamflow measurements indicate streamflow losses to groundwater on the fan. Agricultural fields are located adjacent to the creek with several unrestricted livestock access points. The lowest reach of Naswhito Creek below Westside Road has some minor channelization, and excellent to high quality riparian vegetation (Eyjolfson & Dunn 2016). Instream habitat in this section is characterized by pool-riffle morphology and good quality spawning gravel for Kokanee. For many years the most downstream barrier to fish migration was an irrigation dam located below Westside Road 2.6 km from the mouth (Eyjolfson & Dunn 2016). The dam was washed out during the 2018 freshet and is now passable (Louis pers. comm. 2019). Upstream of Westside Road, substrate size increases and the creek provides high quality Rainbow spawning and rearing habitats.

Naswhito Creek is known to support populations of Kokanee spawning as well as Rainbow spawning and rearing (Associated 2016). Kokanee spawning was confined to the reaches up to the irrigation dam barrier at 2.6 km (Louis 2012) until it was washed out during the 2018 freshet; Kokanee were observed spawning in the newly accessible reaches above the washed out dam in 2019 (Louis pers. comm. 2019). Spawner enumeration reports indicate that low flows tend to create issues with Kokanee migration into the creek and passage and spawning conditions improve at higher flows (e.g., Louis 2010; Louis 2004).

A total of three riffle and two glide transects were established in Naswhito Creek. One particularly wide and shallow riffle transect near the mouth was established to determine suitable passage conditions for migrating spawners. All transects were located downstream of the fish barrier at 2.6 km from the mouth and within the documented Kokanee spawning reaches. The lowermost transect (1) had to be moved following the 2017 freshet due to extensive channel changes at the original location.

At present there are 12 points of diversion within the watershed; however, the actual volume extracted is unknown (Associated 2019). Okanagan Indian Band is the main water user. The creek is currently fully recorded for irrigation unless supported by storage (FLNRORD 2016). One hydrometric station was installed in 2016 and continues to operate presently (Figure B3-2, Appendix B3). Naswhito Creek is 'flow sensitive' during summer and winter when naturalized flows are below 20% LTMAD (Table 3-8).

Estimated naturalized, residual and maximum licensed flow data were provided by Associated (2019). A quality rating of C (data error estimated between 25% and 50%) was assigned to the data. However, the estimated naturalized flows during the late summer and early fall season were consistently below the residual flows recorded at the ONA hydrometric station near the mouth from 2016-2018. Further, WUW curves indicate that Rainbow rearing, insect production and Kokanee spawning at the estimated naturalized flows would be marginal (i.e., less than 20% of maximum WUW available), but Naswhito Creek is known to support a Kokanee population (Louis 2008-2016) and spawning and rearing Rainbow (Wightman & Taylor 1978). Therefore, the Associated (2019) naturalized flow estimates were considered relatively uncertain and summer and fall EFNs were set based on WUW curves and recent hydrometric data. Estimated maximum licensed flows indicate that Naswhito Creek would be dry from early August to mid-September if licensed withdrawals were maximized (Figure 3-6).

Table 3-7: Naswhito Creek description

Drainage Area	86.5 km^2
Median Elevation	1242 m
WSC station	No active stations 08NM047 (Historic) – Naswhito Creek near Ewing's Landing (1921)
ONA station	08NM586 (2016-present) – Naswhito Creek near the Mouth
LTMAD	0.363 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, Prickly Sculpin (ESSA & Solander 2009)
Land use	Forestry in upper watershed, agriculture in lower watershed. The Okanagan Indian Band Reserve #1 is located on the alluvial fan of the confluence of Naswhito Creek with Okanagan Lake (Associated 2016)

Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. Recommended EFNs were increased from the Okanagan Tennant EFNs based on WUW information and recorded streamflow data from 2016-2018. A summary of EFNs is provided in Table 3-9 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-5 and Figure 3-6, and Appendix B3. Critical flows were calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in Naswhito Creek is provided at the end of this section.

Table 3-8: Flow sensitivities in Naswhito Creek

Species & life stage	**1-in-2 yr 30-day summer low flow**		**1-in-2 yr 30-day winter low flow**	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing Insect production Kokanee spawning	0.045	12%		
Rainbow overwintering Kokanee egg incubation			0.038	10%

Source: Associated (2019)

Table 3-9: EFN summary table for Naswhito Creek

Species & life stage	**Time period**	**Okanagan Tennant EFN**		**WUW EFN** (m^3/s)	**Recommended EFN** (m^3/s)				**Critical flow**	
		Median (m^3/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.073	20%	0.090	0.090	25%	0.090	0.259	0.031	9%
Rainbow spawning	May 20 – Jul 10	0.774	213%	0.774	0.774	213%	0.366	1.80	0.502	138%
Kokanee spawning	Sep 12 – Oct 7	0.073	20%	0.090	0.090	25%	0.090	0.090	0.060	17%
Rainbow overwintering	Nov 1 – March 31	0.073	20%	n/a	0.054	15%	0.048	0.071	0.031	9%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

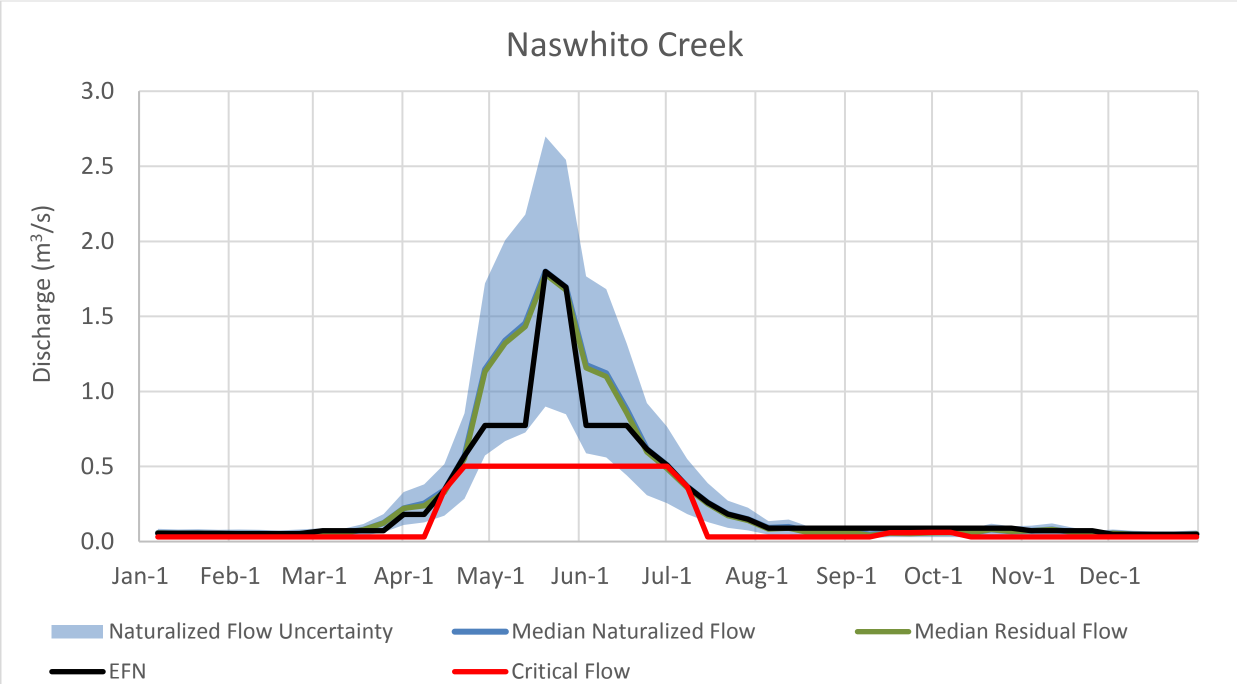


Figure 3-5: Weekly EFNs and critical flows in Naswhito Creek

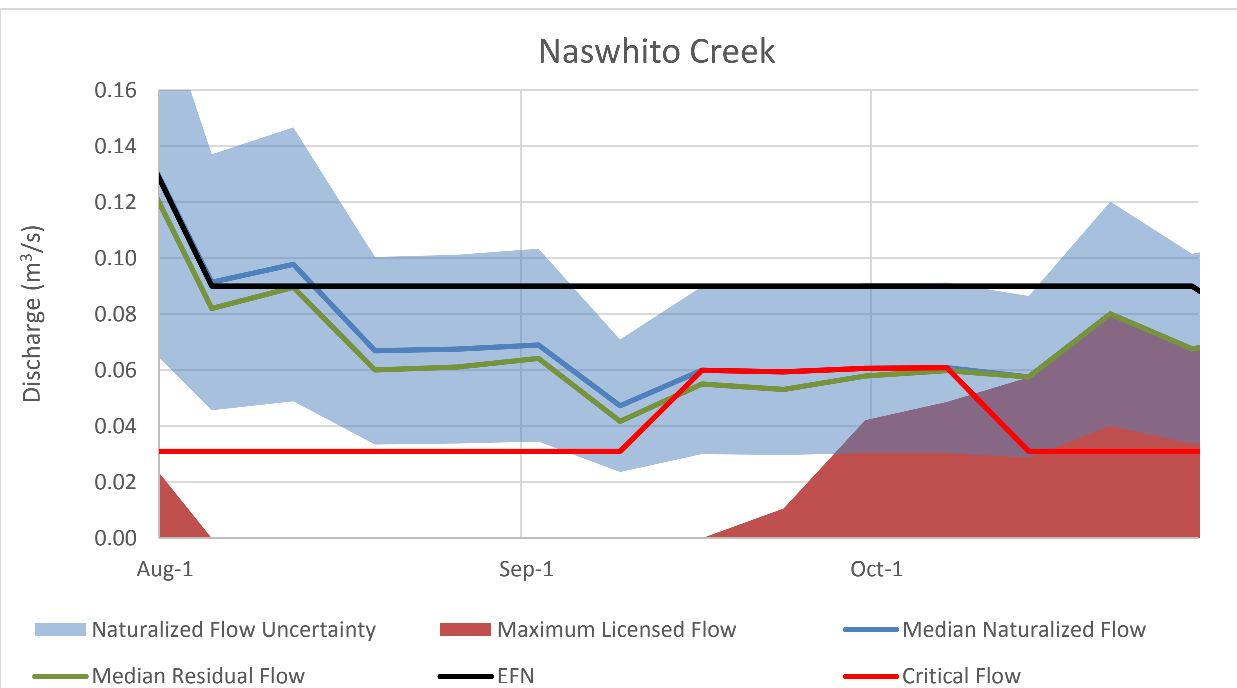


Figure 3-6: Weekly EFNs and critical flows during the summer and fall period in Naswhito Creek

Rainbow parr rearing

The recommended EFN for Rainbow Parr rearing is 0.090 m^3/s (25% LTMAD), which is greater than the Okanagan Tennant EFN (0.073 m^3/s, 20% LTMAD). The recommended EFN maintains approximately 45% of maximum WUW in glides and 20% in riffles (Figure B3-5, Appendix B3), as well as approximately 13% of maximum insect production WUW (Figure B3-6, Appendix B3). The EFN was set higher than the Okanagan Tennant EFN because naturalized summer flows provided by Associated (2019), which define the upper range of the Okanagan Tennant EFN, were implausibly low compared to measured flow data from the mouth. Further, WUW increases rapidly in this flow range. Photos of habitat conditions in Naswhito Creek at the recommended EFN flows are provided in Plate 3-5. The recommended EFN is similar to the minimum flow for Rainbow rearing recommended by the B.C. Fish and Wildlife Branch (Robertson 1983) of 0.085 m^3/s and lower than that recommended by ESSA & Solander (2009) of 0.4 – 1 m^3/s.

The recommended EFN value is lower than the median weekly residual flows recorded at the ONA hydrometric station near the mouth in 2016 and 2018, and slightly higher than in 2017, which was a drought year (Figure B3-3, Appendix B3). Water temperatures in Naswhito Creek recorded at the hydrometric station were generally favorable to Rainbow rearing though approached the upper range of suitable rearing temperatures (20^oC) in late July (Figure B3-4, Appendix B3). The recommended critical flow for Rainbow rearing is 0.031 m^3/s (9% LTMAD, Table B3-2, Appendix B3) based on the riffle width criterion (Table 2-7).

Rainbow spawning

The recommended EFN for Rainbow spawning is 0.774 m^3/s, which is equivalent to the Okanagan Tennant flow standard (213% LTMAD) and slightly below median naturalized flows for the spawning period (1.00 m^3/s, 275% LTMAD). The EFN maintains 80% of maximum spawning WUW (Figure B3-7, Appendix B3) while also maintaining high (>90%) rearing WUW. Flows were above the EFN for the entire spawning period in 2017 and 2018 (Figure B3-3, Appendix B3). Photos of habitat conditions in Naswhito Creek at the recommended EFN flows are provided in Plate 3-6. A previous EFN of 1 m^3/s was recommended by ESSA & Solander (2009).

The recommended critical flow for Rainbow spawning is 0.502 m^3/s (138% LTMAD, Table B3-2, Appendix B3) based on the passage depth criterion (Table 2-7).

Kokanee spawning

The recommended EFN for Kokanee spawning is 0.090 m^3/s (25% LTMAD) and maintains 40% of the maximum WUW (Figure B3-8, Appendix B3). The EFN was set higher than the Okanagan Tennant EFN (0.073 m^3/s, 20% LTMAD) because estimated naturalized flows, which define the upper range of the Okanagan Tennant EFN, were implausibly low compared to measured flow data from the mouth. Further, WUW increases rapidly in this flow range. Recorded residual flows were greater than the EFN in 2016 and 2018, but lower in 2017 (Figure B3-3, Appendix B3). Photos of habitat conditions in Naswhito Creek at the recommended EFN flows are provided in Plate 3-5.

Passage issues for Kokanee spawners during low flows have been noted on occasion in the Kokanee enumeration reports (e.g., Louis 2010) and low flows have been identified as a limiting factor to Kokanee production by Wightman & Taylor (1978). Therefore, Kokanee in Naswhito Creek likely benefit greatly from flows higher than the recommended EFN when available. Robertson (1983) suggested EFNs of approximately 0.14 m^3/s, which may be more appropriate given higher WUW and better riffle passage, though probably not realistically achievable for the entire spawning period during all years. ESSA & Solander (2009) recommended 0.6 m^3/s.

Critical passage flows for Kokanee estimated from riffle analysis were 0.177 m^3/s (49% LTMAD; Table B3-2, Appendix B3). Kokanee riffle passage is known to be a problem during low flows in this creek (Louis 2010). Due to these known passage issues, the recommended critical flow for Kokanee spawning is 0.060 m^3/s (17% LTMAD, Table B3-2, Appendix B3), which corresponds to the median naturalized flow during the Kokanee spawning season. Thus, any water use during Kokanee spawning has the potential to adversely impact Kokanee access and movement. It is likely that fall rain events play a critical role for Kokanee access into Naswhito Creek.

Plate 3-5: Naswhito Creek habitat conditions at flows near the recommended Rainbow parr rearing and Kokanee spawning EFNs ($0.090\ m^3/s$)

Glide 2 at $0.093\ m^3/s$ (26% LTMAD)

Glide 2 at $0.149\ m^3/s$ (41% LTMAD)

Riffle 1a at $0.083\ m^3/s$ (23% LTMAD)

Riffle 1a at $0.139\ m^3/s$ (38% LTMAD)

Plate 3-6: Naswhito Creek habitat conditions at flows near the recommended Rainbow spawning EFN ($0.774\ m^3/s$)

Glide 2 at $0.643\ m^3/s$ (177% LTMAD)

Glide 2 at $1.53\ m^3/s$ (421% LTMAD)

3.4 Whiteman Creek

Whiteman Creek is a tributary to the northwest arm of Okanagan Lake. It drains a gently sloping plateau with several small lakes, then flows eastward through steep hillslopes and finally over a large alluvial fan before entering Okanagan Lake. Its main tributary is Bouleau Creek, which drains Bouleau Lake. Whiteman Creek has no developed storage and flows are not regulated. The stream is approximately 25 km long (Eyjolfson & Dunn 2016) with a watershed area of 203 km^2 (Associated 2016). A summary of creek characteristics is found in Table 3-10 and additional stream-specific data is provided in Appendix B4.

Whiteman Creek supports a population of large adfluvial Rainbow from Okanagan Lake that migrate over 10 km upstream to spawn, as well as a resident smaller bodied population (Agrodev 1996). The lower sections also provide important habitat for a population of approximately 500 Kokanee spawners from Okanagan Lake (Northcote et al. 1972; Louis 2012). The lower reaches of Whiteman Creek below Westside Road flow through a residential area and agricultural fields. The channel in this section was straightened in the past for flood control purposes (Anonymous 1969). Impacts of past channelization were observed during habitat surveys for this project and the lower section remains characterized by a relatively straight channel and a lack of habitat complexity. However, there is good riparian cover and suitable spawning gravels throughout this section. Upstream of Westside Road, habitat becomes more complex and the relatively coarse, cobbly substrate provides for ideal rearing habitat for juvenile Rainbow with high numbers of parr observed during the habitat surveys for this project. Water temperatures in Whiteman Creek remain relatively cold even during the summer low flow period (<20°C, Figure B4-5 Appendix B4), contributing to excellent Rainbow rearing conditions in the creek.

Wightman & Taylor (1978) identified a natural debris jam barrier approximately 4.8 km from the mouth. Habitat surveys for this project were limited to sections closer to the mouth and thus the barrier was not confirmed. However, it is possible and likely that the obstruction has since been washed out by high freshet flows. A previously documented irrigation dam 1.6 km from the mouth (Wightman & Taylor 1978) has since been removed and no other barriers were identified.

A total of two glide and two riffle transects were established in Whiteman Creek in August 2016 (Figure B4-2, Appendix B4). All transects were located in the lowest 1.2 km between Westside Road and Okanagan Lake where the best Kokanee spawning habitat is located and where all spawning activity is typically observed (Louis 2012).

The Okanagan Indian Band is the primary water supplier within the Whiteman Creek watershed (Dobson 2008) and there are 12 points of diversion within the watershed (Associated 2019). Past reports mention serious impairment to fish production from low flows and high water use in Whiteman Creek (Wightman & Taylor 1978); recent streamflow data from the mouth is very limited (2017) and did reveal relatively low late summer flows (9% LTMAD), but it is unknown if flow impairment resulted from water use. Streamflow measurements indicated streamflow losses to groundwater on the alluvial fan but due to the limited spatial extent of surveys and unclear seasonal variation, water losses and gains across the fan are considered unknown. Recent field surveys completed by ONA revealed one diversion ditch upstream of Westside Road (ONA unpublished data 2019) but the diversion was not in use during the late fall survey and its impacts on streamflows during summer is unknown. The stream is currently fully recorded for irrigation unless supported by storage (FLNRORD 2016). Whiteman Creek is 'flow sensitive' during summer and winter as naturalized flows are below 20% LTMAD (Table 3-11). One hydrometric station was installed near the mouth in 2016 and continues to operate (Figure B4-2, Appendix B4).

Table 3-10: Whiteman Creek description

Drainage Area	203 km^2
Median Elevation	1340 m
WSC station	08NM174 – Whiteman Creek above Bouleau Creek
ONA station	08NM587 (2016 – present) Whiteman Creek at Raven Road Bridge
LTMAD	1.092 m^3/s (Associated 2019)
Fish species expected	Kokanee (Northcote et al. 1972; Louis 2012), Rainbow (FIDQ 1996)
Land use	Urban, transportation, agriculture, forestry (Associated 2016). Flows through Okanagan Indian Band No.1 on the alluvial fan

Naturalized, residual and maximum licensed flow data were provided by Associated (2019) with an estimated data quality rating of B (data error between 10% and 25%). Estimated residual flows indicate near zero water withdrawals but this should be verified in the future as at least one large diversion ditch was documented recently. Estimated maximum licensed flows indicate that flows would be below the EFN throughout the summer and below critical flows during the Kokanee spawning period if licensed withdrawals were maximized.

Okanagan Tennant EFNs for Whiteman Creek were developed in accordance with the methods outlined in Section 2.2. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. WUW information from the study transects was then reviewed to determine whether final EFN recommendations needed adjustment from the Okanagan Tennant EFN. A summary of the recommended EFNs is provided in Table 3-12, including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-7, Figure 3-8 and Appendix B4 and flow sensitives in Table 3-11. Critical flows were calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in Whiteman Creek is provided at the end of this section.

Table 3-11: Flow sensitivities in Whiteman Creek

Species & life stage	**1-in-2 yr 30-day summer low flow**		**1-in-2 yr 30-day winter low flow**	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.108	10%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.098	9%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-12: EFN summary table for Whiteman Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m^3/s)	Recommended EFN (m^3/s)				Critical flow	
		Median (m^3/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.158	14%	0.158	0.158	14%	0.112	0.659	0.052	5%
Rainbow spawning	May 20 – Jul 10	1.56	143%	1.10	1.10	101%	0.961	5.70	0.361	33%
Kokanee spawning	Sep 8 – Oct 5	0.141	13%	0.141	0.141	13%	0.112	0.146	0.109	10%
Rainbow overwintering	Nov 1 – March 31	0.138	13%	n/a	0.138	13%	0.122	0.179	0.052	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

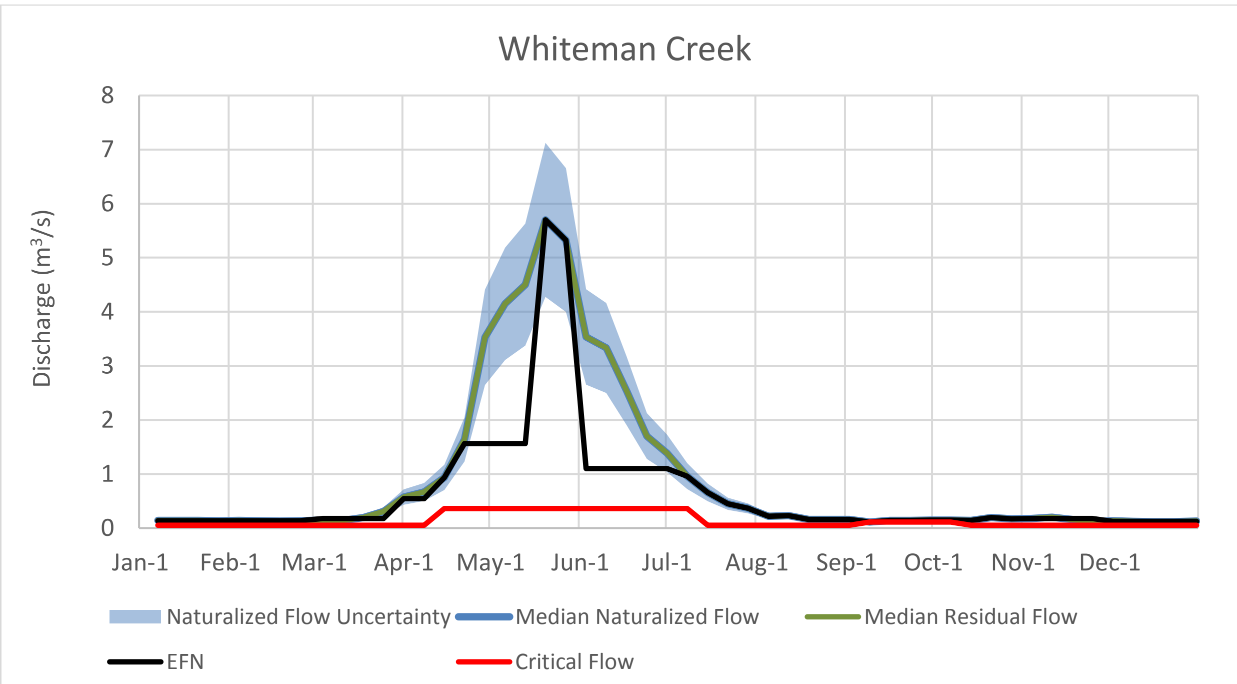


Figure 3-7: Weekly EFNs, critical flow and streamflows in Whiteman Creek

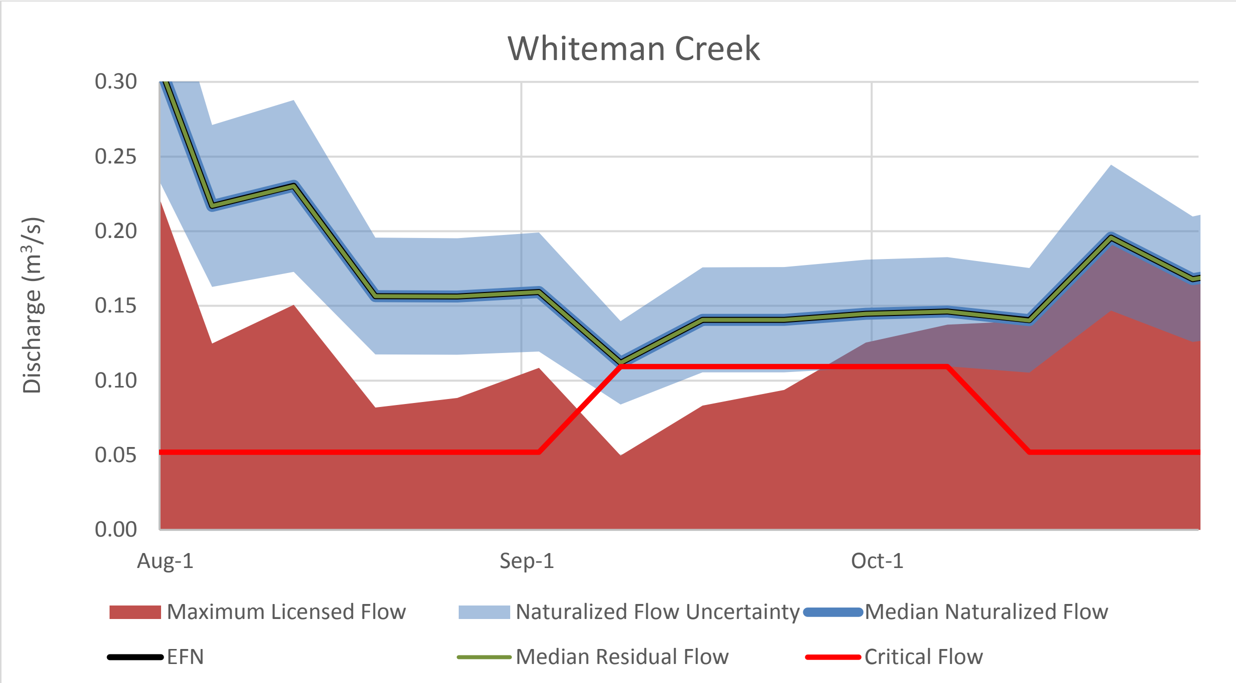


Figure 3-8: Weekly EFNs, critical flow and streamflows during the summer and fall in Whiteman Creek

Rainbow parr rearing

The recommended EFN for Rainbow parr rearing is 0.158 m^3/s (14% LTMAD), which is equivalent to the median Okanagan Tennant EFN and median naturalized flows for the summer and fall low flow period (mid-July from end of Rainbow spawning to end of September). This EFN maintains approximately 45% of maximum WUW in glides and 25% in riffles (Figure B4-6, Appendix B4), and 20% of maximum insect production WUW (Figure B4-7, Appendix B4). Estimated naturalized summer and fall flows in Whiteman Creek are relatively low (the lowest weekly naturalized flow is 0.113 m^3/s = 10% LTMAD in early September) (Associated 2019). WUW curves indicate that rearing conditions at those flows are marginal with <20% parr rearing WUW and ~10% insect production WUW. Thus, the weekly recommended EFNs were set equal to the naturalized flows throughout the summer and fall period to maximize the naturally limited rearing habitat available (Figure 3-8). Parr rearing WUW rapidly increases to 0.4 m^3/s and juvenile Rainbow in Whiteman Creek would benefit from flows greater than the EFN whenever available. Photos of habitat conditions in Whiteman Creek at the recommended EFN flows are provided in Plate 3-7. The recommended EFN is greater than the minimum flow for Rainbow rearing recommended by the B.C. Fish and Wildlife Branch of 0.085 m^3/s (Robertson 1983) as well as those by Shepherd & Ptolemy (1999) and Koshinsky (1972) of 0.09 m^3/s. The recommended critical flow for Rainbow parr is 0.052 m^3/s (5% LTMAD, Table B4-2, Appendix B4) based on the riffle width criterion (Table 2-7).

Residual flows recorded at the hydrometric station near the mouth in 2017 (a drought year) were below the recommended EFN from mid-August to late September (Figure B4-3, Appendix B4). Water temperatures recorded at the station were generally favorable to Rainbow rearing at the observed flows (maximum 18°C in mid-July) (Figure B4-5, Appendix B4). There is one known water diversion upstream of the station (Eyjolfson & Dunn 2016) but surveys were limited and it is unknown to what extent the recorded flows were affected by water withdrawals. Median daily flows at the historic WSC hydrometric station 08NM046 (1920-21 and 1949-70) were generally greater than the recommended EFN during the summer and fall period (Figure B4-4, Appendix B4), therefore the EFN is considered attainable during most years. Records from this station were likely heavily affected by irrigation withdrawals documented in Wightman & Taylor (1978) and Galbraith & Taylor (1969).

Rainbow spawning

The recommended EFN for Rainbow spawning is 1.10 m^3/s (100% LTMAD), which is lower than the Okanagan Tennant EFN (143% LTMAD) and well below the median weekly naturalized flows during the Rainbow spawning period (Figure B4-8, Appendix B4). The recommended EFN maintains high Rainbow spawning WUW (> 90% of maximum) while also maximizing Rainbow parr rearing WUW in riffles and glides. Recent and historic residual streamflows indicate that the EFN is typically met for the duration of the spawning period (Figures B4-3 and B4-4, Appendix B4). Photos of habitat conditions in Whiteman Creek at the recommended EFN flows are provided in Plate 3-8. The recommended critical flow for Rainbow spawning is 0.361 m^3/s (33% LTMAD, Table B4-2, Appendix B4) based on the passage depth criterion (Table 2-7).

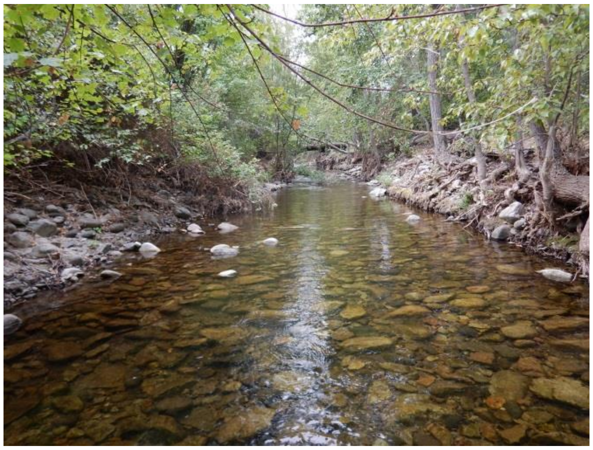
Kokanee spawning

The recommended EFN for Kokanee spawning is 0.141 m^3/s (13% LTMAD) which maintains 45% of maximum WUW (Figure B4-9, Appendix B4). The EFN corresponds to the median Okanagan Tennant EFN and median naturalized flows during the Kokanee spawning period. The rapidly increasing WUW curve up to 0.5 m^3/s suggests that Kokanee in Whiteman Creek would greatly benefit from flows higher than the recommended EFN when available. Minimum passage depth for Kokanee was achieved at the lowermost riffle transect at approximately 0.13 m^3/s (12% LTMAD), and any reduction in flows from the recommended EFN may result in passage issues. The recommended EFN is equal to that recommended for Kokanee spawning in Whiteman Creek by Koshinsky (1972b). Photos of habitat conditions in Whiteman Creek at the recommended EFN flows are provided in Plate 3-7.

The recommended critical flow for Kokanee spawning is 0.109 m^3/s (10% LTMAD, Table B4-2, Appendix B4) based on the %LTMAD criterion (Table 2-7). Riffle analysis indicated average critical passage flows of 0.180 m^3/s (16% LTMAD), which is slightly greater than naturalized flows during the spawning and migration period.

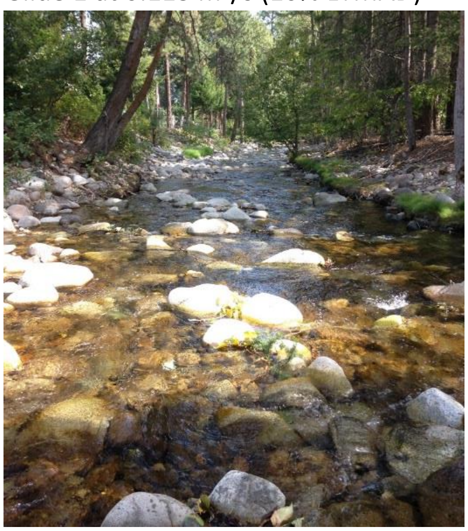
The recommended EFN is slightly higher than the residual flows recorded at the ONA hydrometric station during 2017, which was a drought year, indicating that EFNs may not be met during some years (Figure B4-3, Appendix B4). Historically, median daily flows at the historic WSC hydrometric station 08NM046 (1920-21 and 1949-70) were generally greater than the recommended EFN during the Kokanee spawning period (Figure B4-4, Appendix B4).

Plate 3-7: Whiteman Creek habitat conditions at flows near the recommended Rainbow parr rearing EFN (0.158 m^3/s) and Kokanee spawning EFN (0.141 m^3/s)

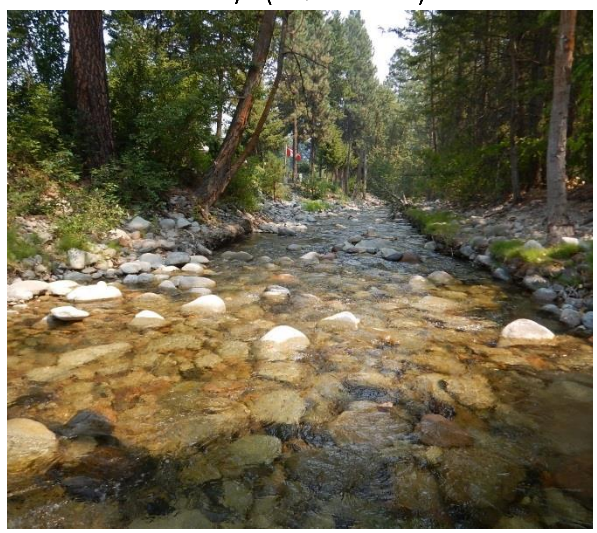


Glide 1 at 0.113 m^3/s (10% LTMAD)

Glide 1 at 0.182 m^3/s (17% LTMAD)



Riffle 2 at 0.125 m^3/s (11% LTMAD)



Riffle 2 at 0.189 m^3/s (17% LTMAD)

Plate 3-8: Whiteman Creek habitat conditions at flows near the recommended Rainbow spawning EFN (1.10 m^3/s)

Glide 2 at 0.904 m^3/s (82% LTMAD)

Glide 1 at 1.20 m^3/s (110% LTMAD)

3.5 Mission Creek

Mission Creek is the largest tributary to Okanagan Lake, flowing from the east side of the Okanagan Basin through Kelowna, B.C. The Mission Creek watershed is the largest in the Okanagan Basin at approximately 845 km^2, and the main tributaries include Pearson, Joe Rich, Belgo, Hydraulic, and KLO Creeks (Associated 2016). Its headwaters drain gently sloping plateaus before flowing through a steep canyon and finally over a large alluvial fan in the Kelowna area before entering Okanagan Lake. Developed storage exists in multiple headwater lakes and flows in Mission Creek are heavily regulated. A summary of creek characteristics is found in Table 3-13 and additional stream-specific data is provided in Appendix B5.

Mission Creek flows from its forested headwaters through agricultural and rural residential areas in its mid-elevation reaches, prior to flowing through a canyon and through the City of Kelowna. The most downstream barrier to fish migration is Gallagher's Falls located 19 km from the mouth in the canyon (Eyjolfson & Dunn 2016). The lower reaches within the city have been heavily straightened and diked in the past for flood control. This has resulted in ongoing sediment deposition problems in the lower reaches, requiring repeated dredging activities in the past to alleviate sediment buildup in the channel and reduce the risk of flooding (Burge 2009). Many bridges cross the creek, with some urban and agricultural influence, and low levels of pollution visible (Eyjolfson & Dunn 2016). There is some riparian cover throughout this section but habitat complexity is lacking.

Despite the extensive fish habitat losses that resulted from channelization and diking (Burge 2009), the majority of Kokanee spawning occurs in the lower reaches, primarily in the spawning channel that was specifically constructed for this purpose in 1988 (Webster 2016). Mission Creek once supported the largest stream-spawning Kokanee population in the Okanagan basin and still is the most important Kokanee producing tributary to Okanagan Lake. Historic escapements on record reached a high of 380,000 in 1971 (Wightman & Taylor 1978). Escapements over the past decade are lower between 7,000 and 32,000 (Webster 2010-2017). Mission Creek also supports a population of large adfluvial Rainbow from Okanagan Lake that migrate into the upstream reaches in and below the canyon to spawn, as well as a resident smaller bodied population. The majority of Rainbow spawning habitat is located approximately 13 to 19 km from the mouth in the mainstem as well as KLO and Hydraulic creeks (Wightman & Taylor 1978). Summer water temperatures in Mission Creek tend to exceed suitable rearing temperatures for Rainbow near the mouth, reaching up to 22°C in the reaches below the canyon and up to 26°C near the mouth (Figure B5-9 to B5-14, Appendix B5).

A total of six glide and five riffle WUW transects were established in Mission Creek in August 2016 (Figure B5-1, Appendix B5). Transects were located throughout the fish accessible portion of the creek below Gallagher's Falls. WUW data was previously collected in Mission Creek from 2005-2009 (Epp 2008a; Epp 2009; Epp 2010a) to aid with the Mission Creek Water Use Plan development (Water Management Consultants 2010) and assess the impacts of sediment dredging. Some transects in this study were in the same reaches as previously monitored (i.e., transects 1 and 3) by Epp (2008a) and Glide 3 was re-established at a transect location previously used by Epp (2008a).

Table 3-13: Mission Creek description

Drainage Area	845 km^2
Median Elevation	1345 m
WSC stations	08NM116 (Active) Mission Creek near E. Kelowna (1949-present) 08NM232 (Active) Belgo Creek Below Hilda Creek (1976-present) Historic records include: 08NM057 Mission Creek Rutland Diversion (1922-1930) 08NM016 Mission Creek near Rutland (1919-1946) 08NM010 Hydraulic Creek near the Mouth (1919-1982) 08NM039 Hydraulic Creek Diversion near Kelowna (1919- 1968) 08NM060 KLO Creek Diversion near Kelowna (1923-1968) 08NM040 Hydraulic Creek SE Kelowna Diversion (1920-1930) 08NM226 KLO Creek at McCulloch Road (1976-1982) 08NM004 KLO Creek near Kelowna (1919-1922) 08NM239 Mission Creek Below B.M.I.D. Intake (1980-1980) 08NM137 Daves Creek near Rutland (1965-1986) 08NM207 Myra Ditch Below KLO Creek (1973-1985) 08NM210 Pooley Creek Above Pooley Ditch (1973-1979) 08NM213 McCulloch Reservoir at McCulloch Dam (1973- 1986) 08NM011 Hydraulic Creek at Outlet of McCulloch Res. (1919-1986) 08NM215 Fish Lake at the Outlet (1973-1977) 08NM217 Long Meadow Lk Reservoir Above the Dam (1973-1977) 08NM216 Browne Lake Reservoir Above the Dam (1973- 1977) 08NM129 Joe Rich Creek near Rutland (1964-1987) 08NM225 Belgo Creek near the Mouth (1976-1982) 08NM172 Pearson Creek near the Mouth (1970-1987) 08NM233 Mission Creek Above Pearson Creek (1977-1982) 08NM018 Hilda Creek near Rutland (1920-1920) 08NM017 Belgo near Rutland (1920- 1920) 08NM231 Ideal Lake near the Outlet (1963-1980) 08NM229 Loch Katrine Cr at Outlet of Graystone Lake (1977-1998) 08NM230 Graystone Lake at the Outlet (1977-1998)
ONA stations	08NM551 Mission Creek above Gordon Drive (Hydromet 1) (2016-present) 08NM552 Mission Creek at Casorso Road (Hydromet 2) (2016-2017) 08NM553 Mission Creek upstream of KLO Road (Hydromet 3) (2016-2017) 08NM554 Mission Creek at Ziprick Road (Hydromet 4) (2016-2017) 08NM555 Mission Creek at Gerstmar Road (Hydromet 4a) (2016-2017) 08NM556 Mission Creek at Hollywood Road (Hydromet 6) (2016-2017) 08NM557 Mission Creek at 12 km Bridge (Hydromet 7) (2016-2017) 08NM558 Mission Creek below KLO Creek (Hydromet 8) (2016-2017) 08NM559 Mission Creek above BMID Intake (Hydromet 10) (2016-2017)
LTMAD	6.35 m^3/s
Fish species expected	Rainbow, Kokanee, Eastern Brook Trout, Burbot, Mountain Whitefish, Redside Shiner, Northern Pikeminnow, Sucker (general), Longnose Dace, Prickly Sculpin, Sculpin (general), Peamouth Chub, and Slimy Sculpin (ESSA & Solander 2009)
Land use	The lower watershed is dominated by urban development. The upper watershed is used for agriculture, forestry, and livestock grazing. A small reserve of the Westbank First Nation sits alongside Mission Creek in its lowest reaches and larger reserves are located in Gallagher's Canyon and the headwaters of Hydraulic Creek.

The Black Mountain Irrigation District and Southeast Kelowna Irrigation District are the major water suppliers within the Mission Creek watershed and operate nine storage reservoirs in the headwaters. In addition, smaller providers include the Falconridge Water Utility, Benvoulin Water Users Community, Mission Creek Water Users Community, Rutland Water Works, and South Kelowna Water Users Community (Associated 2016). The Black Mountain Irrigation district operates storage on Loch Long on behalf of the Province of B.C. for instream flow requirements (Associated 2019) and FLNRORD also holds several conservation licences on Mission Creek. There are 426 points of diversion within the watershed and 10 water licence applications pending (Associated 2019). Interbasin transfers into the watershed can occur between Mission Creek and the West Kettle River, as well as, Mill Creek (Associated 2016).

In 2000, Mission Creek was a candidate for designation as a 'Sensitive Stream' under the *Fish Protection Act* (MOE 2000). Particular concerns were a generally high water demand only partially supported by storage, as well as low summer and fall flows during the Kokanee spawning season and during the winter, leading to reduced egg survival. The stream is currently fully recorded for irrigation unless supported by storage (FLNRORD 2016). Mission Creek is 'flow sensitive' during summer and winter as naturalized flows are below 20% LTMAD (Table 3-14). The Mission Creek Water Use Plan was developed in 2008 (Water Management Consultants 2010) and specifies fisheries conservation flows for the summer months based on a proportion of LTMAD (July - 2.25 m^3/s, August – 2.25 m^3/s, September – 1.9 m^3/s, October – 1.5 m^3/s). The plan allows fish flow releases to vary during wet and dry years by using a multiplier of natural streamflows in the unregulated tributary of Pearson Creek to estimate what natural flows would be in Mission Creek. However, this component was never implemented because it requires re-establishment of a real-time hydrometric station on Pearson Creek.

Eight hydrometric stations were installed throughout the fish accessible portion of the creek in 2016 for the Mission Creek Groundwater and Surface Water Interaction project (Neumann 2018) and the data was utilized for EFN development; the lowermost hydrometric station near Gordon Road continues to operate (Figure B5-1, Appendix B5). The project identified that Mission Creek gained water from groundwater in the intermediate reaches where it flows through the canyon, but gaining and losing conditions were more variable on the alluvial fan in the lower reaches.

Naturalized flow data were provided by Associated (2019) and residual flow data was obtained from the active WSC hydrometric station 08NM116 (Mission Creek near east Kelowna). The naturalized flows have a data quality rating of B (estimated 10 - 25% error) and residual flows have a data quality rating of A (estimated error <10%); maximum licensed flow estimates were not available at the time of reporting.

Okanagan Tennant EFNs for Mission Creek were developed in accordance with the methods outlined in Section 2.2. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. However, as per the Mission Creek Water Use Plan, storage releases are used to augment flows during the summer and fall and residual flows are therefore typically greater than naturalized flows during September and October. Local fish populations have adapted to augmented flows; therefore, final EFN setting in Mission Creek was based on a combination of residual and naturalized flows, informed by WUW curves.

A summary of the recommended EFNs is provided in Table 3-15, including the median and the range of weekly EFNs, with weekly details in Figure 3-9, Figure 3-10 and Appendix B5. The recommended EFNs are intended to maintain current levels of fish production in Mission Creek by protecting flow conditions that local populations have become adapted to. Naturalized flow sensitives are listed in Table 3-14. Critical flows were calculated as described in Section 2.4. However, riffle data from riffle transect 4 and 7 were not considered for the critical flow analysis as the range of flow data collected at these transects was insufficient to complete the analysis. Further information regarding EFN and critical flow setting in Mission Creek is provided at the end of this section.

Table 3-14: Flow sensitivities in Mission Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	1.10	17%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.702	11%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-15: EFN Summary table for Mission Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m^3/s)	Recommended EFN (m^3/s)				Critical flows	
		Median (m^3/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production[a]	April 1 – Oct 31	1.26	20%	1.40	1.40	22%	1.40	4.83	0.635	10%
Rainbow spawning	May 20 – July 10	6.35	100%	4.83	4.83	76%	4.83	32.39	1.12	18%
Kokanee spawning	Aug 31 – Oct 5	1.11	17%	1.40	1.40	22%	1.40	1.40	0.635	10%
Rainbow overwintering	Nov 1 – March 31	0.925	15%	x	0.925	15%	0.790	1.27	0.635	10%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

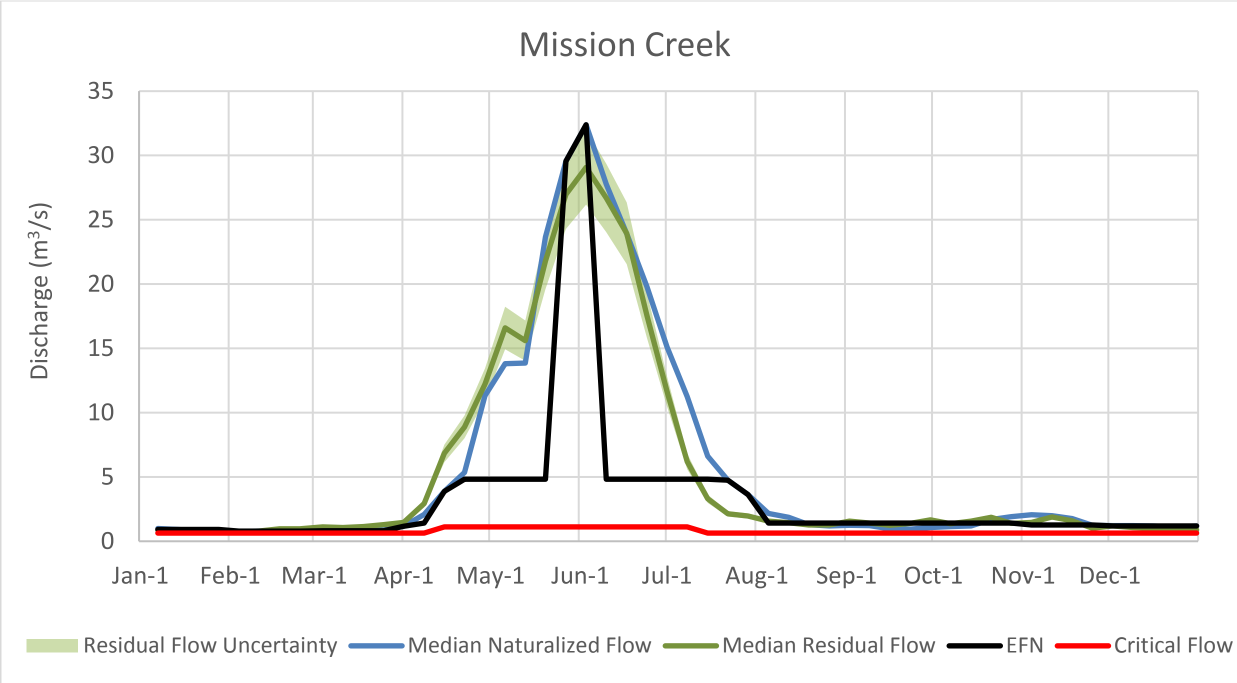


Figure 3-9: Weekly EFN, critical flow, and streamflows in Mission Creek

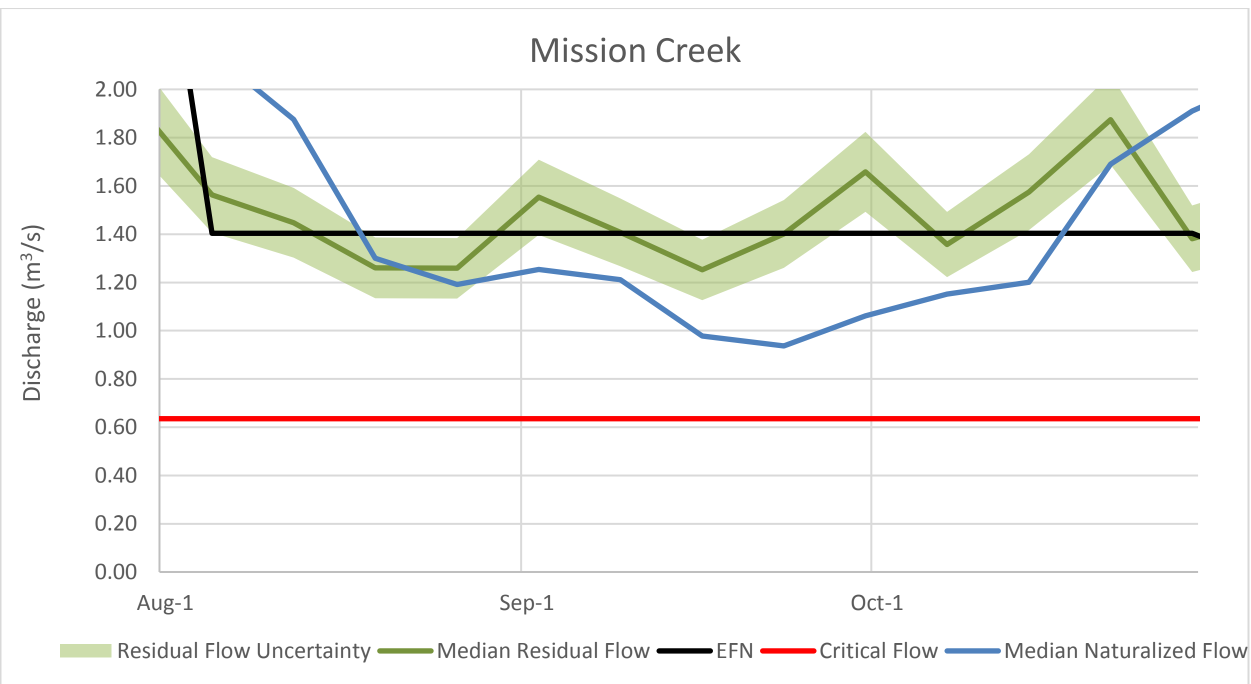


Figure 3-10: Weekly EFN, critical flow, and streamflows during summer and fall in Mission Creek

Rainbow parr rearing

WUW transects for Rainbow parr rearing were situated throughout the entire fish accessible extent of Mission Creek. Due to the wide range of channel conditions with varying gradient, substrate size and levels of channelization, the resulting WUW curve shows a moderate amount of uncertainty (Figure B5-15, Appendix B5). Parr rearing WUW peaked around 2 m^3/s similar to findings by Epp (2009). The recommended EFN for Rainbow parr rearing is 1.40 m^3/s (22% LTMAD), a value that is between the median Okanagan Tennant EFN (1.26 m^3/s, 20% LTMAD; based on naturalized flows) and median residual flows (1.50 m^3/s, 24% LTMAD) for the summer and fall low flow period (mid-July from end of Rainbow spawning to end of September). This EFN maintains approximately 90% of maximum Rainbow parr rearing WUW in glides and 80% in riffles, and 50% of maximum insect production WUW (Figure B5-16, Appendix B5). Though median residual flows are slightly higher than the recommended EFN, the value of 1.40 m^3/s strikes a balance between naturalized and residual flows and is also equal to the recommended Kokanee spawning EFN, which eliminates the need for multiple EFN values through the summer and fall. The Rainbow parr rearing EFN is expected to be met during most years due to extensive headwater storage. Photos of habitat conditions in Mission Creek at the recommended EFN flows are provided in Plate 3-9.

The recommended critical flow for Rainbow parr is 0.635 m^3/s (10% LTMAD; Table B5-2, Appendix B5). Critical riffle analysis indicated that riffle widths decline to <60% at flows of 0.790 m^3/s (12% LTMAD). Channelization and diking in Mission Creek have resulted in large variability in channel conditions ranging from narrow and deep to wide and shallow, which led to higher uncertainty in the critical riffle analysis; thus, slightly lower critical flows of 10% LTMAD are recommended to conform with those recommended for Kokanee spawning. Critical flows of 10% LTMAD rather than the default 5% LTMAD are further recommended because insect WUW declines from about 25% of maximum WUW to less than 10% between those flows (Figure B5-16, Appendix B5). Further, already high summer stream temperatures are more likely to escalate under very low flows.

The recommended EFN is lower than flows specified in the Water Use Plan for August (2.25 m^3/s) and September (1.9 m^3/s) (Water Management Consultants 2010). However, Rainbow parr would benefit from some additional WUW available at those higher flows. Further, greater flows may aid in moderating high summer stream temperatures in the lower reaches of Mission Creek, which are frequently beyond the suitable range for Rainbow rearing reaching up to 26°C (Figure B5-9 to B5-14, Appendix B5). Historically recommended EFNs for parr rearing range from 1.13 m^3/s (Shepherd & Ptolemy 1999; Dobson 1990) to 3 m^3/s (ESSA and Solander 2009). Optimal flow recommendations of 1.42 m^3/s (Tredger 1989a; Shepherd & Ptolemy 1999) are similar to our recommended EFN.

Residual flows recorded at the hydrometric stations near the mouth in 2016 fluctuated but were generally greater than the recommended EFN. In 2017 (a drought year), flows were at or below the recommended EFN from early July throughout most of the summer and fall (Figures B5-2 to B5-7, Appendix B5). Historically, median flows at the WSC station 08NM116 (1949-2017) are near the recommended EFN (Figure B5-8, Appendix B5). However, summer and fall flows below the EFN have occurred periodically in eight of the last 10 years despite significantly higher flows specified in the Mission Creek Water Use Plan.

Rainbow spawning

The recommended EFN for Rainbow spawning is 4.83 m^3/s (76% LTMAD), which corresponds to the Okanagan Tennant EFN flow standard and the peak of the WUW curve. The EFN is well below the median weekly naturalized flows during the Rainbow spawning period (23.79 m^3/s, 375% LTMAD; Figure 3-9) and also below the residual flows. While WUW measurements at such flows were not possible because the stream was not wadeable, WUW curves from other streams suggest that the amount of WUW available likely declines at such high flows. The recommended EFN maintains the maximum Rainbow spawning WUW (100%) and relatively high (>80%) Rainbow parr rearing WUW in riffles and glides. Photos of habitat conditions in Mission Creek at the recommended EFN flows are provided in Plate 3-10. The recommended critical flow for Rainbow spawning is 1.12 m^3/s (18% LTMAD, Table B5-2, Appendix B5) based on the passage depth criterion (Table 2-7). A previous Rainbow spawning EFN recommendation of 7 m^3/s was made by ESSA and Solander (2009).

<u>Kokanee spawning</u>

The recommended EFN for Kokanee spawning is 1.40 m^3/s (22% LTMAD), which maintains near 100% of maximum WUW (Figure B5-18, Appendix B5). The EFN corresponds to the median residual weekly flows during the Kokanee spawning period and is slightly higher than the Okanagan Tennant EFN (1.11 m^3/s; 17% LTMAD), which is based on median naturalized flows. The EFN was adjusted upward from the Okanagan Tennant EFN because flows in Mission Creek are specifically managed for Kokanee spawning and maintaining maximum production of this important Kokanee stock is of high priority. Further, previous studies also showed maximum habitat capacity at 1.42 m^3/s (Tredger 1989a). Very small (<5%) gains in WUW are made between our recommended EFN and Kokanee spawning flows stipulated by the Water Use Plan (1.9 m^3/s). Photos of habitat conditions in Mission Creek at the recommended EFN flows are provided in Plate 3-9. The recommended critical flow for Kokanee spawning is 0.635 m^3/s (10% LTMAD) based on critical riffle analysis (Table B5-1, Appendix B5).

Residual flows during the 2016 Kokanee spawning season were fluctuating above and below the recommended EFN, and in 2017 were well below the EFN and dropped below the critical flow on one occasion (Figures B5-3 and B5-4, Appendix B5). Median daily flows at the WSC hydrometric station 08NM116 (1949-2017) were consistently near the EFN; however, flows below the EFN have occurred periodically in 8 of the last 10 years despite significantly higher flows specified in the Mission Creek Water Use Plan.

Previous EFN recommendations for Kokanee spawning ranged from 0.9 m^3/s (Houston n.d.; Dobson 1990) to 4 m^3/s (ESSA & Solander 2009). Overwinter incubation flow recommendations from previous studies ranged from 0.6 m^3/s (Dobson 2004) to 0.99 m^3/s (CBCOBA 1974; Houston n.d.), which is in agreement with the recommended overwintering EFN of 0.925 m^3/s (Table 3-15).

Plate 3-9: Mission Creek habitat conditions at flows near the recommended Rainbow parr rearing and Kokanee spawning EFNs (1.40 m³/s)

Glide 1 at 1.38 m^3/s (22% LTMAD)

Glide 3 at 1.40 m^3/s (22% LTMAD)

Riffle 3 at 1.40 m^3/s (22% LTMAD)

Riffle 6 at 1.37 m^3/s (22% LTMAD)

Plate 3-10: Mission Creek habitat conditions at flows near the recommended Rainbow spawning EFN (4.83 m³/s)

Glide 2 at 4.40 m^3/s (69% LTMAD)

Glide 3 at 6.47 m^3/s (102% LTMAD)

3.6 McDougall Creek

McDougall Creek is a tributary to Okanagan Lake, flowing from the west side of the Okanagan Basin through West Kelowna, B.C. The watershed has an area of approximately 53 km^2 (Associated 2016) with a total stream length of approximately 16 km (Summit 1996). From the forested uplands, the creek flows through an incised valley onto a gently sloped terrace before flowing over an alluvial fan and into Okanagan Lake (Associated 2017). A summary of creek characteristics is found in Table 3-16 and additional stream-specific data is provided in Appendix B6.

The lower reaches of McDougall Creek flow through urban areas in West Kelowna with related impacts such as bank stabilization, stormwater outfalls, road crossings, and extensive channel straightening and armouring for flood control purposes in the lowermost 1 km from the mouth. Riparian vegetation cover is relatively good considering the location of the creek in an urban center, except for the lowermost 500 m, which are almost completely devoid of riparian vegetation due to recent flood control modifications.

No permanent barriers to fish migration have been reported for McDougall Creek (Associated 2016). The stream is known to support populations of Rainbow (Associated 2016; Summit 1996) and Rainbow fry and parr were observed in the reaches above Westside Road during field visits for this project. McDougall Creek may have historically supported a small Kokanee spawning population that was naturally constrained by low summer and fall flows. With increasing irrigation water demand on the creek, the amount of residual flow to accommodate Kokanee spawning had become almost negligible, which likely resulted in the elimination of the population (Wightman & Taylor 1978). No Kokanee were observed during the (very limited) enumeration visits over the past 20 years (Webster 2008-2016). However, it is possible that Kokanee spawners may use McDougall Creek in the future, particularly if sufficient flows during the spawning period and during the winter incubation period were maintained.

A total of three riffle and four glide transects were established in McDougall Creek in August of 2016 (Figure B6-3, Appendix B6). Transects were distributed between the mouth and the top of the alluvial fan above the city of West Kelowna.

At present there are 63 points of diversion within the watershed and 5 pending water licence applications; however, the actual volume extracted annually is unknown (Associated 2019). The City of West Kelowna and Westbank First Nation are the two main water users in the watershed, with developed storage at the headwaters at Hidden and Hayman lakes (Associated 2016). McDougall Creek is subject to numerous points of diversion through West Kelowna, as documented during field surveys in 2017. The stream is currently fully recorded for irrigation unless supported by storage (FLNRORD 2016). During the summer low flow season, the creek goes completely dry from just upstream of Shannon Lake Road downstream to a large groundwater discharge area below Daimler Drive where the creek regains a substantial amount of flow. Stranded Rainbow parr were observed in the dry section below Shannon Lake Road. Water losses and gains across the alluvial fan are unknown and could not be clearly characterized during this study due to the number and complexity of water diversions in the system. Inter-basin water transfers out of the basin occur when water is diverted from the headwater lakes to Shannon Lake. There is relatively little historic hydrometric information available for McDougall Creek. Two hydrometric stations were installed for this project: one at the top of the alluvial fan upstream of West Kelowna and most points of diversion; and one at the mouth which continues to operate (Figure B6-3, Appendix B6). McDougall Creek is 'flow sensitive' during summer and winter as naturalized flows are below 20% LTMAD (Table 3-17).

Table 3-16: McDougall Creek description

Drainage Area	53.5 km^2
Median Elevation	1071 m
WSC station	08NM014 (Historic) – McDougall Creek near Westbank (1920-1926)
ONA station	08NM590 – McDougall Creek at Jennens Road Bridge – Hydromet 1 (2016-present) 08NM591 – McDougall Creek at mouth of Canyon – Hydromet 2 (2016-2018)
LTMAD	0.132 m^3/s (Associated 2019)
Fish species expected	Rainbow (ESSA & Solander 2009)
Land use	The lower watershed contains irrigated agricultural land and commercial and residential developments (Associated 2016). The lowest reaches of McDougall Creek flows through Westbank First Nation reserve.

Naturalized, residual and maximum licensed flow data were provided by Associated (2019) with an estimated data quality rating of C (data error between 25% and 50%). Naturalized flow estimation in McDougall Creek is complicated because of numerous points-of-diversion, scant information on flow regulation, and complicated groundwater-surface water interactions on the fan (water disappears and then re-emerges in a large wetland area). Naturalized flow estimates by Associated (2019) for the summer and fall period were considered uncertain because they appeared extremely low. Residual flow estimates by Associated (2019) indicate flow augmentation, which is highly unlikely in this creek, and likely underestimate the true magnitude of diversions. They are not shown in the EFN plots below for that reason. Estimated maximum licensed flows indicate that the creek would be dry from late July to mid-September if licensed withdrawal and storage volumes were maximized.

Okanagan Tennant EFNs for McDougall Creek were developed in accordance with the methods outlined in Section 2.2. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. WUW information from the study transects was then reviewed to determine whether final EFN recommendations needed adjustment from the Okanagan Tennant EFN. A summary of EFNs for McDougall Creek is provided in Table 3-18 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-11, Figure 3-12 and Appendix B6, and flow sensitives in Table 3-17. Critical flows were calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in McDougall Creek is provided at the end of this section.

Table 3-17: Flow sensitivities in McDougall Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.024	18%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.023	17%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-18: EFN summary table for McDougall Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m³/s)	Recommended EFN (m³/s)				Critical flow	
		Median (m³/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m³/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.026	20%	0.026	0.026	20%	0.026	0.659	0.010	8%
Rainbow spawning	May 20 – Jul 10	0.373	281%	0.373	0.363	274%	0.128	0.659	0.161	122%
Kokanee spawning	Sep 1 – Oct 20	0.026	20%	0.028	0.028	21%	0.028	0.028	0.013	10%
Rainbow overwintering	Nov 1 – March 31	0.026	20%	n/a	0.026	20%	0.025	0.032	0.010	8%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

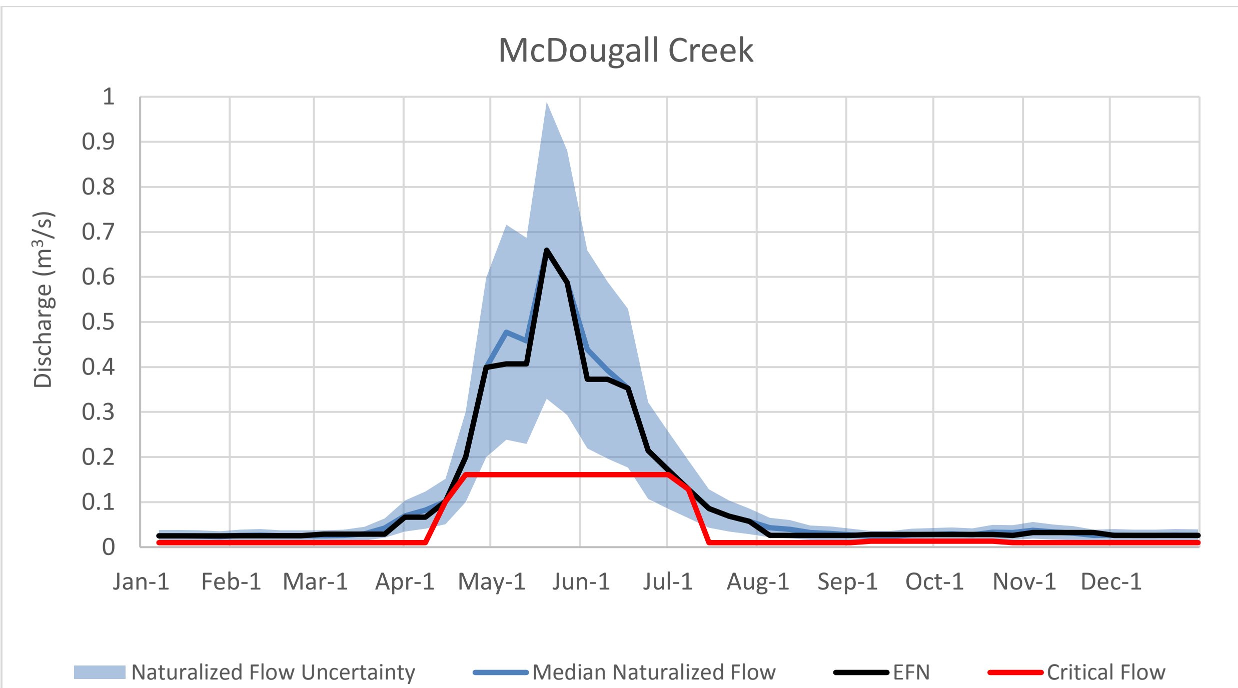


Figure 3-11: Weekly EFNs, critical flow and streamflows in McDougall Creek

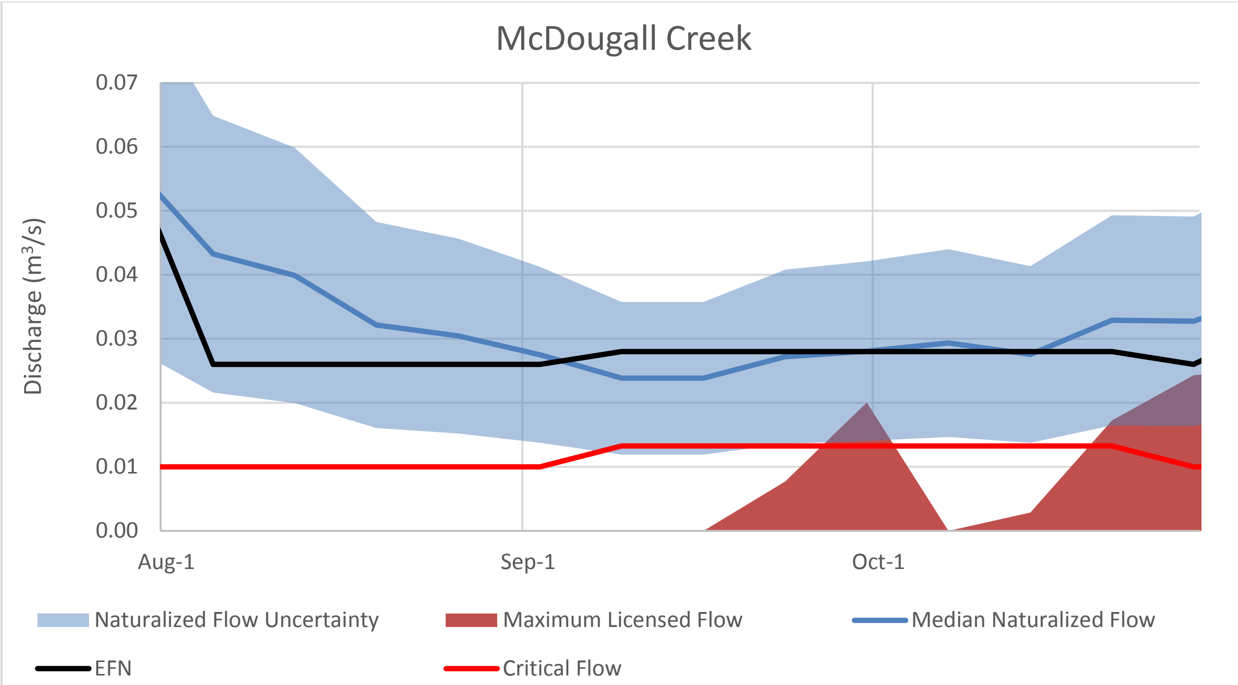


Figure 3-12: Weekly EFNs, critical flow and streamflows during the summer and fall period in McDougall Creek

Note: the peak and subsequent decline in maximum licensed flows in late September is an artifact resulting from assumptions about water use and reservoir release schedules made in the streamflow estimation process.

Rainbow parr rearing

The recommended EFN for Rainbow parr rearing is 0.026 m^3/s (20% LTMAD), which is equal to the median Okanagan Tennant EFN. The EFN maintains approximately 25% of maximum WUW in glides and 20% in riffles (Figure B6-8, Appendix B6) and approximately 10% of maximum insect production WUW from riffles (Figure B6-9, Appendix B6). This EFN value is near the average naturalized summer 30-day low flow (0.027 m^3/s; Associated 2019). Photos of habitat conditions in McDougall Creek at the recommended EFN flows are provided in Plate 3-11. Historical EFN recommendations were substantially higher at 0.085 m^3/s (Robertson 1983) and 0.2 m^3/s (ESSA & Solander 2009) but were not based on field observations in McDougall Creek. Critical flows of 0.01 m^3/s (8% LTMAD) are recommended for Rainbow rearing as riffle widths decline to <60% (Table B6-2, Appendix B6) and insect production from riffles becomes zero (Figure B6-9, Appendix B6).

The recommended EFN value is approximately equal to the lowest summer residual flows recorded at the ONA hydrometric station on Bartley Road (at the top of the alluvial fan above all water diversions but influenced by flow regulation from Hayman Lake) in 2017, which was a drought year (Figure B6-4, Appendix B6). Flows recorded at the mouth, however, were much lower and nearly dry (minimum 0.007 m^3/s in 2017 and 0.012 m^3/s in 2018). Between the two stations the creek has a section that goes dry but then regains most of its flow in a large groundwater discharge area below Daimler Drive. The limited historical discharge data also indicates very low flows near the mouth (Figure B6-5, Appendix B6). Meeting the Rainbow rearing EFN is likely difficult during most years (Figure B6-4 and B6-5, Appendix B6).

Water temperatures in McDougall Creek recorded at the upper hydrometric station at Bartley Road were generally favorable to Rainbow rearing at the recorded flows (maximum 17°C in early August; Figure B6-

6, Appendix B6) but were unsuitable at the mouth, with daily maximum temperatures above 20°C from late June to early September, and reaching over 25°C in late July (Figure B6-7, Appendix B6).

<u>Rainbow spawning</u>

The recommended EFN for Rainbow spawning is 0.373 m^3/s (283% LTMAD), which is equal to the median naturalized weekly flows during the Rainbow spawning period. This EFN maintains high spawning WUW (~90% of maximum, Figure B6-10, Appendix B6) while also maximizing Rainbow parr rearing WUW in riffles and glides. Residual flows were above the EFN from late April to early June during recent years (Figure B6-4, Appendix B6). Photos of habitat conditions in McDougall Creek at the recommended EFN flows are provided in Plate 3-12. The recommended critical flow for Rainbow spawning is 0.161 m^3/s (122% LTMAD, Table B6-3, Appendix B6) based on the passage depth criterion (Table 2-7). One historical EFN recommendation of 0.6 m^3/s was made by ESSA & Solander (2009).

<u>Kokanee spawning</u>

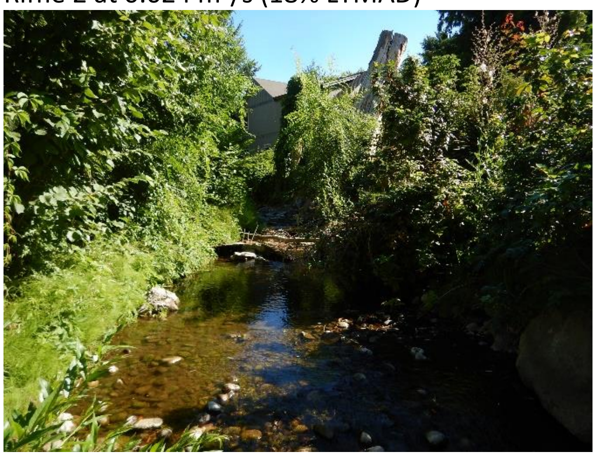
The recommended EFN for Kokanee spawning is 0.028 m^3/s (21% LTMAD), which is the median naturalized flow during the general Kokanee spawning period observed in other local streams (early September to mid-October). This EFN maintains approximately 30% of maximum Kokanee spawning WUW (Figure B6-11, Appendix B6) and is near the average naturalized summer 30-Day Low Flow (0.027 m^3/s; Associated 2019). Kokanee would benefit substantially from flows greater than the recommended EFN as WUW increases rapidly. Spawning flows near the mouth were substantially greater than the recommended EFN in 2017 (0.06 - 0.10 m^3/s) and ranging from critical flows (0.013 m^3/s) to greater than the EFN (0.069 m^3/s) in 2018 (Figure B6-4, Appendix B6). They were below the EFN during the short period of available historical records (Figure B6-5, Appendix B6). Given the extensive history of low flows and water use in McDougall Creek, Kokanee spawning EFNs are unlikely to be met during most years. Photos of habitat conditions in McDougall Creek at the recommended EFN flows are provided in Plate 3-11.

The recommended critical flow for Kokanee spawning is 0.013 m^3/s (10% LTMAD; Table B6-3) based on the %LTMAD criterion (Table 2-7). Safe riffle passage (0.12 m depth over $\geq$25% of riffle width) would be achieved at 0.046 m^3/s (35% LTMAD; Table B6-2, Appendix B6), which is greater than naturalized flows during the spawning and migration period, indicating that riffle passage may frequently be problematic.

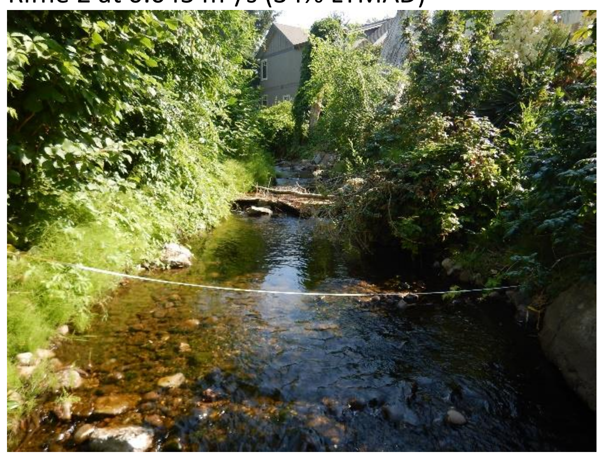
Plate 3-11: McDougall Creek habitat conditions at flows near the recommended Rainbow parr rearing (0.026 m³/s) and Kokanee spawning EFNs (0.028 m³/s)

Riffle 2 at 0.024 m³/s (18% LTMAD)

Riffle 2 at 0.045 m³/s (34% LTMAD)



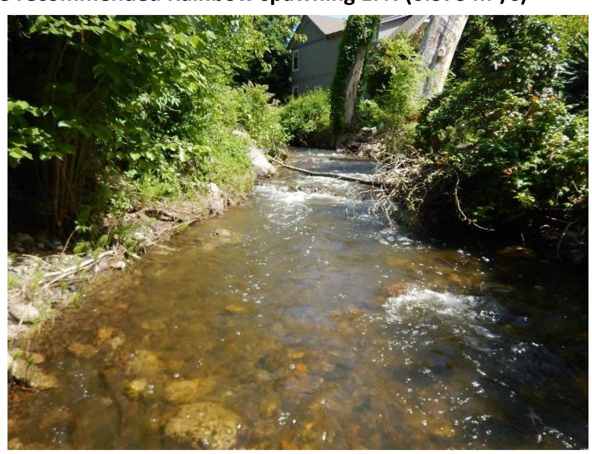
Glide 1 at 0.026 m³/s (20% LTMAD)



Glide 1 at 0.053 m³/s (40% LTMAD)

Plate 3-12: McDougall Creek habitat conditions at flows near the recommended Rainbow spawning EFN (0.373 m³/s)

Glide 4 at 0.377 m³/s (286% LTMAD)



Glide 1 at 0.448 m³/s (339% LTMAD)

3.7 akɬxʷminaʔ - Shingle Creek

Shingle Creek flows from the west side of the basin into the Okanagan River, just south of Okanagan Lake at Penticton, B.C. The Shingle Creek watershed is approximately 299 km^2 and has one main tributary, Shatford Creek (Associated 2016). This project focused on two reaches of Shingle Creek, named Lower Shingle Creek and Upper Shingle Creek for the purpose of this study (Figure 3-13). Information regarding stream conditions and recommended EFNs in the two reaches is provided in sections 3.7.1 and 3.7.2 and general information about the stream is provided below. A summary of creek characteristics is found in Table 3-19 and stream-specific data is provided in Appendices B7.1 and B7.2.

Until 2015, the lowest barrier to fish migration was an irrigation dam 2 km from the mouth. Removal of the irrigation dam opened up over 30 km of stream habitat to migrating fish including anadromous salmon (Rivard-Sirois 2013). The Upper Shingle Creek tributary was also made available to anadromous salmon (Enns 2015), which has led to additional scrutiny of flow management practices in those reaches due to the high quality of habitat and wetlands upstream of the dam site (Lukey & Louie 2015). The stream currently supports populations of fluvial and adfluvial Rainbow, spawning Kokanee, and spawning Sockeye (Lukey & Louie 2015; Ernst & Vedan 2000). It is also possible that anadromous Steelhead utilize the stream. Shingle Creek once provided spawning habitat for Okanagan Spring Chinook (Rae 2005) but the species was previously extirpated from the system; however, returns from hatchery programs downstream have been observed to enter the creek in recent years (Mahony et al. 2019). The only nearby existing Okanagan Chinook population, Okanagan summer Chinook, which spawn in the mainstem, are designated as “Endangered” by COSEWIC (2017). There is a greater effort underway by ONA to re-build Okanagan Chinook populations.

At present there are 222 points of diversion within the watershed; however, the actual volume extracted is unknown (Associated 2019). The Penticton Indian Band is the main water supplier in the watershed (Associated 2016). Water storage for licences is held in Brent and Farleigh Lakes (Associated 2016). In 1969, Shingle Creek was designated as having a possible water shortage for water licensing purposes (FLNRORD 2016).

Table 3-19: Shingle Creek description (Upper and Lower)

Drainage Area	299 km^2 (Lower) & 118.4 km^2 (Upper)
Median Elevation	1273 m
WSC station	08NM037 (Active) – Shatford Creek near Penticton (1919-present) 08NM038 (Historic) – Shingle Cr above Kaledon Div. (1920-1977) 08NM070 (Historic) – Riddle Creek near W. Summerland (1930-1931) 08NM150 (Historic) – Single Creek at the Mouth (1969-1981)
ONA station	08NM706 – Lower Shingle Creek PIT Array (2015-2018) 08NM170 – Upper Shingle Gabriel Field (2016-2018)
LTMAD	Lower 0.641 m^3/s (Associated 2019) Upper 0.272 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, Eastern Brook Trout, Mountain Whitefish, Largescale Sucker, Longnose Dace, Prickly Sculpin, Peamouth Chub (ESSA & Solander, 2009). Steelhead, Spring Chinook, Summer Chinook, Sockeye (Ernst & Vedan 2000)
Land use	Forestry, agriculture (Associated 2016). Most of Shingle Creek is on the Penticton India Band reserve except for the upper most reaches and the Shatford tributary

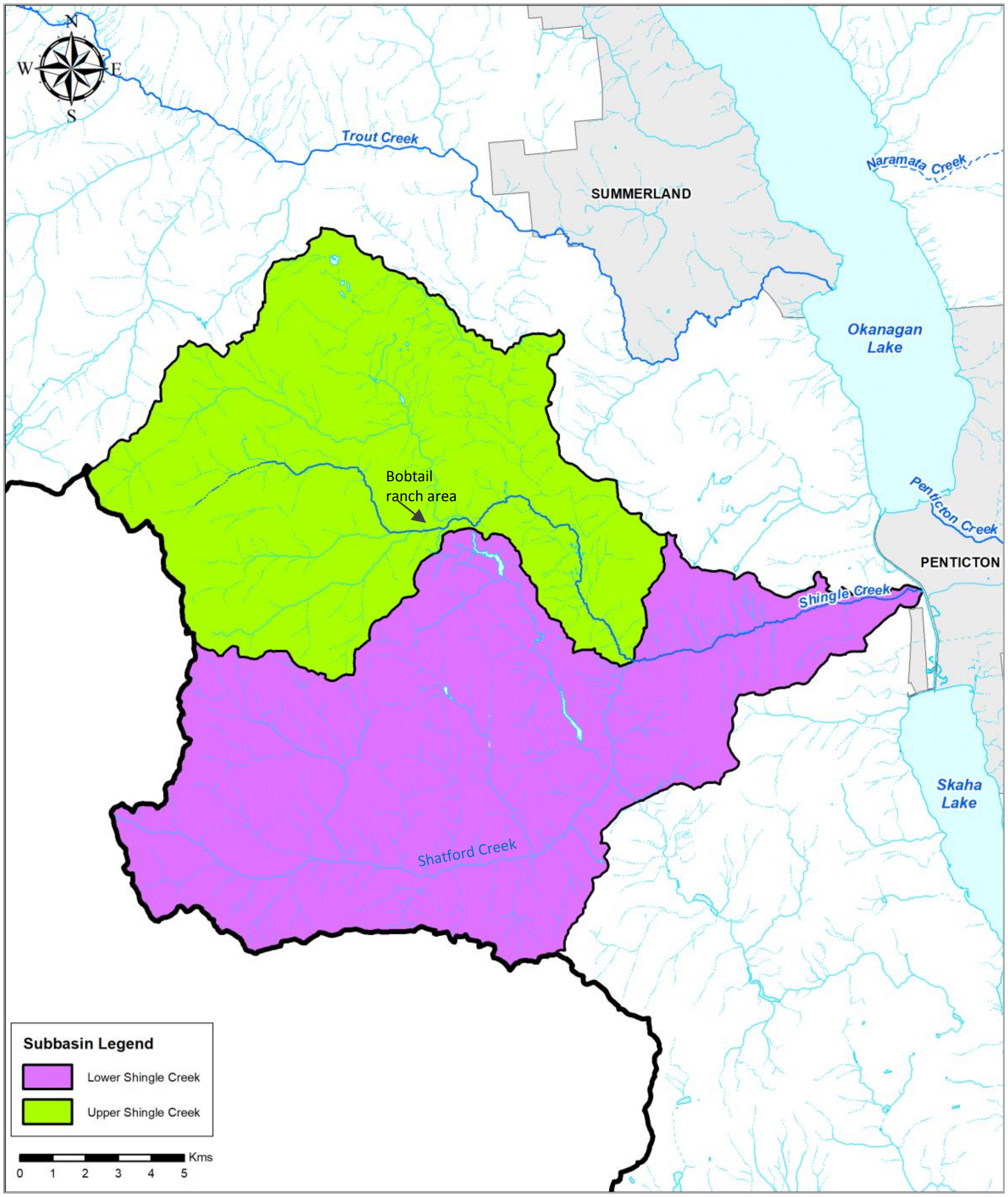


Figure 3-13: Upper and lower reaches of Shingle Creek

3.7.1 Lower Shingle Creek

The Lower Shingle Creek reach is 10.8 km long, extending from its confluence with Shatford Creek to the mouth at the Okanagan River. Most of the water volume in Lower Shingle Creek originates from Shatford Creek. The lowest reach of Shingle Creek has been subjected to rural and industrial encroachment and considerable hydro-modification and riparian function impairment. Downstream of an old irrigation dam, Shingle Creek has been straightened with corresponding intermittent makeshift diking and bank armouring especially adjacent to bridges. Modifications to the streambanks reduce the creek's ability to interact with riparian areas, and riparian vegetation has been reduced to tree cover with some light shrub cover in some areas. There is a subsequent deficiency of large woody debris. The width of the riparian areas is typically limited to a narrow strip of trees with yards and roads directly adjacent. The lowest sections of Shingle Creek are highly entrenched in areas subject to bank erosion. Industrial encroachment includes a storage yard, gravel storage yard, gas station, and the ONA Fish Hatchery. Shingle Creek flows over an alluvial fan in this reach before its confluence with the Okanagan River. Paired streamflow measurements indicate streamflow gains from groundwater on the fan.

Two riffle and two glide transects were installed in the lowest 1 km of the stream downstream of the removed irrigation dam in August 2016. One hydrometric station was installed in this reach. The station was subsequently washed out during the 2017 freshet and data provided in this report is from the ONA hydrometric station at the removed irrigation dam 2 km from the mouth (station is operated by the Okanagan Basin Monitoring and Evaluation Program [OBMEP]). Lower Shingle Creek is 'flow sensitive' during summer and winter as naturalized flows are below 20% LTMAD (Table 3-20). Naturalized flow data were provided by Associated (2019) with an estimated data quality rating of B (data error between 10% and 25%); residual and maximum licensed flow data were not available at the time of reporting.

Okanagan Tennant EFNs for Lower Shingle Creek were developed in accordance with the methods outlined in Section 2.2. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. WUW information from the study transects was then reviewed to determine whether final EFN recommendations needed adjustment from the Okanagan Tennant EFN. A summary of EFNs for Lower Shingle Creek is provided in Table 3-21 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-14, Figure 3-15 and Appendix B7.1 and flow sensitives in Table 3-20. Critical flows were calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in Lower Shingle Creek is provided at the end of this section.

Table 3-20: Flow sensitivities in Lower Shingle Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
O. mykiss & Chinook rearing	0.110	17%		
Insect production				
Kokanee & Chinook spawning				
O. mykiss & Chinook overwintering			0.063	10%
Kokanee, Sockeye & Chinook egg incubation				

Source: Associated (2019)

Table 3-21: EFN summary table for Lower Shingle Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m^3/s)	Recommended EFN (m^3/s)				Critical flow	
		Median (m^3/s)	% of LTMAD		Median	% of LTMAD	Min	Max	Flow (m^3/s)	% of LTMAD
O. mykiss parr, Chinook fry & insect production[a]	April 1- Oct 31	0.128	20%	0.128	0.128	20%	0.098	0.629	0.053	8%
Steelhead spawning	April 1 – June 25	0.702	110%	1.12	1.12	174%	0.094	3.87	0.493	77%
Rainbow spawning	May 20 – July 10	1.12	174%	1.12	1.12	174%	0.893	3.87	0.493	77%
Chinook migration	July 1 – Sep 17	0.321	50%	x	0.321	50%	0.144	1.12	0.321[b]	50%
Chinook spawning	Aug 27 – Sep 30	0.125	19%	0.125	0.125	19%	0.098	0.184	0.125[c]	19%
Kokanee spawning	Sep 25 – Nov 1	0.127	20%	0.128	0.127	20%	0.098	0.128	0.064	10%
Sockeye spawning	Sep 16 – Oct 31	0.126	20%	0.128	0.126	20%	0.098	0.128	0.064	10%
Overwintering salmonids	Nov 1 - March 31	0.073	11%	x	0.073	11%	0.064	0.115	0.053	8%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.
b median for the migration period
c median for the spawning period

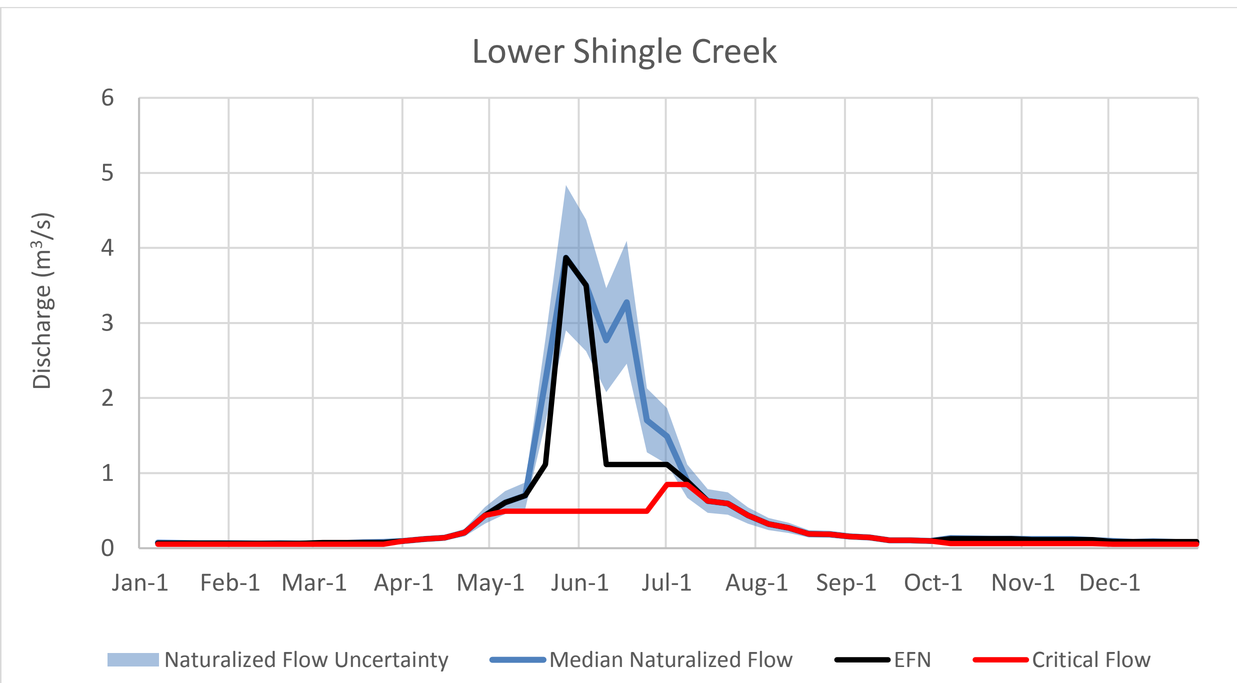


Figure 3-14: Weekly EFNs, critical flow and streamflows in Lower Shingle Creek

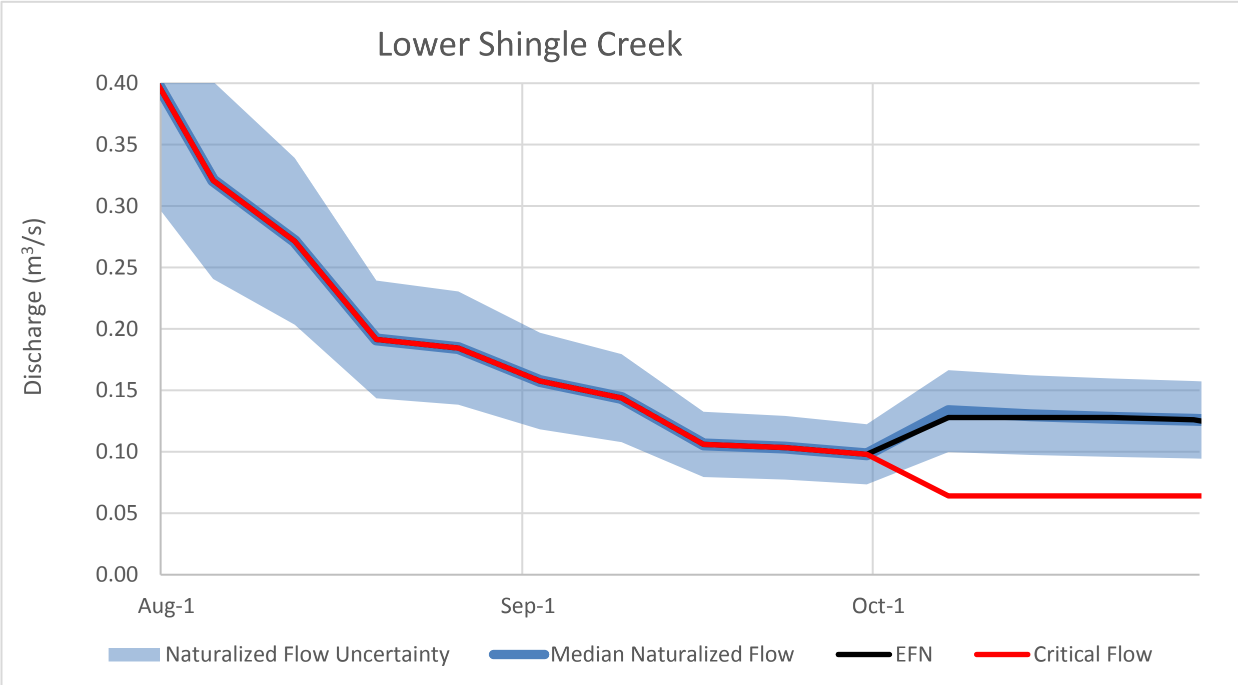


Figure 3-15: Weekly EFNs, critical flow and streamflows during the summer and fall period in Lower Shingle Creek

<u>*O. Mykiss* parr and Chinook fry rearing</u>

The recommended EFN for Steelhead and Rainbow (*O. mykiss*) parr and Chinook fry rearing is 0.128 m^3/s, which is equivalent to the flow standard of 20% (Table 3-21). The recommended EFN maintains approximately 50% of maximum WUW for *O. mykiss* parr rearing (Figure B7-6, Appendix B7.1) and 60% for Chinook fry rearing (Figure B7-7, Appendix B7.1), as well as 28% of maximum insect production WUW (Figure B7-8, Appendix B7.1). Previously recommended EFNs for Lower Shingle Creek range from 0.11 m^3/s (Koshinsky 1972b) to 0.25-0.6 m^3/s (ESSA & Solander 2009). Photos of habitat conditions in Lower Shingle Creek at the recommended EFN flows are provided in Plate 3-13.

Median naturalized flows for the summer and fall period (mid-July to late September, 0.188 m^3/s) are above the recommended EFN, with weekly flows greater than the EFN except from mid- to late September when they are approximately 0.1 m^3/s. Residual flows recorded at the ONA hydrometric station were frequently at or above the recommended EFN in late summer of 2018 and below it for a brief period in early September 2016 (Figure B7-3, Appendix B7.1). Limited historical residual streamflow data from 1969-1972 and 1978-1981 (WSC 08NM150, Shingle Creek near the Mouth; Figure B7-4, Appendix B7.1) demonstrate that the reaches near the mouth frequently went dry from early August to late October. Abrupt fluctuations in the record suggest that this was related to water storage and diversion activities rather than natural causes.

Water temperatures in Lower Shingle Creek recorded at the hydrometric station were generally favourable to *O. mykiss* and Chinook rearing, except in late July when they were at the upper range of suitable rearing temperatures (20^{o}C) (Figure B7-5, Appendix B7.1). Given the presence of a species of concern (spring Chinook), maintaining sufficient flows is vital to maintain favourable thermal conditions in this creek though flow thresholds for temperature maintenance were not formally studied under this project.

The recommended critical flow for *O. mykiss* parr and Chinook fry rearing is 0.053 m^3/s (8% LTMAD, Table B7-2, Appendix B7.1) based on the riffle width criterion (Table 2-7) applied to the lowermost riffle. It is approximately equal to the Summer 1 in 10-year return period 30-Day naturalized low flow (Table B7-3, Appendix B7.1).

Steelhead and Rainbow spawning

The recommended EFN for Steelhead and Rainbow spawning is 1.12 m^3/s (174% LTMAD, Table 3-21, Figure B7-9 and B7-10, Appendix B7.1), which is equivalent to the Okanagan Tennant EFN. This EFN maintains near maximum spawning WUW (>90% for both) while also maximizing *O. mykiss* parr and Chinook fry rearing WUW during the freshet period, and maintains high insect production from riffles. ESSA & Solander (2009) previously recommended an EFN of 0.4-1.9 m^3/s during the Steelhead spawning period and an EFN of 1.5-1.9 m^3/s during the Rainbow spawning period. Photos of habitat conditions in Lower Shingle Creek at the recommended EFN flows are provided in Plate 3-14.

Flows greater than the recommended EFN are observed under naturalized flows for a substantial portion of the freshet season (mid-May to early July), and have been recorded at the ONA hydrometric station from mid-April to late June (Figure B7-3, Appendix B7.1), and thus EFNs are considered achievable.

The recommended critical flow for Steelhead and Rainbow spawning is 0.493 m^3/s (77% LTMAD) from May to early July based on the passage depth criterion (Table 2-7). Prior to this period, critical flows are defaulted to the lower naturalized median weekly flows (Table B7-2, Appendix B7.1).

Spring Chinook spawning

Low numbers of spring Chinook have been observed to enter and spawn in the creek in recent years (Mahony et al. 2019). Flows needed to ensure good conditions for Chinook spawning, and particularly migration, likely exceed naturally available flows at times and as a result it is recommended that EFNs during the Chinook migration and spawning period are set to the weekly naturalized flow estimates. The median naturalized flow during the Chinook spawning period is 0.125 m^3/s (19% LTMAD), which provides approximately 23% of maximum spawning WUW (Table 3-21, Figure B7-11, Appendix B7.1). ESSA & Solander (2009) previously recommended an EFN of 0.3 m^3/s during the Chinook spawning period. Photos of habitat conditions in Lower Shingle Creek at the recommended EFN flows are provided in Plate 3-13.

While appropriate spawning WUW is maintained under relatively low flows (e.g. ~45% at 0.25 m^3/s), riffle passage conditions for Chinook are of concern. Riffle analysis indicates that 0.849 m^3/s (138% LTMAD) would be required to sustain safe riffle passage for Chinook (Table B7-1, Appendix B7.1). These conditions are met under naturalized flow conditions at the end of freshet in early July, which is the typical timing of spring Chinook migration into other streams in Washington State (CCT 2004; Snow et al. 2018; PTAGIS 2018). The 10% LTMAD (0.06 m^3/s) typically used by FLNRORD as a critical flow for Chinook spawning would result in <10% spawning WUW and likely total inability for Chinook to pass riffles because average depths would be approximately 5 cm. It is thus recommended to set critical flows in Shingle Creek at naturalized flows to protect the spring Chinook population. Further, protecting natural flows during rainfall driven flow pulses in the migration period is likely vital to enable spawner access.

Recently recorded flow data from the mouth indicates that EFNs and critical flows are frequently not met and that low flows likely limit Chinook migration and spawning during some years (Figure B7-3, Appendix B7.1), which matches field observations of Chinook spawners during low flows. Residual flow data estimates from Associated (2019) were not available but would be useful to illustrate the impact of water use on fish populations in Shingle Creek. Historical discharge data shows dry periods near the mouth during Chinook spawning and migration (Figure B7-4, Appendix B7.1).

Water temperatures in Lower Shingle Creek during the Chinook migration and spawning season reached thermal tolerance limits (20–22°C, Keefer et al. 2018) in July and August (Figure B7-5, Appendix B7.1). Any water use during mid-July to late September will have serious consequences for Chinook migration and spawning conditions in the creek. Maintaining EFNs and critical flows at naturalized flows until spawning has ended will protect Chinook that have entered Lower Shingle Creek and provide the best chance for successful spawning. Flows higher than the recommended EFN should be strongly encouraged to improve migration and spawning conditions.

Sockeye and Kokanee spawning

Sockeye and Kokanee spawn in Lower Shingle Creek from mid-September to late October. The median naturalized weekly flow during the spawning period is 0.127 m^3/s; however, the recommended EFN is 0.128 m^3/s, equal to the flow standard for Kokanee (20% LTMAD) as well as the summer juvenile rearing EFN (Table 3-21, Figure B7-12 and B7-13, Appendix B7.1). The recommended EFN maintains 50% of maximum Kokanee spawning WUW. The flow standard for Sockeye (40% LTMAD) is greater than naturalized flows and the recommended EFN, but adequate (~45%) spawning WUW for Sockeye is maintained at the recommended EFN. However, riffle passage conditions are of concern. Riffle analysis indicates that 0.173 m^3/s (27% LTMAD) would be required to sustain safe riffle passage for Kokanee and for Sockeye would be 0.493 m^3/s (77% LTMMAD) (Table B7-1, Appendix B7.1). These flows are greater than estimated naturalized flows during the spawning season and rain events are likely of very high importance to allow for movement between successive glides during the spawning period. Thus, the recommended critical flow for Sockeye and Kokanee spawning is 0.064 m^3/s (10% LTMAD, Table B7-2, Appendix B7.1) based on the %LTMAD criterion (Table 2-7). Previously recommended EFNs for the Sockeye and Kokanee spawning period were 0.20-0.23 m^3/s (Koshinsky 1972b) and 0.3 m^3/s (ESSA & Solander 2009). Photos of habitat conditions in Lower Shingle Creek at the recommended EFN flows are provided in Plate 3-13.

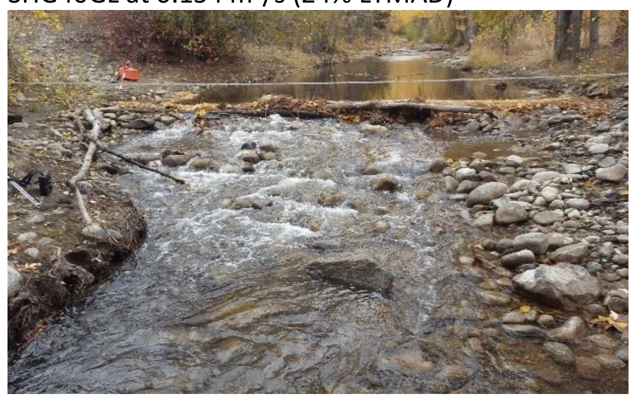
Residual flows recorded during the spawning season at the ONA hydrometric station between 2016 and 2018 were generally above the recommended EFN (up to 0.481 m^3/s, Figure B7-3, Appendix B7.1), indicating that the EFN can be met under current water use conditions. However, decreases in flow below the EFN did occur and flow conditions should be closely monitored during the spawning season. Flows greater than the EFN lead to relatively rapid gains in Kokanee and Sockeye spawning WUW and improved riffle passage conditions, and should be encouraged where possible.

Plate 3-13: Lower Shingle Creek habitat conditions at flows near the recommended *O. Mykiss* parr and Chinook fry rearing EFNs and Kokanee and Sockeye spawning EFNs (0.128 m³/s), and median Chinook spawning EFNs (0.125 m³/s)

SHG20GL at 0.145 m^3/s (23% LTMAD)

SHG40GL at 0.154 m^3/s (24% LTMAD)

SHG10SCR at 0.120 m^3/s (19% LTMAD)



SHG30SCR at 0.145 m^3/s (23% LTMAD)

Plate 3-14: Lower Shingle Creek habitat conditions at flows near the recommended Rainbow and Steelhead spawning EFNs (1.12 m³/s)

SHG40GL at 1.02 m^3/s (160% LTMAD)

SHG20GL at 1.07 m^3/s (168% LTMAD)

3.7.2 Upper Shingle Creek

The Upper Shingle Creek reach is 12.74 km long, extending from Bobtail Ranch down to the confluence of Upper Shingle Creek and Shatford Creek. This section of the creek has not been straightened or armoured but has some agricultural encroachment with minimal hydromodification and riparian function impairment. The stream is able to flood its banks regularly and interact with the riparian areas, and riparian vegetation is a complex of large trees, shrubs, and herb layers with subsequent large woody debris. The riparian area is wide in most sections except for some localized sections of canyon and agricultural encroachment. An extensive area of wetlands providing prime fish rearing habitat is located at the downstream end of this reach near the confluence with Shatford creek. The dewatering of Upper Shingle Creek above the wetland and below a known irrigation intake has been observed during several years and is an issue considering the high quality of habitat in this reach.

Very large *O. mykiss* have been observed to spawn in Upper Shingle Creek (OBMEP 2016-2019). There is no recent record of Chinook spawning in Upper Shingle Creek though spawning has been noted by Okanagan Knowledge Keepers historically near the confluence with Shatford Creek. Therefore, spring Chinook fry use in Upper Shingle is highly likely due to nearby spawning and suitable habitat. Upper Shingle Creek occurs at an elevation that is higher than the other creeks. As a result, winter breakup starts later and therefore the periodicity of migration and spawning for Steelhead have been altered to coincide with a natural increase in flows at the beginning of freshet (Table 2-2).

Two riffle, 2 glide and 1 pool tailout transects were installed in a 1 km section starting 7.19 km upstream from the Upper Shingle and Shatford confluence. During previous habitat surveys (OBMEP 2016-2019), this section of Upper Shingle Creek was observed to go dry frequently in summer months and there are a number of large water extraction points upstream. One hydrometric station was previously installed by ONA in this reach through the OBMEP program. Naturally, Upper Shingle Creek is 'flow sensitive' during summer and winter as naturalized flows are below 20% LTMAD (Table 3-22).

Naturalized flow data were provided by Associated (2019) with an estimated data quality rating of B (data error between 10% and 25%); residual and maximum licensed flow data were not available at the time of reporting. Okanagan Tennant EFNs for Upper Shingle Creek were developed in accordance with the methods outlined in Section 2.2. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. Available WUW at the flow standards was often relatively low; thus, WUW information from the study transects was used to adjust the recommended EFN upward to match median naturalized flows. A summary of EFNs for Upper Shingle Creek is provided in Table 3-23 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-16, Figure 3-17 and Appendix B7.2, and flow sensitivities in Table 3-22. Critical flows were calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in Upper Shingle Creek is provided at the end of this section.

Table 3-22: Flow sensitivities in Upper Shingle Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
O. mykiss & Chinook rearing	0.036	13%		
Insect production				
Chinook spawning				
O. mykiss & Chinook overwintering			0.020	7%
Chinook egg incubation				

Source: Associated (2019)

Table 3-23: EFN summary table for Upper Shingle Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m^3/s)	Recommended EFN (m^3/s)				Critical flow	
		Median (m^3/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
O. Mykiss parr & Chinook Fry rearing, insect production [a]	April 1 – Oct 31	0.054	20%	0.064	0.064	24%	0.032	0.240	0.020	7%
Steelhead spawning	April 16 – Jun 25	0.641	236%	0.900	0.900	331%	0.074	1.74	0.306	113%
Rainbow spawning	May 20 – Jul 10	0.641	236%	0.900	0.900	331%	0.352	1.74	0.306	113%
Chinook migration	July 1 – Aug 26	0.115	42%	n/a	0.115	42%	0.048	0.613	0.054	20%
Chinook spawning	Aug 27 – Sep 30	0.041	15%	0.063	0.041	15%	0.032	0.063	0.027	10%
Overwintering salmonids	Nov 1 - March 31	0.023	9%	n/a	0.023	9%	0.021	0.038	0.020	7%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

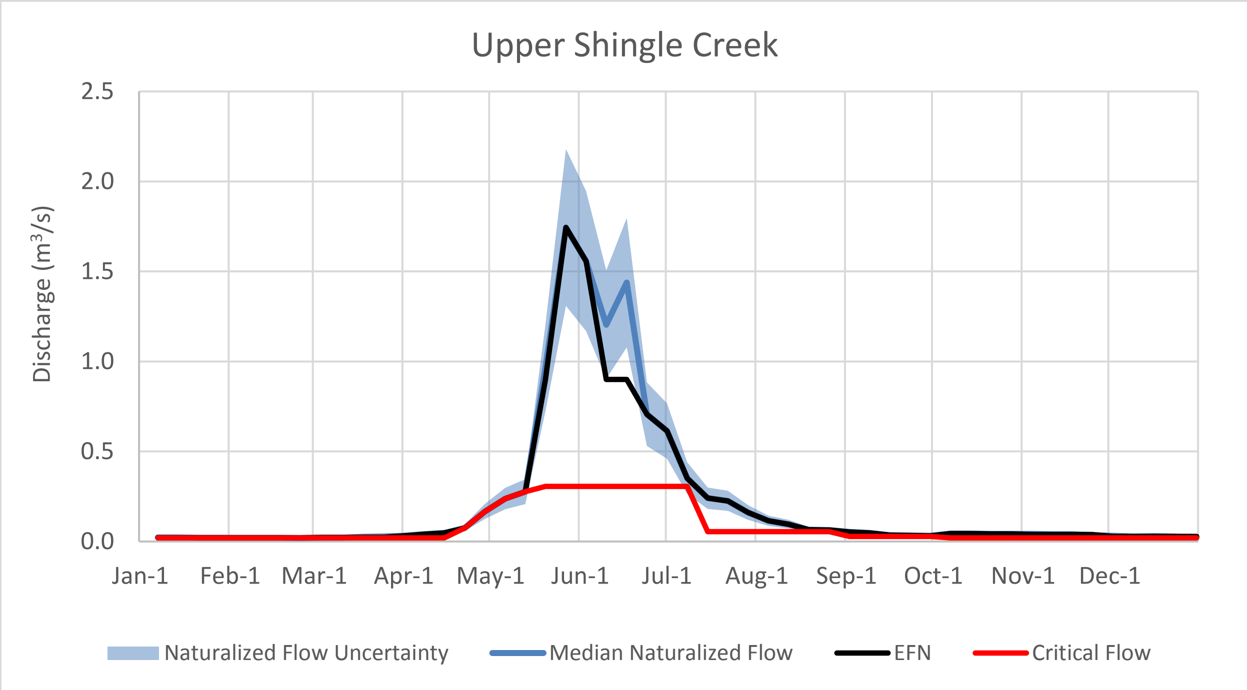


Figure 3-16: Weekly EFNs, critical flow and streamflows in Upper Shingle Creek

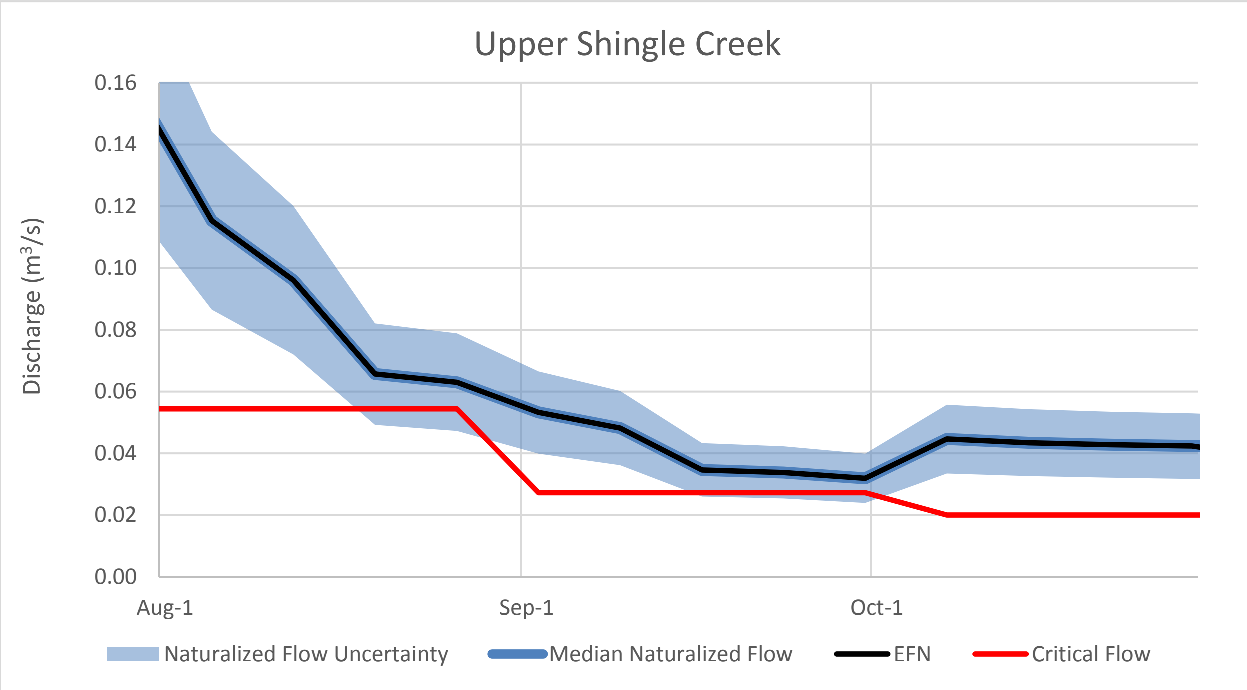


Figure 3-17: Weekly EFNs, critical flow and streamflows during the summer and fall period in Upper Shingle Creek.

O. Mykiss parr and Chinook fry rearing

The recommended EFN for Steelhead and Rainbow (*O. mykiss*) parr and Chinook fry rearing is 0.064 m^3/s (24% LTMAD), which is equal to the median naturalized flow during the summer low flow period (mid-July to late September) and slightly greater than the flow standard of 20% LTMAD. The recommended EFN maintains approximately 25% of maximum WUW for *O. mykiss* parr rearing and 35% for Chinook fry rearing (Figure B7-18 and B7-19, Appendix B7.2). Insect production under these flows is somewhat marginal at 8% of maximum WUW (Figure B7-20, Appendix B7.2). The steeply increasing WUW curves indicate that rearing conditions improve rapidly at flows above the recommended EFN during wetter years. Photos of habitat conditions in Upper Shingle Creek at the recommended EFN flows are provided in Plate 3-15. The recommended critical flow for *O. mykiss* parr and Chinook fry rearing is 0.020 m^3/s (7% LTMAD, Table B7-5, Appendix B7.2) based on the riffle width criterion (Table 2-7).

Naturalized flows approach critical flows in early September. Measured residual flows were above the recommended EFN until mid-July when a sudden drop to zero flow was observed during 2017 and 2018, suspected to be the result of known water withdrawals upstream of the station (Figure B7-16 Appendix B7.2). Water temperatures in Upper Shingle Creek recorded at the hydrometric station were generally favorable to *O. mykiss* and Chinook rearing though they approached the upper range of suitable rearing temperatures (20°C) in mid-July and slightly exceeded it in August (21°C) during 2016 when the creek remained wetted (Figure B7-17, Appendix B7.2).

Rainbow and Steelhead spawning

The recommended EFN for Steelhead spawning and Rainbow spawning is 0.900 m^3/s (330% LTMAD). This maintains spawning WUW near 80-85% for both and is slightly above the median naturalized flows during the Steelhead spawning period (Figure B7-22, Appendix B7.2) and slightly below the median naturalized flows for Rainbow spawning (Figure B7-23, Appendix B7.2). The WUW EFN is greater than the Okanagan Tennant EFN (236% LTMAD). The recommended EFN maximizes *O. mykiss* parr rearing and maintains high Chinook fry rearing WUW (>85%) during the freshet period, and maintains high insect production from riffles. Flows greater than the recommended EFN are observed under naturalized flows from mid-May to mid-June; similar flow rates were recorded at the hydrometric station from early May to mid-June (Figure B7-16, Appendix B7.2), and the recommended EFNs are thus considered achievable. Photos of habitat conditions in Upper Shingle Creek at the recommended EFN flows are provided in Plate 3-16.

The recommended critical flow for Rainbow and Steelhead spawning is 0.306 m^3/s (113% LTMAD) from late May to early July, based on the minimum passage depth criterion (Table 2-7) at one of the two riffle transects (the other riffle produced minimum passage flows near the EFN and naturalized flows and was excluded from analysis). Prior to this period (late April – mid May), critical flows are defaulted to the lower naturalized median weekly flows (Table B7-6, Appendix B7.2).

Chinook spawning

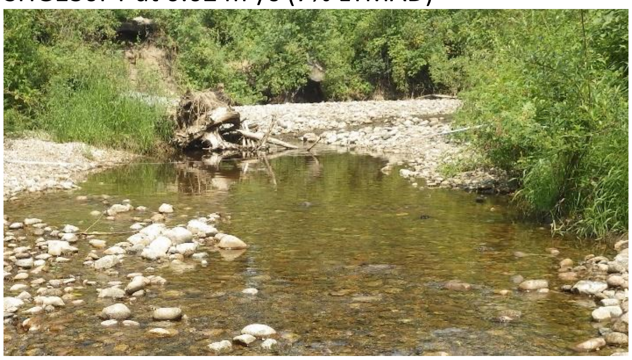
Spring Chinook spawning habitat conditions in Upper Shingle Creek are naturally constrained by summer low flows. If suitable conditions are to be maintained for spring Chinook spawning, it is recommended that EFNs during the migration and spawning period are set to naturalized flows. Median naturalized flows during the spawning period are 0.043 m^3/s (15% LTMAD). At these flows, <5% spawning WUW remains (Figure B7-23, Appendix B7.2) and riffle passage for Chinook is likely not possible. The ability of spring Chinook to successfully spawn in this reach is likely limited to wet years with flows greater than 0.15 m^3/s during the spawning period. Any water use during mid-July to late September will have serious consequences for Chinook migration and spawning conditions in the creek. The recommended critical flow for Chinook is 0.054 m^3/s (20% LTMAD) for migration and 0.027 m^3/s for spawning (10% LTMAD; Table B7-6, Appendix B7.2) based on the LTMAD criteria (Table 2-7), though riffle passage at those flows is not likely possible. Photos of habitat conditions in Upper Shingle Creek at the recommended EFN flows are provided in Plate 3-15.

Residual flows recorded at the ONA hydrometric station were above the recommended EFN until mid-July when they suddenly dropped to zero flows during 2017 and 2018, likely the result of known water withdrawals upstream of the station (Figure B7-16, Appendix B7.2). Meeting the EFN for Chinook spawning in Upper Shingle Creek is likely problematic because of naturally low flows and water diversions.

Plate 3-15: Upper Shingle Creek habitat conditions at flows near the recommended *O. mykiss* parr and Chinook fry rearing EFNs (0.064 m³/s) as well as Chinook spawning EFNs (0.063 m³/s)

SHG130PT at 0.02 m^3/s (7% LTMAD)

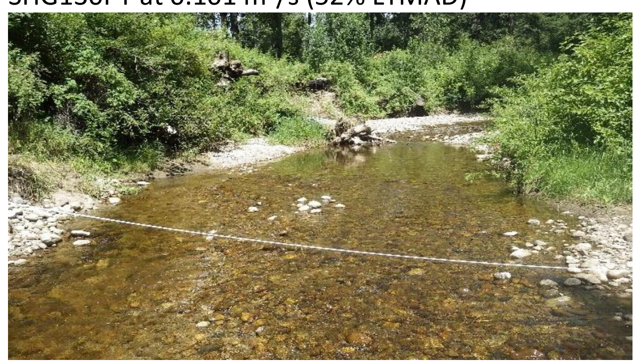
SHG130PT at 0.141 m^3/s (52% LTMAD)



SHG130PT at 0.02 m^3/s (7% LTMAD)

SHG130PT at 0.101 m^3/s (52% LTMAD)

SHG120GL at 0.08 m^3/s (29% LTMAD)



SHG120GL at 0.135 m^3/s (50% LTMAD)

Plate 3-16: Upper Shingle Creek habitat conditions at flows near the recommended Rainbow and Steelhead spawning EFNs (0.900 m³/s)

SHG40GL at 0.913 m^3/s (336% LTMAD)

SHG120GL at 0.967 m^3/s (356% LTMAD)

3.8 Shuttleworth Creek

Shuttleworth Creek is a tributary to the Okanagan River, flowing from the east side of the Okanagan Basin to Okanagan River just downstream of the Skaha Lake outlet dam at Okanagan Falls, B.C. The Shuttleworth Creek drainage area is approximately 90 km^2 (OBMEP 2019). Its headwaters drain gently sloping plateaus before flowing through a steep canyon and finally over a large alluvial fan before its confluence with the Okanagan River below Okanagan Falls. A summary of creek characteristics is found in Table 3-24 and additional stream-specific data is provided in Appendix B8.

The lower reaches of Shuttleworth Creek are extremely impaired due to upstream water withdrawals and excessive urban and agricultural encroachment (Rivard-Sirois & Audy 2010). The creek has been subjected to intense urban and industrial encroachment, significant hydro-modification and riparian function impairment. Lower Shuttleworth Creek has been straightened with corresponding diking and complete bank armouring. Modifications to the streambanks eliminates the creek's ability to regularly interact with riparian areas, and riparian vegetation has been reduced to tree cover with some light shrub cover in some areas. There is a subsequent deficiency of large woody debris. The width of the riparian areas is quite narrow, usually just a thin strip of trees with houses, yards and roads directly adjacent to the stream bank, some even within the bankfull width of the stream itself. Industrial encroachment includes lumberyards, pipeline crossings, an industrial area, parking lots, gravel storage yard, gas station, and a sediment basin near the mouth.

The lowest permanent barrier to adult anadromous fish migration is believed to be 8.5 km from the mouth, which is a long, high gradient cascade in the canyon (OBMEP 2019). A previously identified weir that formed a barrier at the sediment basin near the mouth (Walsh & Long 2006a) has since been altered to allow fish passage (Sungaila 2015). The stream is known to support populations of adfluvial Rainbow. As well, returns of Spring Chinook from downstream hatchery programs have recently been reported to access the lower reaches (OBMEP 2018). The stream is also accessible to salmonid species including anadromous Steelhead, Kokanee, Sockeye and Coho Salmon. This project focused on the lowest 1 km reach of Shuttleworth Creek, just upstream of the Cedar Street Bridge and upstream of the sediment basin.

One hydrometric station was previously installed by ONA in lower Shuttleworth Creek through the OBMEP program. At present there are 15 points of diversion within the watershed and 2 pending water licence applications (Associated 2019); however, the actual volume extracted annually is unknown (OBMEP 2019). The Allendale Water Users Community (AWUC) is the main water user (B.C. Government 2019) and manages water storage at Allendale Lake and Clark Meadows headwater dams. Shuttleworth Creek is considered fully recorded for all purposes except small domestic unless storage is provided as of 1991 (FLNRORD 2016). Extensive water diversions in Shuttleworth Creek are suspected to contribute to periods of very low or no flow in the lower loosing reaches during the summer and fall. Ensuring stored water is released from the upstream reservoirs to offset downstream withdrawals, as per licence conditions, is important for ensuring that water use does not exacerbate impacts to EFNs during periods of scarcity. Streamflow measurements on the alluvial fan undertaken for this study did not provide a clear understanding whether the stream was losing streamflow to groundwater; however, losses were assumed in the flow naturalization process based on previous hydrologic models (Associated 2019).

In years when lower Shuttleworth Creek was not dry in summer months, the corresponding water temperature data gathered showed very warm conditions with temperatures well above (24°C) preferred values for salmonid life histories in summer months (Figure B8-4, Appendix B8). Shuttleworth Creek is 'flow sensitive' during summer and winter as naturalized flows are below 20% LTMAD (Table 3-25).

Table 3-24: Shuttleworth Creek description

Drainage Area	89 km^2
Median Elevation	1543 m
WSC station	08NM006 (historic) Shuttleworth Cr near OK Falls (1921-1964) 08NM149 (historic) Shuttleworth Cr near the Mouth (1969-2010)
ONA station	08NM698 – Maple Street (2015-2018)
LTMAD	0.436 m^3/s (Associated 2019)
Fish species expected	Rainbow, Longnose Dace (ESSA & Solander, 2009), Steelhead, Chinook, Sockeye (Ernst & Vedan 2000)
Land use	Agriculture, urban development in lower reaches (Associated 2016)

Naturalized, residual and maximum licensed flow data were provided by Associated (2019) with an estimated data quality rating of C (data error between 25% and 50%). Summer and fall naturalized low flow estimates appeared quite low. Further, a suspected mismatch between residual and maximum licensed flow estimates and those observed in the field (creek dries up frequently below a point of diversion) warrants further investigation and requires continued collection of hydrometric data.

Okanagan Tennant EFNs for Shuttleworth Creek were developed in accordance with the methods outlined in Section 2.2. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. WUW information from the study transects was then reviewed to determine whether final EFN recommendations needed adjustment from the Okanagan Tennant EFN. A summary of EFNs for Shuttleworth Creek is provided in Table 3-26 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-18, Figure 3-19 and Appendix B8 and flow sensitives in Table 3-25. Critical flows were calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in Shuttleworth Creek is provided at the end of this section.

Table 3-25: Flow sensitivities in Shuttleworth Creek

Species & life stage	**1-in-2 yr 30-day summer low flow**		**1-in-2 yr 30-day winter low flow**	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
O. mykiss & Chinook rearing	0.049	11%		
Insect production				
Chinook spawning				
O. mykiss & Chinook overwintering			0.028	6%
Sockeye & Chinook egg incubation				

Source: Associated (2019)

Table 3-26: EFN summary table for Shuttleworth Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m^3/s)	Recommended EFN (m^3/s)				Critical flow	
		Median (m^3/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
O. Mykiss parr & Chinook Fry rearing, insect production [a]	April 1 – Oct 31	0.080	18%	0.080	0.080	18%	0.045	0.340	0.022	5%
Steelhead spawning	April 1 – Jun 25	0.871	200%	0.871	0.871	200%	0.079	2.16	0.445	102%
Rainbow spawning	May 20 – Jul 10	0.871	200%	0.871	0.871	200%	0.497	2.16	0.445	102%
Chinook migration	July 1 – Aug 26	0.111	26%	n/a	0.111	26%	0.067	0.645	0.087	20%
Chinook spawning	Aug 27 – Sep 30	0.060	14%	0.200	0.060	14%	0.045	0.087	0.044	10%
Sockeye spawning	Sep 16 – Oct 31	0.053	12%	0.150	0.053	12%	0.041	0.070	0.044	10%
Overwintering salmonids	Nov 1 - March 31	0.043	10%	n/a	0.043	10%	0.032	0.081	0.022	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

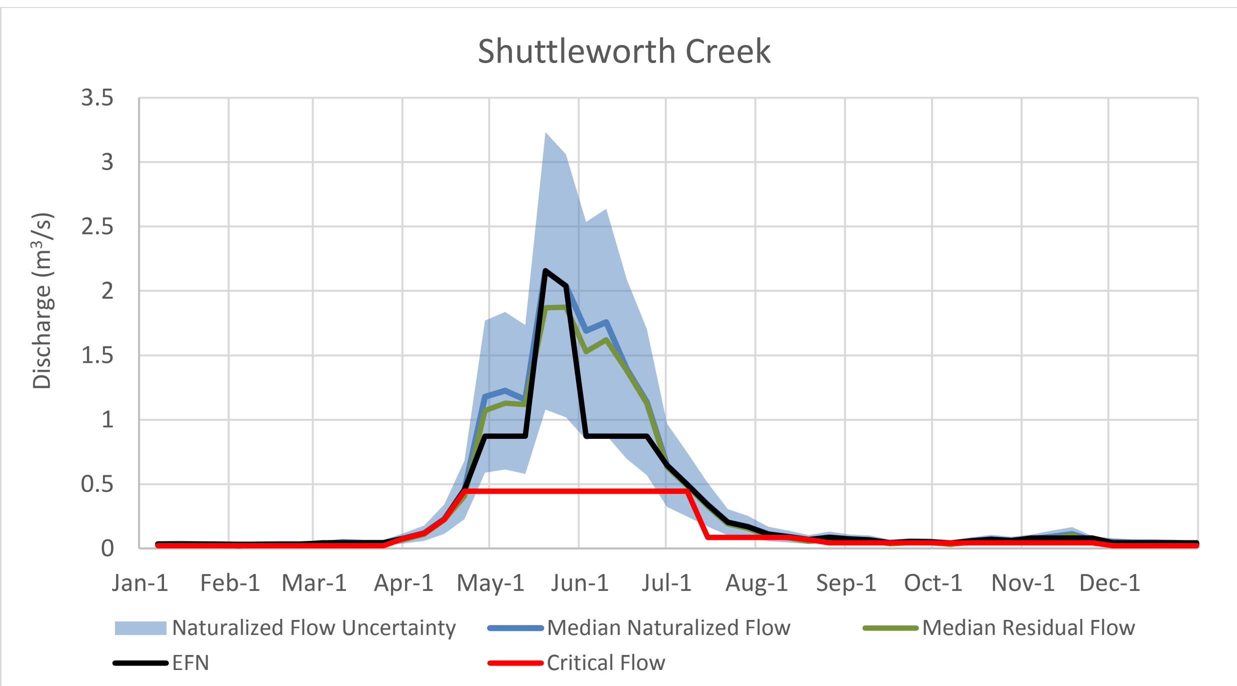


Figure 3-18: Weekly EFNs, critical flow and streamflows in Shuttleworth Creek

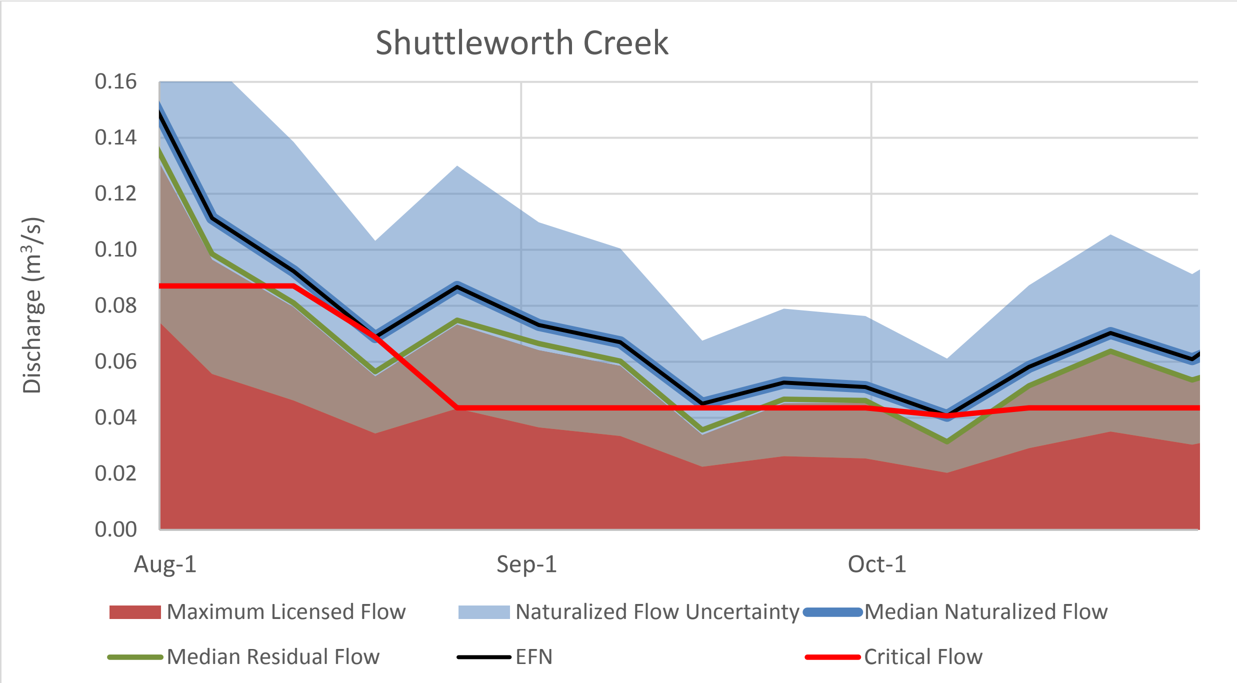


Figure 3-19: Weekly EFNs, critical flow and streamflows during the summer and fall period in Shuttleworth Creek

<u>*O. mykiss* parr and Chinook fry rearing</u>

The recommended EFN for Steelhead and Rainbow (*O. mykiss*) parr and Chinook fry rearing is the median naturalized weekly flows during the summer low flow season (0.080 m^3/s, 18% LTMAD). The recommended EFN reflects naturalized low flows occurring in September, maintains 30% of maximum WUW for *O. mykiss* parr rearing (Figure B8-5, Appendix B8) and 40% for Chinook fry rearing (Figure B8-6, Appendix B8). Insect production under these flows is somewhat marginal at 18% of maximum WUW (Figure B8-7, Appendix B8). Photos of habitat conditions in Shuttleworth Creek at the recommended EFN flows are provided in Plate 3-17. ESSA & Solander (2009) previously recommended an EFN of 0.1-0.2 m^3/s during the Rainbow parr rearing period.

Naturalized flows are generally greater than the EFN until mid-September. The WUW curves for rearing and insect production indicate that rearing conditions improve quickly at flows above the recommended EFN, and higher flows should be maintained where possible. Residual flows recorded in 2017 and 2018 were below the EFN for the entire post-freshet summer and fall period and the creek went dry during both years (Figure B8-2, Appendix B8). Major water diversions are present upstream of the station and the creek is reported dry during most summers; thus, achieving EFNs is problematic during most years.

When the creek was flowing, summer water temperatures in Shuttleworth Creek recorded at the hydrometric station generally exceeded upper temperature thresholds (20°C) for *O. mykiss* and Chinook rearing and daily maximum temperatures reached up to almost 25°C from mid-June to early August (Figure B8-4, Appendix B8). Maintaining sufficient flows is vital to maintain favorable thermal conditions in this creek though flow thresholds for temperature maintenance were not formally studied under this project.

The recommended critical flow for *O. mykiss* parr and Chinook fry rearing is 0.022 m^3/s (5% LTMAD; Table B8-2, Appendix B8), based on the LTMAD criterion (Table 2-7). While riffle width analysis indicated slightly lower critical flows (3% LTMAD), the extremely low WUW remaining and the high stream temperatures supported leaving the critical flow recommendation at 5% LTMAD.

Steelhead and Rainbow spawning

The recommended EFN for Steelhead spawning and Rainbow spawning is 0.871 m^3/s (200% LTMAD), which is equal to the Okanagan Tennant EFN flow standard. This maintains spawning WUW over 90% for both (Figure B8-8 and B8-9, Appendix B8). ESSA & Solander (2009) previously recommended an EFN of 0.6-0.9 m^3/s. The recommended EFN also maintains near maximum *O. mykiss* parr and Chinook fry rearing (~90%) WUW during the freshet period, and maintains high (~90%) insect production from riffles. Photos of habitat conditions in Shuttleworth Creek at the recommended EFN flows are provided in Plate 3-18.

The recommended critical flow for *O. mykiss* spawning is 0.445 m^3/s (102% LTMAD) from late April to early July, based on the minimum passage depth criterion (Table 2-7). Prior to this period (early April – mid April), critical flows are defaulted to the lower naturalized median weekly flows (Table B8-2, Appendix B8).

The recommended EFN is slightly below the median naturalized flows during the Steelhead spawning period and well below median naturalized flows during the Rainbow spawning period. Flows greater than the recommended EFN are observed under naturalized flows from early May to mid-June (Figure 3-18); similar flow rates were recorded at the ONA hydrometric station from late April to late May (Figure B8-2, Appendix B8), and the recommended EFNs are thus considered achievable.

Spring Chinook migration and spawning

While spring Chinook have been observed to enter Shuttleworth Creek in the early summer (PTAGIS 2018), spawning habitat conditions in late summer are naturally constrained by the small stream size and summer low flows. If suitable conditions are to be maintained for spring Chinook spawning, it is recommended that EFNs during the entire Chinook migration and spawning period are set to naturalized flows. Estimated median naturalized flows are 0.111 m^3/s (26% LTMAD) during the migration period. The estimated median naturalized flow during the Chinook spawning period is 0.060 m^3/s (14% LTMAD). At these flows, approximately 5% spawning WUW remains and riffle passage for Chinook is likely not possible (Figure B8-10, Appendix B8). ESSA & Solander (2009) previously recommended an EFN of 0.1-0.2 m^3/s during the Chinook spawning period. Photos of habitat conditions in Shuttleworth Creek at the recommended EFN flows are provided in Plate 3-17.

The recommended critical flow for migrating Chinook is 0.087 m^3/s (20% LTMAD) and for spawning Chinook is 0.044 m^3/s (10% LTMAD; Table B8-2, Appendix B8), based on the LTMAD criteria (Table 2-7). Riffle analysis indicated much higher safe passage flows of 0.611 m^3/s (140% LTMAD) but these only occur naturally early in the migration period (early July) and would rarely occur naturally during the spawning season.

The ability of spring Chinook to successfully access Shuttleworth Creek is likely limited to the end of freshet (which coincides with the detection of PIT-tagged Chinook at the mouth of the creek in early July), or wet years with flows greater than 0.2 m^3/s during the spawning period. Any water use during mid-July to late September will have serious consequences for Chinook migration and spawning conditions in Shuttleworth Creek. Flows recorded at the ONA hydrometric station in 2017 and 2018 were above 0.2 m^3/s until mid-June, and then fluctuated wildly before dropping to zero in late July or early August (Figure B8-2, Appendix B8), rendering it unusable for Chinook.

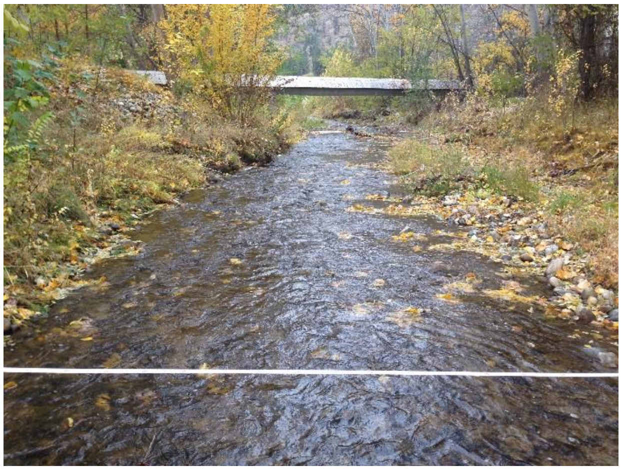
Sockeye spawning

Sockeye have been observed entering and attempting to spawn in Shuttleworth Creek although spawning habitat conditions are constrained by the small stream size and low fall flows. It is therefore recommended that EFNs during the spawning period be set to the estimated naturalized flows. Median naturalized flows during the spawning period are 0.053 m^3/s (12% LTMAD). At these flows, Sockeye spawning WUW is very marginal (2-6%) and riffle passage is likely difficult as safe riffle passage flows were estimated at 0.445 m^3/s (102 % LTMAD) (Figure B8-11 and Table B8-1, Appendix B8). ESSA & Solander (2009) previously recommended an EFN of 0.2 m^3/s during the Sockeye spawning period. Photos of habitat conditions in Shuttleworth Creek at the recommended EFN flows are provided in Plate 3-17.

The recommended critical flow for Sockeye spawning is 0.044 m^3/s (10% LTMAD, Table B8-2, Appendix B8) based on the %LTMAD criterion (Table 2-7). The ability of Sockeye to successfully spawn in Shuttleworth creek is likely limited to wet years with October flows greater than 0.15-0.2 m^3/s, which provides a moderate amount of spawning WUW (25-35%).

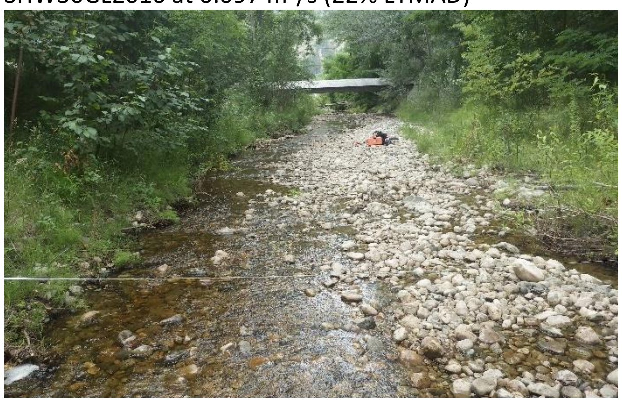
Any water use during mid-September to late October will have serious consequences for Sockeye spawning conditions in Shuttleworth Creek. Flows recorded at the ONA hydrometric station in 2017 and 2018 during the Sockeye spawning period were either dry (2017) or near dry (2018) (Figure B8-2, Appendix B8), rendering it unusable.

Plate 3-17: Shuttleworth Creek habitat conditions at flows near the recommended *O. mykiss* parr and Chinook fry rearing EFNs (0.08 m^3/s), and Chinook spawning (0.06 m^3/s) and Sockeye spawning (0.053 m^3/s) EFNs

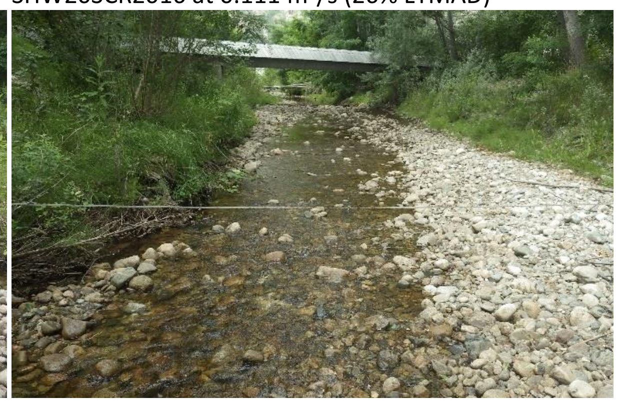


SHW30GL2016 at 0.097 m^3/s (22% LTMAD)

SHW20SCR2016 at 0.111 m^3/s (26% LTMAD)



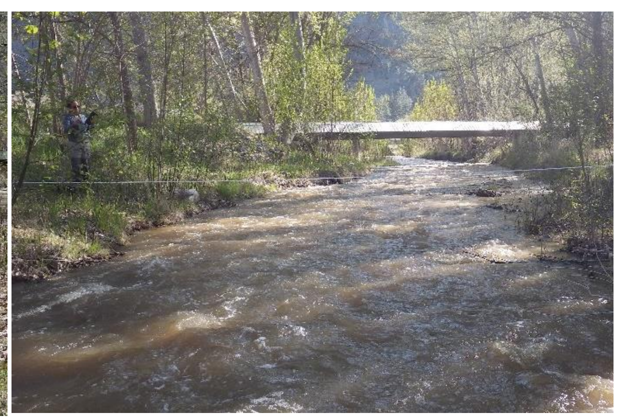
SHW40SCR2016 at 0.016 m^3/s (4% LTMAD)



SHW20SCR2016 at 0.024 m^3/s (5% LTMAD)

Plate 3-18: Shuttleworth Creek habitat conditions at flows near the recommended Steelhead and Rainbow spawning EFNs (0.871 m^3/s)

SHW30GL2016 at 0.476 m^3/s (109% LTMAD)



SHW30GL2016 at 1.25 m^3/s (286% LTMAD)

3.9 snʕaχ̌əlqaxʷiyaʔ - Vaseux Creek

Vaseux Creek flows from the east side of the Okanagan Basin into the Okanagan River just downstream of McIntyre Dam at the outlet of Vaseux Lake near Oliver, B.C. The Vaseux Creek watershed is approximately 296 km^2 (OBMEP 2019) and has one main tributary, Solco Creek (Associated 2016). The lower portion of Vaseux Creek was straightened and diked for flood control purposes in the 1950s. In response, extensive erosion and active channel migration upstream of the channelized section has been observed as the stream is trying to establish new equilibrium conditions (Agrodev 1996). A summary of creek characteristics is found in Table 3-27 and additional stream-specific data is provided in Appendix B9.

The lower reaches of Vaseux Creek have been subjected to rural and industrial encroachment and corresponding hydro-modification and riparian function impairment. From the mouth of the canyon downstream to the Highway 97 Bridge, the stream has a history of modifications around a large power station and significant water withdrawals. In this section, the stream is somewhat entrenched; however, there is a large complex of side channels and stream diversions that can be difficult to assess. During freshet flows, Vaseux Creek frequently floods these side channel areas, but in summer, flow is reduced to a very localized thalweg profile. Low summer flows are exacerbated by the significant water withdrawals and Vaseux Creek frequently runs dry somewhere between the canyon and the highway bridge. Much of the reach is devoid of any riparian vegetation with limited shading provided by rare large conifers. Industrial encroachment includes a gravel yard, the power station, and pipeline crossings. As well, a large concrete irrigation flume running from the mainstem Okanagan River down to Osoyoos crosses just upstream of the highway bridge. The flume is not hydraulically connected to the creek and a large boulder weir was built around it in 1996 because active erosion of the streambed around the flume was threatening its integrity and also blocking fish passage.

The lowest reach of Vaseux Creek, from the Highway 97 Bridge down to the mouth, has been subjected to intense urban encroachment and significant hydro-modification and riparian function impairment. In this section, the stream has been straightened with corresponding diking and complete bank armouring. Modifications to the streambanks eliminate the creek's ability to regularly interact with riparian areas, and riparian vegetation has been reduced to light tree cover. There is a subsequent deficiency of large woody debris. The width of the riparian areas is very thin, usually just a thin strip of trees, with houses, yards, and roads directly adjacent to the diking. Water losses are known to occur across most of the alluvial fan, though there is likely re-emergence somewhere downstream of the highway bridge as the bed elevation eventually intersects the water table (primarily the one that is connected to the river, with some possible groundwater mounding from the losses from Vaseux Creek). Losses across this fan are likely greater than for other streams because of the coarse fan material and the high elevation of the fan where it leaves the canyon (Neumann pers. comm. 2019).

A natural barrier to fish migration is located approximately 5 km from the mouth and this is the extent of available habitat to anadromous salmon populations (Associated 2016). The stream is known to currently support populations of adfluvial Rainbow, Steelhead, and Sockeye spawning (OBMEP 2019). As well, returns of spring Chinook from downstream hatchery programs have been observed to use the stream for spawning (OBMEP 2018). The stream is also available to Kokanee and Coho Salmon populations. Two riffle and 2 glide transects were installed in the lowest 1 km reach of Vaseux Creek between Highway 97 and the confluence with the Okanagan River.

At present there are 27 points of diversion within the watershed; however, the actual volume extracted is unknown (Associated 2019). There are no main water suppliers listed in the watershed

(Associated 2016) although there is a water licence for a Water Use Community (Associated 2019); water-use is largely for irrigation purposes. There is also no major developed water storage listed for the watershed (Associated 2016); one licence permits storage in a dugout in the Dutton Creek tributary (Associated 2019). Two large diversion channels have been noted on the Vaseux Creek alluvial fan; the water diverted appears substantial during some field visits though total volumes are unknown. One hydrometric station was previously installed by ONA upstream of Highway 97 through the OBMEP program. Naturally, Vaseux Creek is 'flow sensitive' during summer and winter as naturalized flows are below 20% LTMAD (Table 3-28).

Table 3-27: Vaseux Creek description

Drainage Area	294 km^2
Median Elevation	1535 m
WSC station	08NM171 (active) Vaseux Cr above Solco Creek (1970-present) 08NM015 (historic) Vaseux Cr above Dutton Creek (1919-1982) 08NM246 (historic) Vaseux Cr near the Mouth (2006-2010)
ONA station	08NM246-HDS real-time station (2016-to present)
LTMAD	1.285 m^3/s (Associated 2019)
Fish species expected	Rainbow, Steelhead, Sockeye, Mountain Whitefish, Bridgelip Sucker, Longnose Dace, Prickly Sculpin (ESSA & Solander 2009), Chinook (Ernst & Vedan 2000)
Land use	Land use is predominately forestry in the upper watershed. The Bighorn National Wildlife Area is situated in the lower reaches (Associated 2016)

Okanagan Tennant EFNs for Vaseux Creek were developed in accordance with the methods outlined in Section 2.2. Naturalized, residual and maximum licensed flow data were provided by Associated (2019) with an estimated data quality rating of C (data error between 25% and 50%). The LTMAD estimate appeared relatively low; summer and fall naturalized low flow estimates were extremely low and highly uncertain. Estimated maximum licensed flows indicate relatively little licensed water use on Vaseux Creek. However, the creek frequently dries up abruptly in mid-July and the extent to which two large and unmonitored diversions on the alluvial fan contribute is unknown and warrants further investigation.

Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. WUW information from the study transects was then reviewed to determine whether EFNs needed adjustment from the Okanagan Tennant EFN. In some cases, recommended EFNs were adjusted upward due to the uncertainty in the extremely low naturalized summer low flow estimates, and an associated lack of suitable habitat. A summary of EFNs for Vaseux Creek is provided in Table 3-29 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-20, Figure 3-21 and Appendix B9, and flow sensitives in Table 3-28. Critical flows calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in Vaseux Creek is provided at the end of this section.

Table 3-28: Flow sensitivities in Vaseux Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
O. mykiss & Chinook rearing	0.042	3%		
Insect production				
Chinook spawning				
O. mykiss & Chinook overwintering			0.002	0%
Sockeye & Chinook egg incubation				

Source: Associated (2019)

Table 3-29: EFN summary table for Vaseux Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m^3/s)	Recommended EFN (m^3/s)				Critical flow	
		Median (m^3/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
O. Mykiss parr & Chinook Fry rearing, insect production [a]	April 1 – Oct 31	0.179	14%	0.15	0.150	12%	0.150	1.15	0.064	5%
Steelhead spawning	April 1 – Jun 25	1.74	135%	1.50	1.50	117%	0.191	6.61	0.477	37%
Rainbow spawning	May 20 – Jul 10	1.74	135%	1.50	1.50	117%	1.50	6.61	0.477	37%
Chinook migration	July 1 – Aug 26	0.313	24%	n/a	0.313	24%	0.200	1.50	0.257	20%
Chinook spawning	Aug 27 – Sep 30	0.107	8%	0.200	0.200	16%	0.200	0.200	0.129	10%
Sockeye spawning	Sep 16 – Oct 31	0.086	7%	0.150	0.150	12%	0.150	0.200	0.129	10%
Overwintering salmonids	Nov 1 - March 31	0.070	5%	n/a	0.070	5%	0.025	0.133	0.064	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

O. mykiss parr and Chinook Fry rearing

The recommended EFN for Steelhead and Rainbow (*O. mykiss*) parr and Chinook Fry rearing is 0.150 m^3/s (12% LTMAD), which is slightly lower than the Okanagan Tennant EFN and median naturalized flow for the summer period (0.179 m^3/s, 14% LTMAD). The EFN maintains approximately 45% of maximum WUW for *O. mykiss* parr rearing (Figure B9-5, Appendix B9) and 60% for Chinook fry rearing (Figure B9-6, Appendix B9), as well as 25% of maximum insect production WUW (Figure B9-7, Appendix B9). Riffles decline below 60% of maximum wetted width at 9% LTMAD (Table B9-1, Appendix B9). The recommended critical flow for *O. mykiss* parr and Chinook fry rearing is 0.064 m^3/s (5% LTMAD; Table B9-2, Appendix B9) based on the LTMAD criterion (Table 2-7) due to naturally low flows. Photos of habitat conditions in Vaseux Creek at the recommended EFN flows are provided in Plate 3-19. ESSA & Solander (2009) previously suggested an EFN of 0.4-0.8 m^3/s for *O. mykiss* rearing.

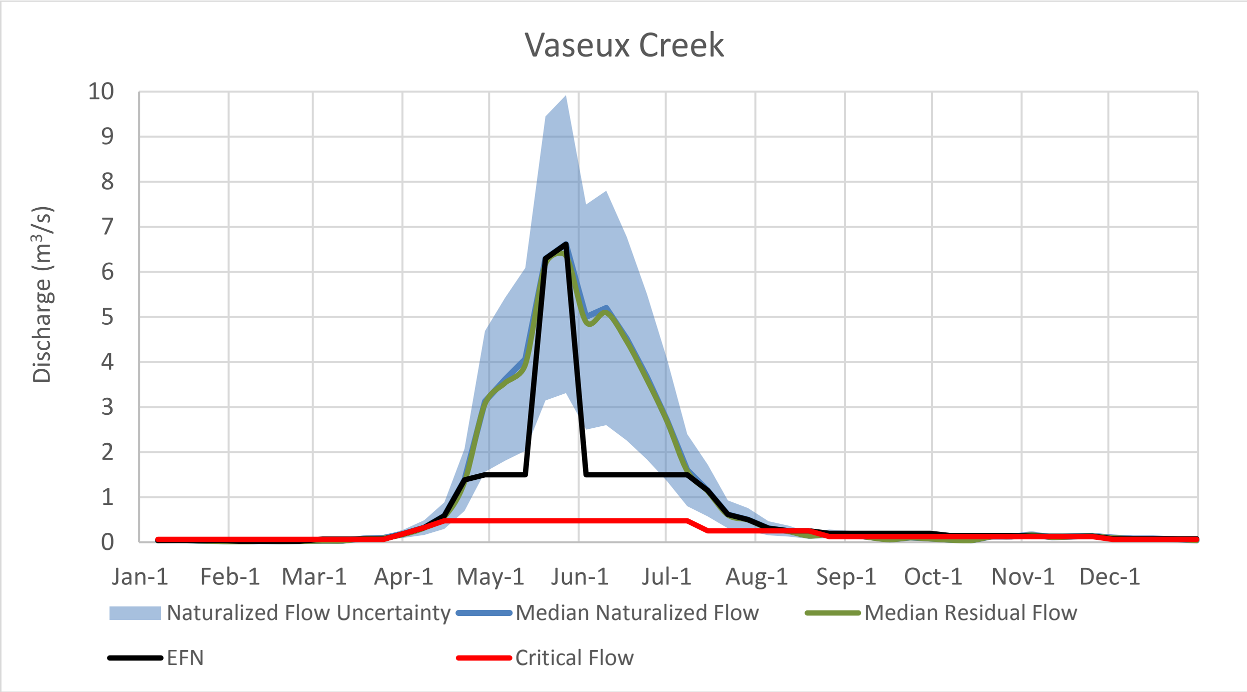


Figure 3-20: Weekly EFNs, critical flow and streamflows in Vaseux Creek

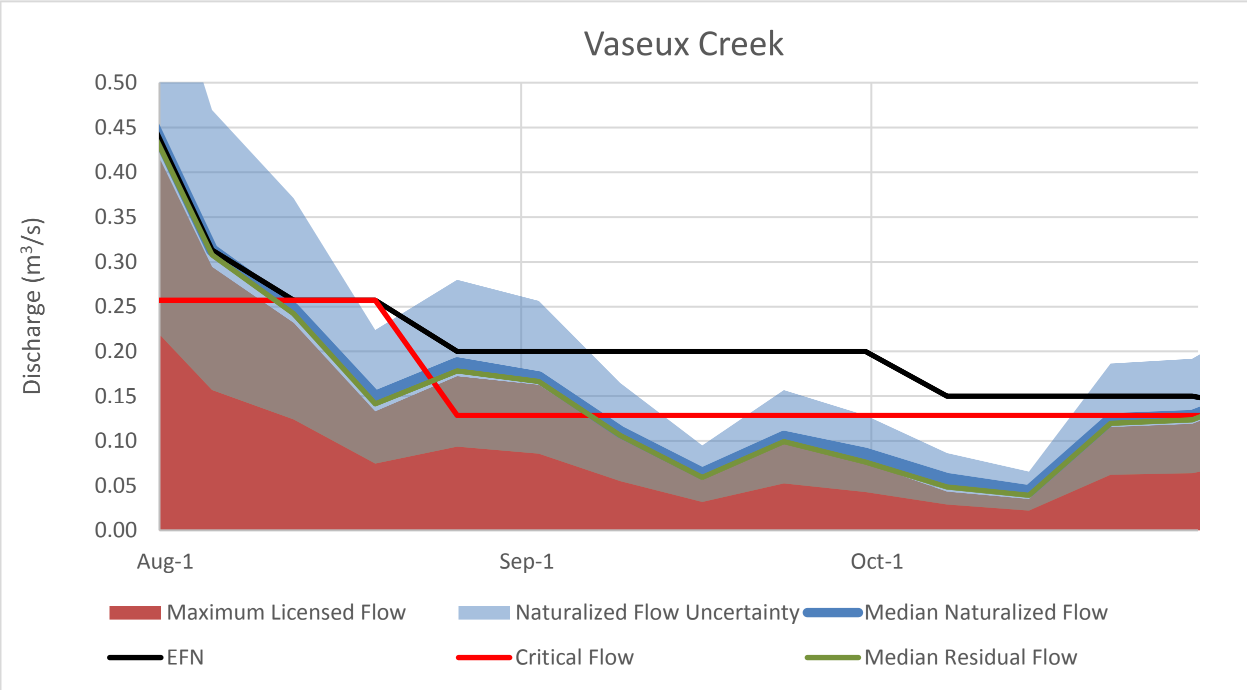


Figure 3-21: Weekly EFNs, critical flow and streamflows during the summer and fall period in Vaseux Creek

Naturalized summer flows estimated by Associated (2019) are generally above the recommended EFN except a period from early September to late October when they decrease to 0.05-0.1 m^3/s. Flows at the WSC hydrometric station 08NM171, which is located much further upstream in the watershed, as well as the historic WSC station 08NM015, located above the alluvial fan and most points of diversion, are adequate for meeting the recommended EFNs year-round (Figures B9-3, Appendix B9). However, flow naturalization on the Vaseux Creek alluvial fan is difficult and highly uncertain given relatively large unmonitored irrigation diversions as well as unknown but likely significant losses to groundwater on the fan. It is unknown what influence straightening and channelization of the streambed (Agordev 1994), had on historic groundwater-surface water interactions on the fan. The limited available flow records from the mouth, in addition to field observations, indicate that the creek frequently goes dry in late summer, fall and winter (Figures B9-2 and B9-3, Appendix B9), rendering it unusable for rearing fish.

Water temperatures in Vaseux Creek recorded at the hydrometric station were unsuitable for *O. mykiss* and Chinook rearing (>20°C) from early July to early September reaching up to 24°C (Figure B9-4, Appendix B9). High water temperatures are likely exacerbated by the very low flows typically observed in the lower reaches and the lack of riparian vegetation. Given the presence of a species of concern (spring Chinook), maintaining sufficient flows is vital to maintain favorable thermal conditions in this creek though flow thresholds for temperature maintenance were not formally studied under this project.

Steelhead and Rainbow spawning

The recommended EFN for Steelhead and Rainbow spawning is 1.50 m^3/s (167% LTMAD), which is slightly lower than the Okanagan Tennant EFN. This EFN maintains spawning WUW near 100% for both species (Figure B9-8 and B9-9, Appendix B9). It is well below median naturalized flows during the Steelhead and Rainbow spawning periods and it is therefore likely that spawning in Vaseux Creek naturally occurs at the beginning (Steelhead) or end (Rainbow) of freshet. The recommended EFN also maintains near maximum WUW for *O. mykiss* parr and Chinook fry rearing as well as very high insect production from riffles. ESSA & Solander (2009) previously suggested an EFN of 2.1-3.6 m^3/s for Steelhead spawning and 2.6-3.6 m^3/s for Rainbow spawning. Photos of habitat conditions in Vaseux Creek at the recommended EFN flows are provided in Plate 3-20. Recent and historical residual flows were greater than the EFN from mid-April to late June (Figure B9-2 and B9-3, Appendix B9).

The recommended critical flow for the Steelhead spawning period is defaulted to the naturalized median weekly flows for the last week of March (0.191 m^3/s; 15% LTMAD) and the first week of April (0.327 m^3/s; 25% LTMAD). For the remainder of the Steelhead spawning period and the entirety of the Rainbow spawning period, the recommended critical flow is 0.477 m^3/s (37% LTMAD, Table B9-2, Appendix B9), based on the minimum passage depth criterion (Table 2-7).

Spring Chinook spawning

Spring Chinook spawn in Vaseux Creek and have been detected at the Vaseux Creek PIT array in early July in recent years (OBMEP 2018). Spawning may be naturally constrained by low streamflows in the August/September spawning period although, historically, spawning may have occurred slightly earlier starting in late July and peaking in August (Fish and Hanavan 1948) prior to the lowest streamflows in late August/early September. Naturalized streamflow estimates (Associated 2019) for the Chinook spawning season are very low, particularly in comparison to WSC hydrometric station 08NM171 (Figure B9-3, Appendix B9), which is much further upstream in the watershed and not affected by irrigation withdrawals and losses to groundwater to the same extent as the lower reaches of the stream. This complicates EFN setting according to the methods outlined in the Phase I report (Associated 2016) considerably. There are concerns that the naturalized flow estimates during the spawning period are lower than expected for a stream of this size; thus, EFNs were set to weekly naturalized flows for the migration period and based on WUW information for the spawning period, resulting in EFNs higher than naturalized flow estimates for spawning. No historical long-term streamflow data for Chinook spawning reaches near the mouth exists for comparison.

The recommended median EFN for Chinook migration is 0.313 m^3/s (24% LTMAD), which is the median naturalized flow during the migration period. Critical migration flows for Chinook are 0.257 m^3/s (20% LTMAD) based on the LTMAD criterion typically used by FLNRORD (Table 2-7). However, safe riffle passage (0.24 m depth over $\geq$25% of riffle width) would be maintained at 1.17 m^3/s (91% LTMAD), which is much greater than naturalized flows during the latter part of the migration period in late July and August.

A preliminary Chinook spawning EFN of 0.200 m^3/s (16% LTMAD) is recommended as it provides a reasonable amount of spawning WUW (30%, Figure B9-10, Appendix B9). Significant increases in WUW can be achieved at flows greater than the EFN with >90% WUW available at flows of 1 m^3/s. Naturalized flow estimates for the spawning period are lower than the EFN at 0.063 - 0.187 m^3/s (5-15% LTMAD), which provides virtually no suitable spawning conditions. However, the accuracy of the naturalized flows is uncertain due to unknown losses on the alluvial fan and unknown volumes of water diversion. Recorded residual flows near the mouth are well below the EFN and frequently approach zero (Figure B9-2, Appendix B9), which is likely a combination of streamflow losses to groundwater and irrigation withdrawals. As such, spring Chinook spawning in Vaseux Creek will only be possible if sufficient flows can be re-established and maintained on a consistent annual basis. The recommended critical flow for Chinook spawning is 0.129 m^3/s (10% LTMAD, Table B9-2, Appendix B9) based on the LTMAD criterion of 10% LTMAD typically employed by FLNRORD (Table 2-7). Photos of habitat conditions in Vaseux Creek at the recommended EFN flows are provided in Plate 3-19.

When Chinook are known to have entered the creek under higher flow conditions in July, sudden decreases in flow, as observed in the hydrometric records from the mouth (Figure B9, Appendix B9), may lead to stranding and mortality. Thus, if suitable conditions are to be maintained for spring Chinook spawning, any water diversion between early July and late September would have to be severely limited for survival and spawning success. High water temperatures observed during July and August would also be problematic for Chinook spawners. However, maintaining sufficient flows for spawning may also serve to lower temperatures.

Sockeye spawning

The recommended EFN for Sockeye spawning is 0.150 m^3/s (12% LTMAD). This flow maintains approximately 30% of maximum WUW for Sockeye spawners (Figure B9-11, Appendix B9). The recommended EFN is near average flows from the hydrometric station above Solco Creek (08NM171) (Figure B9-3, Appendix B9) but greater than naturalized flows near the mouth estimated by Associated (2019). The recommended critical flow for Sockeye spawning is 0.129 m^3/s (10% LTMAD, Table B9-2, Appendix B9) based on the LTMAD criterion (Table 2-7). Safe riffle passage is achieved at flows of 0.477 m^3/s (37% LTMAD, Table B9-1, Appendix B9), but naturalized flows are well below that during the Sockeye spawning period. Photos of habitat conditions in Vaseux Creek at the recommended EFN flows are provided in Plate 3-19. ESSA & Solander (2009) previously suggested an EFN of 0.8 m^3/s for Sockeye spawning.

If Sockeye and Chinook spawning takes place, maintenance of flows throughout the winter incubation period is critical to ensure egg survival. Any water diversion during this period should therefore be discouraged.

Plate 3-19: Vaseux Creek habitat conditions at flows near the recommended *O. mykiss* parr and Chinook rearing and Sockeye spawning EFNs (0.150 m^3/s), and Chinook spawning EFN (0.200 m^3/s)

VAS40GL at 0.126 m^3/s (10% LTMAD)

VAS40GL at 0.224 m^3/s (17% LTMAD)

VAS30SCR at 0.126 m^3/s (10% LTMAD)

VAS30SCR at 0.224 m^3/s (17% LTMAD)

Plate 3-20: Vaseux Creek habitat conditions at flows near the recommended Steelhead and Rainbow spawning EFNs (1.50 m^3/s)

VAS40GL at 1.37 m^3/s (106% LTMAD)

VAS40GL at 1.81 m^3/s (141% LTMAD)

3.10 *akskʷəkʷant - Inkaneep Creek*

Inkaneep Creek flows from the east side of the Okanagan Basin into suwiw̓s (Osoyoos Lake). It lies between the towns of Oliver and Osoyoos, B.C. The Inkaneep Creek drainage area is approximately 179 km^2 (Associated 2019) and the main tributaries include McCuddy, Baldy, Gregoire, and Coteay Creeks (Associated 2016). The upper reaches drain a gently sloping plateau before flowing through a steep canyon and onto an alluvial fan before entering Osoyoos Lake. A summary of creek characteristics is found in Table 3-30 and additional stream-specific data is provided in Appendix B10.

The lowest reach of Inkaneep Creek has been subjected to some agricultural encroachment and some localized hydromodification and riparian function impairment especially near the road crossing at the WSC station 08NM200. Lower Inkaneep Creek (further downstream of the road crossing) has not been straightened or diked but is deeply entrenched with corresponding bank erosion. The stream in this section meanders with several side channels. The entrenchment of the creek reduces the creek's ability to regularly interact with riparian areas, and riparian vegetation varies from healthy to nonexistent. In highly entrenched areas with reduced riparian vegetation, agricultural encroachment has occurred, sometimes to the bankfull width of the stream.

The lowest permanent barrier to adult anadromous fish migration is approximately 4.5 km from the mouth (OBMEP 2016). Inkaneep Creek is known to support populations of adfluvial Rainbow and anadromous Steelhead (Folks et al. 2009). Historically, Inkaneep was used by Chinook for spawning (Ernst and Vedan 2000) and juvenile Chinook have been observed utilizing the lower reaches (OBMEP 2014). Other salmonid species that may occur in Inkaneep Creek and Osoyoos Lake include Kokanee, Sockeye and Coho (Associated 2016). Two riffle and 2 glide transects were installed in August 2016 in the lowest 1 km reach of Inkaneep Creek between the WSC hydrometric station (08NM200) and the confluence with the lake.

At present there are 94 points of diversion within the watershed; however, the actual volume extracted annually is unknown (Associated 2019). The Osoyoos Indian Band is the main water user in the watershed (Associated 2016). The only known water storage is Cassidy Lake (Waterdog Lake), which has no outlet. Paired streamflow measurements indicate streamflow losses to groundwater on the alluvial fan. Naturalized flow data provided by Associated (2019) indicate that Inkaneep Creek is not 'flow sensitive' during the summer and winter as naturalized flows are above 20% LTMAD (Table 3-31). However, due to the lower than average freshet compared to the size of the drainage basin, the LTMAD estimates by Associated (2019) are lower than expected; as a result, using the LTMAD with flow standards to recommend EFNs creates unrealistic low flow expectations.

Table 3-30: Inkaneep Creek description

Drainage Area	179 km^2
Median Elevation	1227 m
WSC station	08NM200 (Active) – Inkaneep Cr near the Mouth (1973-present) 08NM012 (Historic) – Inkaneep Cr near Oliver (Lower Stn) (1919-1950) 08NM082 (Historic) – Inkaneep Cr near Oliver (Upper Stn) (1941-1950)
LTMAD	0.362 m^3/s (Associated 2019)
Fish species expected	Rainbow, Steelhead, Eastern Brook Trout (ESSA & Solander 2009), Chinook (Ernst & Vedan 2000)
Land use	Agriculture, forestry. The middle and lower reaches are within the Osoyoos Indian Band Reserve

Naturalized, residual and maximum licensed flow data were provided by Associated (2019) with an estimated data quality rating of C (data error between 25% and 50%). The LTMAD estimate for Inkaneep Creek was lower than expected due to low freshet peak flows used in the hydrologic analysis. Estimated maximum licensed flows indicate that the creek would be dry from mid-July to mid-September if licensed withdrawal and storage volumes were maximized.

Okanagan Tennant EFNs for Inkaneep Creek were developed in accordance with the methods outlined in Section 2.2. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. WUW information from the study transects was then reviewed to determine whether final EFN recommendations needed adjustment from the Okanagan Tennant EFN. Contrary to most other creeks, flow standard EFNs for juvenile fish rearing were lower than naturalized flows during the summer and fall season, a result of the low LTMAD estimate. WUWs at the flow standards were very low. Therefore, WUW information was used to adjust the Okanagan Tennant EFNs upwards during the summer and fall period. A summary of EFNs for Inkaneep Creek is provided in Table 3-32 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-22, Figure 3-23 and Appendix B10 and flow sensitives in Table 3-31. Critical flows were calculated as described in Section 2.4. Further information regarding EFN and critical flow setting in Inkaneep Creek is provided at the end of this section.

Table 3-31: Flow sensitivities in Inkaneep Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
O. mykiss & Chinook rearing	0.081	22%		
Insect production				
Chinook spawning				
O. mykiss & Chinook overwintering			0.071	20%
Chinook egg incubation				

Source: Associated (2019)

Table 3-32: EFN summary table for Inkaneep Creek

Species & life stage	Time period	Okanagan Tennant EFN		WUW EFN (m^3/s)	Recommended EFN (m^3/s)				Critical flow	
		Median (m^3/s)	% LTMAD		Median	% LTMAD	Min	Max	Flow (m^3/s)	% LTMAD
O. Mykiss parr & Chinook Fry rearing, insect production [a]	April 1 – Oct 31	0.072	20%	0.136	0.136	38%	0.090	0.388	0.030	8%
Steelhead spawning	April 1 – Jun 25	0.771	213%	0.771	0.771	213%	0.130	1.86	0.468	129%
Rainbow spawning	May 20 – Jul 10	0.771	213%	0.771	0.771	213%	0.502	1.86	0.468	129%
Chinook migration	July 1 – Aug 26	0.180	50%	x	0.180	50%	0.109	0.766	0.180[b]	50%
Chinook spawning	Aug 27 – Sep 30	0.100	28%	0.100	0.100	28%	0.090	0.139	0.100[c]	28%
Overwintering salmonids	Nov 1 - March 31	0.082	23%	x	0.082	23%	0.075	0.108	0.030	8%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15- Sept 30.
b median for the migration period
c median for the spawning period

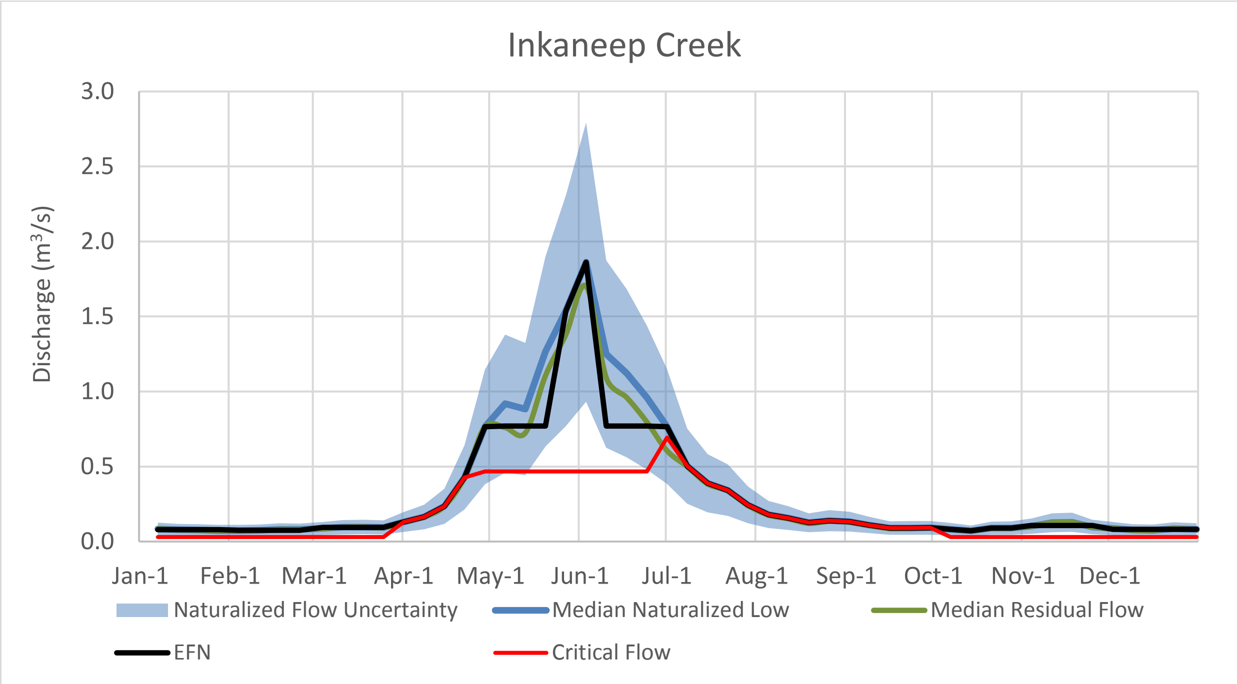


Figure 3-22: Weekly EFNs, critical flow and streamflows in Inkaneep Creek

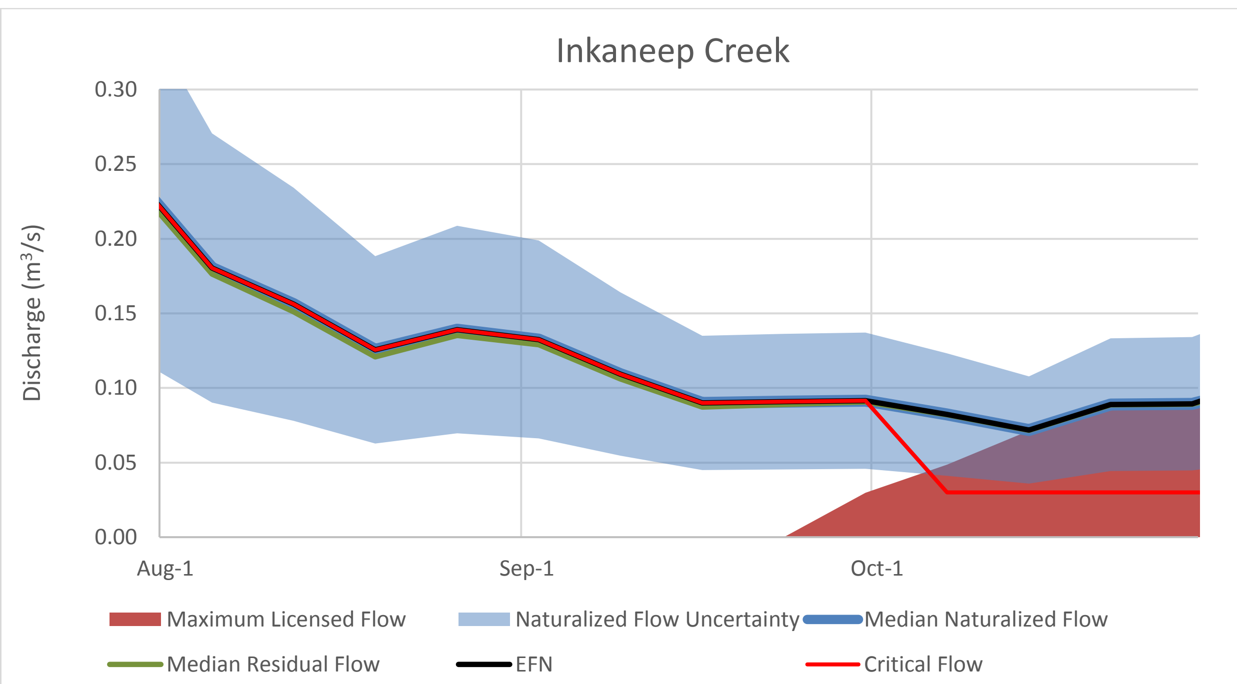


Figure 3-23: Weekly EFNs, critical flow and streamflows during the summer and fall period in Inkaneep Creek

O. mykiss parr and Chinook fry rearing

The recommended EFN for Steelhead and Rainbow (*O. mykiss*) parr and Chinook fry rearing is 0.136 m^3/s (38% LTMAD), which is equivalent to median naturalized flows during the summer low flow period and greater than the Okanagan Tennant EFN of 20% (0.072 m^3/s). This adjustment upward was made based on very low WUWs at the Okanagan Tennant EFN (<20% of maximum WUW). The recommended EFN is almost identical to that for Lower Shingle Creek, which has similar channel widths, and maintains approximately 40% of maximum WUW for *O. mykiss* parr rearing (Figure B10-5, Appendix B10) and 50% for Chinook fry rearing (Figure B10-6, Appendix B10), as well as 26% of maximum insect production WUW (Figure B10-7, Appendix B10). ESSA & Solander (2009) previously recommended an EFN of 0.2-0.3 m^3/s for *O. mykiss* rearing in Inkaneep Creek. Photos of habitat conditions in Inkaneep Creek at the recommended EFN flows are provided in Plate 3-21. The recommended critical flow for *O. mykiss* parr and Chinook fry rearing is 0.030 m^3/s (8% LTMAD; Table B10-2, Appendix B10) based on the riffle width criterion (Table 2-7).

Residual flows estimated by Associated (2019) are almost equal to naturalized flows; however, residual flows recorded at the currently operating (08NM200) and historical (08NM012) WSC hydrometric stations near the mouth were frequently below the EFN (0.03-0.04 m^3/s; Figures B10-2 and B10-3, Appendix B10) from early August to late October, therefore achieving EFNs may be problematic.

Summer water temperatures in Inkaneep Creek under residual flow conditions often exceed suitable rearing temperatures for juvenile *O. mykiss* and Chinook in July and August, reaching up to 24°C (Figure B10-4, Appendix B10; Rae 2005; OBMEP 2019). Maintaining sufficient flows is vital to maintain favorable thermal conditions in this creek though flow thresholds for temperature maintenance were not formally studied under this project.

Steelhead and Rainbow spawning

The recommended EFN for Steelhead and Rainbow spawning is 0.771 m^3/s (213% LTMAD), which is equivalent to the Okanagan Tennant EFN. The EFN maintains near maximum spawning WUW (90% of maximum for both; Figure B10-8 and B10-9, Appendix B10) while maximizing *O. mykiss* parr and Chinook fry rearing WUW during the freshet period, and maintaining high insect production from riffles. Flows greater than the recommended EFN are achieved under naturalized flows for a substantial portion of the freshet season (late April to late June); similarly, high residual flows from mid-May to mid-June indicate that these EFNs are achievable (Figure 3-22). Photos of habitat conditions in Inkaneep Creek at the recommended EFN flows are provided in Plate 3-22. ESSA & Solander (2009) previously recommended an EFN of 0.7–1.05 m^3/s for Steelhead and Rainbow spawning in Inkaneep Creek.

The recommended critical flow for Steelhead and Rainbow spawning is 0.468 m^3/s (129% LTMAD, Table B10-2, Appendix B10) from late April to late June, based on the minimum passage depth criterion (Table 2-7). Prior to this period, critical flows are set at the lower naturalized median weekly flows.

Spring Chinook spawning

Inkaneep Creek once provided spawning habitat for Spring Chinook (Rae 2005). However, none have been observed in recent years, likely due to low streamflows and high water temperatures in the creek during the migration (early July to mid-August) and spawning periods (late August to late September - though timing is unclear due to the low population abundance and records). Spawning conditions for spring Chinook in Inkaneep Creek are likely naturally limited by low summer and fall flows; however, a small amount of Chinook WUW (7%) could be maintained at EFNs that are equal to the naturalized weekly flows throughout the migration and spawning period. In essence, any water use during mid-July to late September will have dire impacts on Chinook migration and spawning conditions in the creek. Thus, EFN flows for Chinook spawning are recommended at naturalized weekly flows throughout the migration and spawning period. The median spawning naturalized flow is 0.100 m^3/s (28% LTMAD, Figure 3-23, Figure B10-10, Appendix B10).

Riffle analysis indicates that 0.693 m^3/s (191% LTMAD) would be required to sustain safe riffle passage for Chinook (Table B10-2, Appendix B10). These conditions are met under naturalized flow conditions at the end of freshet in early July, which is the typical timing of spring Chinook migration into other streams in Washington State (CCT 2004; Snow et al. 2018; PTAGIS 2018). The 10% LTMAD (0.06 m^3/s) typically used by FLNRORD as a critical flow for Chinook spawning would result in near zero spawning WUW and likely total inability of Chinook to pass riffles because average water depths would be approximately 3 cm. It is thus recommended to set critical flows for Chinook spawning in Inkaneep Creek to naturalized flows. Photos of habitat conditions in Inkaneep Creek at the recommended EFN flows are provided in Plate 3-21.

Residual flows estimated by Associated (2019) are almost equal to naturalized flows; however, residual flows recorded at the currently operating (08NM200) and historical (08NM012) WSC hydrometric stations near the mouth were frequently below the EFN (0.03-0.04 m^3/s; Figures B10-2 and B10-3, Appendix B10) from early August to late October; therefore achieving Chinook spawning EFNs in Inkaneep Creek may be difficult. High water temperatures (24°C) recorded during July and August (Figure B10-4, Appendix B10) would also be problematic for Chinook spawners. ESSA & Solander (2009) previously recommended an EFN of 0.2 m^3/s during the Chinook spawning period in Inkaneep Creek.

Plate 3-21: Inkaneep Creek habitat conditions at flows near the recommended *O. mykiss* parr and Chinook fry rearing EFNs (0.136 m³/s) and Chinook spawning EFN (0.100 m³/s)

INK10SCR at 0.119 m³/s (33% LTMAD)

INK45SCR at 0.139 m³/s (38% LTMAD)

INK20GL at 0.119 m³/s (33% LTMAD)

INK30GL at 0.139 m³/s (33% LTMAD)

Plate 3-22: Inkaneep Creek habitat conditions at flows near the recommended Steelhead and Rainbow spawning EFNs (0.771 m³/s)

INK20GL at 0.677 m³/s (187% LTMAD)

INK20GL at 1.01 m³/s (278% LTMAD)

3.11 Shorts Creek

Shorts Creek flows from the west side of the Okanagan Basin into Okanagan Lake north of Westbank, B.C. The watershed has an area of approximately 186 km^2 with Dunwaters Creek as the main tributary (Associated 2016). The creek flows over a series of waterfalls through a steep-sided canyon near the mouth. Below the canyon, Shorts Creek flows over a large alluvial fan before its confluence with Okanagan Lake. Forest harvesting is the primary land use in the upper reaches and some agricultural use occurs in the lower reaches. The land near the mouth is a residential area as well as Fintry Provincial Park. A summary of creek characteristics is found in Table 3-33 and additional stream-specific data is provided in Appendix B11.

The lower section of Shorts Creek shows signs of prior channelization but a relatively large amount of productive fish habitat remains (Koshinsky 1972b; Wildstone Resources Ltd. 1997). Shorts Creek is known to support populations of Kokanee (spawning) and Rainbow (Associated 2016). The lowest barrier to fish migration is a series of falls that begin approximately 1.2 km from the mouth (Eyjolfson & Dunn 2016). However, Rainbow occur in reaches upstream of the falls (Wildstone Resources Ltd. 1997). Kokanee access to the lower reaches of Shorts Creek has been limited during some years by sediment buildup at the mouth resulting from longshore drift. During the 2017 freshet, a log jam washed out upstream of the falls resulting in a large deposit of bedload and the channel near the mouth was dry. Restoration works are currently underway by FLNRORD to restore fish access and reconstruct the channel (White pers. comm. 2019).

Shorts Creek is headed by several small lakes and wetlands. Historic reports indicate that the stream was not known to go dry (Anonymous 1969) but late summer and fall flows during dry years are sometimes too low to sustain Kokanee spawning (Wildstone Resources Ltd. 1997). It is estimated that water losses to groundwater occur on the alluvial fan near the mouth (Associated 2019). At present there are 33 points of diversion within the watershed, though the actual volume extracted annually is unknown (Associated 2019). There is no main water user listed in the watershed and there is no developed water storage (Associated 2016). There have been inter-basin water transfers out of the Shorts Creek watershed and a potential for further transfers (Associated 2016) and there are no restrictions or reserves on future water licensing noted for Shorts Creek (FLNRORD 2016). Naturalized flow data provided by Associated (2019) indicate that the lower reaches of Shorts Creek are 'flow sensitive' during summer and winter as naturalized flows are well below 20% LTMAD (Table 3-34). ONA maintains one hydrometric station upstream of the falls. Stream temperatures recorded at the station are generally favourable to rainbow rearing (<20°C; Figure B11-3, Appendix B11).

Table 3-33: Shorts Creek description

Drainage Area	186 km^2
Median Elevation	1350 m
ONA station	08NM151HDS Shorts Creek near the Mouth (2014-to present)
WSC station	08NM151 (historic) Shorts Creek at the Mouth (1969-1982)
LTMAD	1.007 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, Eastern Brook Trout, Largescale Sucker, Longnose Dace, Prickly Sculpin, Sculpin (general) (ESSA & Solander, 2009)
Land use	Forestry in the upper watershed. Creek runs through Fintry Provincial Park in the lower watershed (Associated 2019)

Naturalized, residual and maximum licensed flow data were provided by Associated (2019) with an estimated data quality rating of B (data error between 10% and 25%). Estimated naturalized summer low flows for Shorts Creek were extremely low (3% LTMAD) and not sufficient to sustain fish habitat. Flows near the mouth fluctuate greatly from year to year and the reach is known to go dry during some years due to the coarse gravel deposits near the mouth. Estimated maximum licensed flows indicate that the creek would be nearly dry from mid-August to mid-September if licensed withdrawal volumes were maximized.

Okanagan Tennant EFNs for Shorts Creek were developed in accordance with the methods outlined in Section 2.2. No WUW data was collected in Shorts Creek. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. EFNs for Kokanee spawning and Rainbow rearing were set under consideration of flow standards, naturalized flow estimates, previously collected habitat data (Tredger 1989b) and WUW information from nearby Whiteman Creek which is similar in size. Some resulting EFN recommendations were greater than the naturalized flow estimates; however, it is acknowledged that flows may naturally be lower than the recommended EFN during some years. A summary of EFNs for Shorts Creek is provided in Table 3-35 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-24, Figure 3-25 and Appendix B11, and flow sensitives in Table 3-34. Further information on EFN setting in Shorts Creek is provided at the end of this section.

Table 3-34: Flow sensitivities in Shorts Creek

Species & life stage	**1-in-2 yr 30-day summer low flow**		**1-in-2 yr 30-day winter low flow**	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.029	3%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.035	3%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-35: EFN summary table for Shorts Creek

Species & life stage	**Time period**	**Okanagan Tennant Recommended EFN**				**Critical flow**	
		Median (m^3/s)	% LTMAD	Min (m^3/s)	Max (m^3/s)	Median (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.100	10%	0.100	0.419	0.050	5%
Rainbow spawning	May 20 – Jul 10	1.49	148%	0.667	5.78	0.503	50%
Kokanee spawning	Sep 18 – Oct 26	0.140	14%	0.140	0.140	0.101	10%
Rainbow overwintering	Nov 1 – Mar 31	0.057	6%	0.046	0.082	0.050	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15- Sept 30.

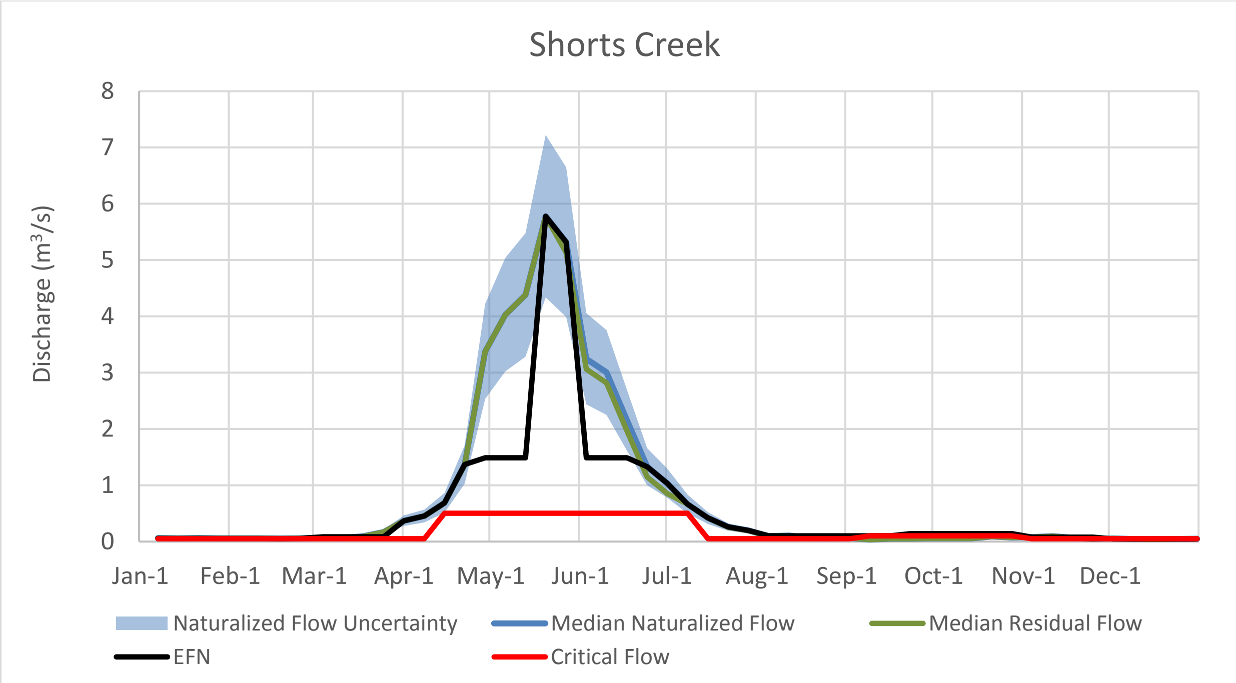


Figure 3-24: Weekly EFNs, critical flow and streamflows in Shorts Creek

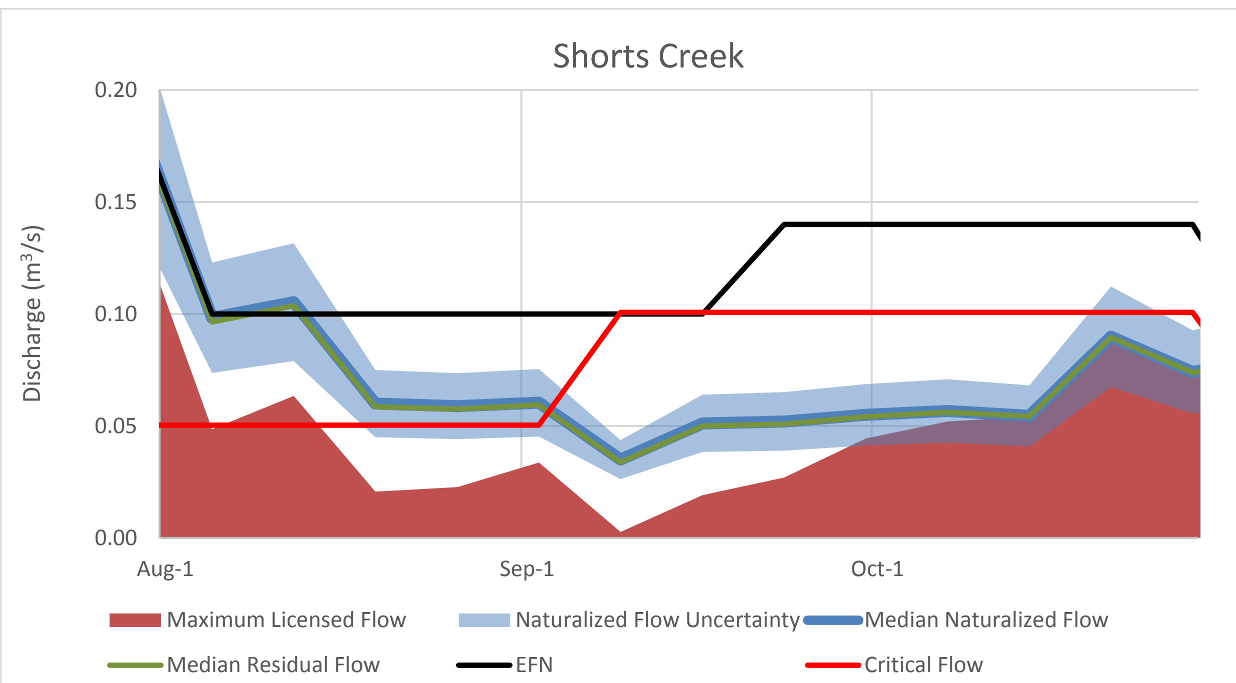


Figure 3-25: Weekly EFNs, critical flow and streamflows during the flow sensitive time in Shorts Creek

Rainbow parr rearing

Estimated weekly naturalized flows (Associated 2019) range from 0.035 to 0.419 m^3/s (median 0.06 m^3/s, 6% LTMAD) during the mid-July to late September period. However, the recommended EFN for Rainbow parr rearing is 0.100 m^3/s (10% LTMAD), which is greater than the weekly naturalized flow estimates from mid-August onward (Figure 3-25), for the following reasons:

1) WUW information collected by Tredger (1989b) in the lower reaches of Shorts Creek indicates large gains in Rainbow parr rearing capacity up to about 0.100 m^3/s (10% LTMAD);
2) The Rainbow parr rearing EFN recommendation for nearby Whiteman Creek is 0.158 m^3/s and for Naswhito Creek is 0.090 m^3/s based on WUW data;
3) The lowest weekly flows recorded at the ONA hydrometric station between 2014 and 2018 (records residual flows upstream of the falls) ranged from 0.062 m^3/s to 0.092 m^3/s (Figure B11-1, Appendix B11);
4) Previous EFN recommendations for Rainbow rearing ranged from 0.1 - 0.382 m^3/s (Dobson 1990), 0.17 - 0.23 m^3/s (Koshinsky & Wilcocks 1973) and 0.4 - 0.8 m^3/s (ESSA & Solander 2009); and
5) While flows might be naturally lower than the recommended EFN during some years, there is significant benefit to parr rearing capacity by maintaining flows greater than 0.100 m^3/s whenever possible.

Recent and historical residual flows are below the EFN during some years (Figures B11-1 and B11-2), indicating that there may be difficulty in achieving EFNs during some years. The recommended critical flow for Rainbow parr rearing is 0.050 m^3/s (5% LTMAD) based on the LTMAD criterion (Table 2-7).

Rainbow spawning

The recommended Okanagan Tennant EFN for Rainbow spawning is 1.49 m^3/s (148% LTMAD). One previous EFN recommendation was 2.2 m^3/s (ESSA & Solander 2009); however, based on WUW information from nearby Whiteman Creek, which is similar in size and channel characteristics, the recommended EFN of 1.49 m^3/s is thought to be sufficient. Naturalized and residual flows are greater than the EFN for most of the spawning period (Figure 3-24). The recommended critical flow for Rainbow spawning is 0.503 m^3/s (50% LTMAD) based on the LTMAD criterion (Table 2-7).

Kokanee spawning

Estimated naturalized flows (Associated 2019) during the Kokanee spawning period range from 0.052 – 0.090 m^3/s. However, the recommended EFN for Kokanee spawning is 0.140 m^3/s (14% LTMAD), which is greater than the naturalized flow estimates (Figure 3-25), for the following reasons:

1) WUW information collected by Tredger (1989b) in the lower reaches of Shorts Creek indicates relatively little habitat capacity at the estimated naturalized flows during the spawning period (median 0.056 m^3/s);
2) The EFN recommendation for nearby Whiteman Creek is 0.141 m^3/s and for Naswhito Creek is 0.090 m^3/s based on WUW data;
3) Previous EFN recommendations for Kokanee spawning were 0.23 - 0.28 m^3/s (Koshinsky 1972b) and 0.16 m^3/s (Dobson 1990);
4) Ptolemy (2019) notes that average year base flow is 0.11 m^3/s and Dobson (1990a) provides estimates of mean monthly flows (September = 0.197 m^3/s). Discharges of 0.11 m^3/s are equal to a historic

minimum flow obtained in late August 1977, which was a hot and dry year when several other streams were reported to be dry (Wightman & Taylor 1978);

5) WUW data by Tredger (1989b) indicates that Kokanee spawning capacity more than doubles between the estimated median naturalized flows and the recommended EFN of 0.14 m^3/s; and

6) While flows might naturally be lower than the recommended EFN during some years, Shorts Creek demonstrates significant potential Kokanee spawning capacity as long as sufficient flows are maintained (Tredger 1989b; Koshinsky 1972b).

Recent and historical residual flows are below the EFN during most years (Figures B11-1 and B11-2), indicating that there may be frequent difficulty in achieving EFNs. The recommended critical flow for Kokanee spawning is 0.101 m^3/s (10% LTMAD) based on the LTMAD criterion (Table 2-7).

3.12 Mill Creek

Mill Creek flows from the east side of the Okanagan Basin into Okanagan Lake at Kelowna, B.C. The Mill Creek watershed is approximately 224 km^2 with three main tributaries, Scotty, Whelan and Dilworth Creeks (Associated 2017). The total stream length is 33 km (Eyjolfson & Dunn 2016). Mill Creek flows from its gently rolling forested uplands over moderately steep hillslopes through an entrenched bedrock canyon before entering the valley bottom. A substantial portion of the stream is located in low-gradient valley bottom reaches where it traverses agricultural and industrial lands before flowing through the City of Kelowna (Associated 2017). A summary of creek characteristics is found in Table 3-36 and additional stream-specific data is provided in Appendix B12.

The lower reaches of Mill Creek are impaired with low to moderate riparian vegetation and intense urban influence, along with multiple bridges and pipe arch crossings (Eyjolfson & Dunn 2016). Due to its urban setting, a large portion of the valley bottom reach has experienced some level of modification while approximately 30% has been channelized (Ecoscape 2006). Poor water quality is thought to be the main limitation to fish production capacity (Canadian EarthCare Society 1992). Besides industrial and urban runoff impacts (Ecoscape 2006), high turbidity and siltation of spawning gravels are of concern (Webster 2017). Sediment inputs mainly arise from bank erosion due to riparian vegetation removal (Wildstone Resources 1999, Ecoscape 2006). The channel is characterized by extensive pool habitat resulting from beaver activity. Reduced freshet peak flows from floodwater diversions to Mission Creek, as well as extensive water storage activities, have reduced the stream's seasonal ability to blow out beaver dams and flush streambed substrates of fine sediment (Ecoscape 2006). Habitat restoration initiatives in the late 1990s resulted in a number of restoration activities, including installation of spawning gravels; approximately 745 linear meters of suitable spawning gravels remain in the lower reaches (Ecoscape 2006). The most downstream permanent barrier is a waterfall located 20 km from the mouth (Eyjolfson & Dunn 2016).

Mill Creek is known to currently support populations of Kokanee (spawning) and Rainbow, as well as Burbot and a number of non-salmonid fishes (Associated 2016). Kokanee spawners utilize the lowest 4 km (Webster 2005) with the largest concentration and best habitat for spawners found in 1 km between Elliot Avenue and Lindahl Street (Tredger 1976). Rainbow likely spawn further upstream of the Kelowna International Airport as substrates change from fines to gravel and cobble (Ecoscape 2006).

The Mill Creek headwaters contain a series of small lakes. The largest, Postill Lake, was dammed in the early 1900s for storage of irrigation water (Wildstone Resources 1999). At present there are 149 points of diversion within the watershed and three pending water licence applications (Associated 2019); however, the actual volume extracted is unknown. The Rutland Water Works withdraw groundwater generally within the Mission Creek watershed and distribute it to areas within the Mill and Mission Creek watersheds. Black Mountain Irrigation District manages James Lake (which is in the headwaters of the tributary Scotty Creek; Associated 2016). The Glenmore-Ellison Improvement District operates three reservoirs: Postill, Moore, and South reservoirs (Associated 2016). Inter-basin water transfers do occur between Mill Creek and Mission Creek under flood conditions, when flood waters from Mill Creek are diverted to Mission Creek to prevent flooding in downtown Kelowna.

Mill Creek (along with Coldstream Creek) has the highest base flows of any of the study streams and experiences significant groundwater inflows in the valley bottom reaches (Associated 2019). Poor understanding of annual patterns in upland streamflow contribution, as well as groundwater gains along the valley floor indicate that monitoring of streamflows at several locations along the creek is needed

(Lejbak pers. comm. 2019). Mill Creek is considered fully recorded for all purposes as of 1990 unless storage is provided (Shepherd & Ptolemy 1999). The lower reaches of Mill Creek are not ‘flow sensitive’ during summer or winter as naturalized flows (Associated 2019) are approximately 35% of LTMAD (Table 3-37). Significant groundwater contributions are thought to contribute to higher baseflows in Mill Creek than most other study streams (Associated 2019). The B.C. MOE holds several conservation licences on Mill Creek which stipulate that 0.3 m^3/s is to be maintained within the creek for fisheries purposes (Dobson 2008).

Table 3-36: Mill Creek description

Drainage Area	224 km^2
Median Elevation	983 m
WSC station	No active stations 08NM117 (historic) Kelowna Cr at Rutland Station (1950-1975) 08NM053 (historic) Kelowna Cr near Kelowna (Lower stn) (1922-1998) 08NM061 (historic) Kelowna Cr near Rutland (1924-1931) 08NM026 (historic) Kelowna Cr near Rutland (Upper Station) (1911-1922) 08NM036 (historic) Scotty Creek near Rutland (1911-1964) 08NM145 (historic) Bulman Creek at the Mouth (1968-2004) 08Nm234 (historic) Moore Lake Reservoir at the dam (1973-1986)
LTMAD	0.774 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, Eastern Brook Trout, Burbot, Northern Pike minnow, Longnose Sucker, Largescale Sucker, Leopard Dace, Longnose Dace, Prickly Sculpin, Redside Shiner, Carp, Peamouth Chub (ESSA & Solander 2009)
Land use	Forestry in the upper watershed, and agriculture and urban development in the lower watershed (Associated 2016)

No WUW data was collected in Mill Creek. Naturalized flow data were provided by Associated (2019) with an estimated data quality rating of C (data error between 25% and 50%); residual and maximum licensed flows were not available at the time of reporting. Okanagan Tennant EFNs for Mill Creek were developed in accordance with the methods outlined in Section 2.2. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Contrary to most other study streams, naturalized flows and recorded residual flows in Mill Creek are much greater than flow standards during the non-freshet period. Recommended EFNs were adjusted upward from Okanagan Tennant EFNs to approach naturalized flows as well as minimum flows stipulated by the conservation licence. The recommended EFNs are intended to maintain current levels of fish production in Mill Creek by protecting flow conditions that local populations have become adapted to. Further, the extensive channel alterations and water quality problems (Wightman and Taylor 1978) in Mill Creek likely necessitate higher flows than those provided by flow standards. A summary of EFNs for Mill Creek is provided in Table 3-38 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-26, Figure 3-27 and Appendix B12, and flow sensitives in Table 3-37. Further information on EFN setting in Mill Creek is provided at the end of this section.

Table 3-37: Flow sensitivities in Mill Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.266	36%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.257	35%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-38: EFN summary table for Mill Creek

Species & life stage	Time period	Okanagan Tennant Recommended EFN				Critical flow	
		Median (m^3/s)	% LTMAD	Min (m^3/s)	Max (m^3/s)	Median (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.250	34%	0.250	0.644	0.037	5%
Rainbow spawning	May 20 – Jul 10	1.23	165%	0.801	2.82	0.372	50%
Kokanee spawning	Sep 17 – Oct 13	0.250	34%	0.250	0.250	0.074	10%
Rainbow overwintering	Nov 1 – Mar 31	0.250	34%	0.250	0.250	0.037	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

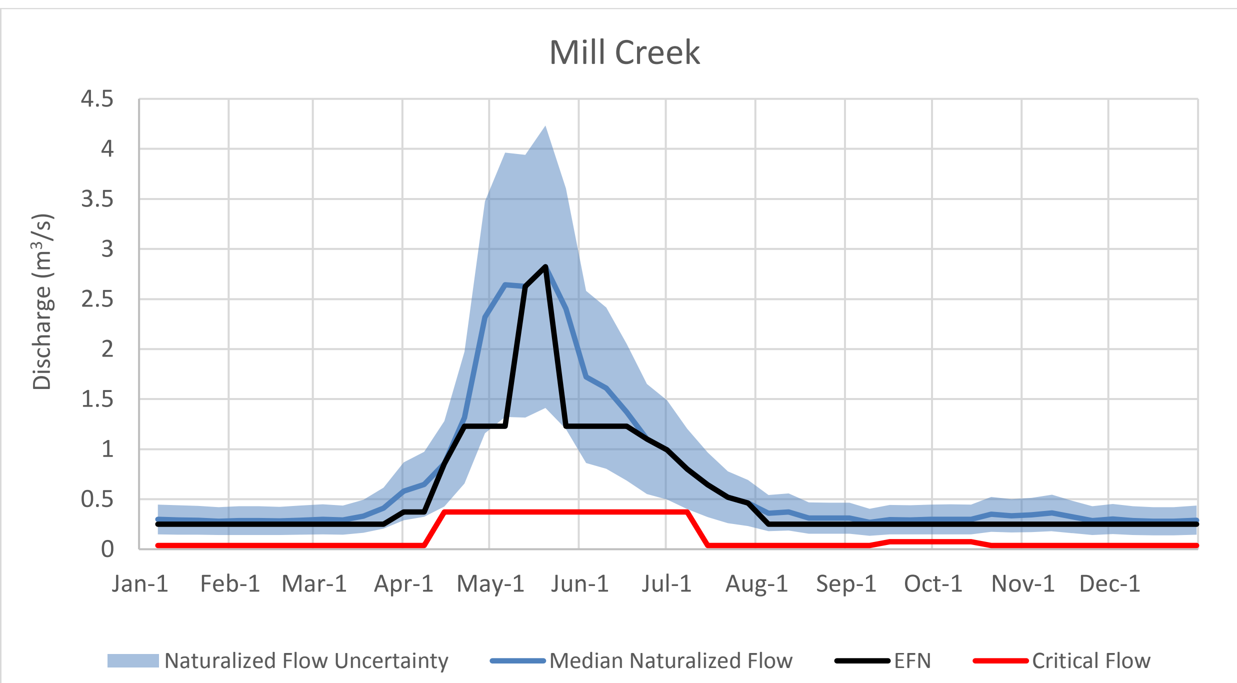


Figure 3-26: Weekly EFNs, critical flow and streamflows in Mill Creek

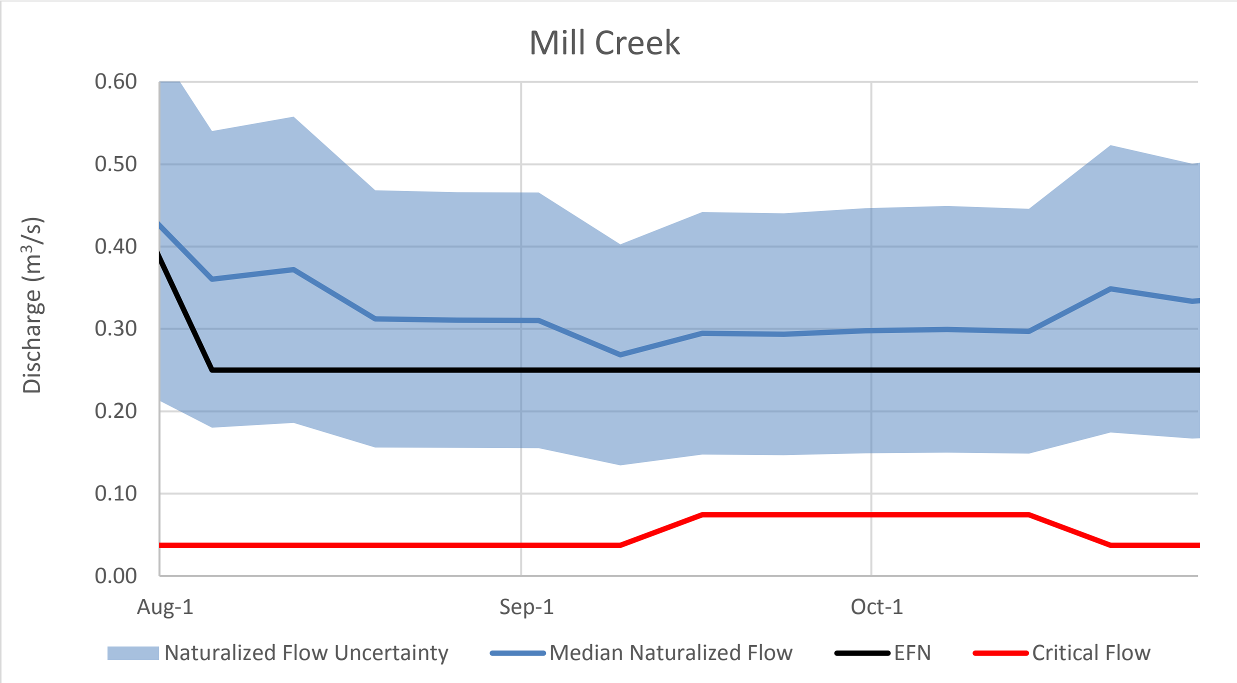


Figure 3-27: Weekly EFNs, critical flow and streamflows during the summer and fall period in Mill Creek

Rainbow parr rearing

The recommended EFN for Rainbow rearing is 0.250 m^3/s (34% LTMAD, Table 3-38) which is slightly lower than median naturalized flows during the mid-July to late September period (0.311 m^3/s) and approximately equal to the naturalized 1-in-2 year 30-day low flow (Table 3-37). It is slightly below the required minimum release of 0.3 m^3/s stipulated by the conservation licence (Dobson 2008). Historical EFN recommendations of 0.7-1.6 m^3/s were provided by ESSA & Solander (2009). The recommended critical flow for Rainbow rearing is 0.037 m^3/s (5% LTMAD) based on the LTMAD criterion (Table 2-7).

Estimated weekly naturalized flows are always greater than the recommended EFN (Figure 3-26). Estimated residual flows were not available; however, median daily recorded flows at the WSC hydrometric station 08NM053 between 1950 and 1996 were generally all at or above the recommended EFN (Figure B12-1, Appendix B12). A trend of declining summer flows below the recommended EFN (and conservation licence minimum flow) is apparent toward the end of the record in the 1990s. No recent flow records exist. Achieving EFNs for Rainbow rearing in Mill Creek is relatively feasible in comparison to other Okanagan streams, due to the comparatively high naturalized and residual flows.

Rainbow spawning

The recommended Tennant EFN for Rainbow spawning is 1.23 m^3/s, which is equal to the flow standard of 165% LTMAD (Table 3-38). Naturalized flows are greater than the recommended EFN for most of the Rainbow migration and spawning period (Figure 3-26). A previous EFN recommendation was 1.7 m^3/s (ESSA & Solander 2009) but based on WUW information from other study creeks with similar size and channel characteristics (e.g., Coldstream Creek), a flow of 1.23 m^3/s is considered sufficient. The recommended critical flow for Rainbow spawning is 0.372 m^3/s (50% LTMAD) based on the LTMAD criterion (Table 2-7).

Estimated residual flows were not available; however, median daily recorded flows at the WSC hydrometric station 08NM053 between 1950 and 1996 were at or above the recommended EFN for the month of May (Figure B12-1, Appendix B12). It is likely that the timing of Rainbow spawning in Mill Creek varies to coincide with peak flows. However, the impact of water storage activities on peak flows is apparent in the observed flow record in that the EFN is not achieved at all or only for a short duration (< 1 week) in approximately 30% of the years on record.

Kokanee spawning

The recommended EFN for Kokanee spawning is 0.250 m^3/s (34% LTMAD, Table 3-38) which is slightly lower than median naturalized flows during the spawning period (0.297 m^3/s) and approximately equal to the naturalized 1-in-2 year 30-day low flow (Table 3-37). It is slightly below the required minimum release of 0.3 m^3/s stipulated by the conservation licence (Dobson 2008). The recommended critical flow for Kokanee spawning is 0.074 m^3/s (10% LTMAD) based on the LTMAD criterion (Table 2-7).

Estimated weekly naturalized flows are greater than the recommended EFN (Figure 3-27). Estimated residual flows were not available; however, median daily recorded flows at the WSC hydrometric station 08NM053 between 1950 and 1996 were all at or above the recommended EFN (Figure B12-1, Appendix B12). A trend of declining summer flows below the recommended EFN (and below the conservation licence minimum flow) is apparent toward the end of the record in the 1990s. No recent flow records exist. Achieving EFNs for Kokanee spawning in Mill Creek is considered relatively feasible in comparison to other study streams, due to the comparatively high naturalized and residual flows.

Historical EFN recommendations ranged from 0.5 to 0.9 m^3/s (Mackinnon 1988, ESSA & Solander 2009) and recommended minimum discharges range from 0.14 m^3/s to 0.25 m^3/s, at which changes in usability were detected (Mackinnon 1988). WUW information was not collected in Mill Creek for this project; however, it is suspected based on WUW information from other streams as well as historical observations (Mackinnon 1988) that Kokanee spawning capacity increases at flows somewhat greater than the recommended EFN of 0.250 m^3/s, and higher flows should be encouraged.

3.13 Powers Creek

Powers Creek flows from the west side of the Okanagan Basin into Okanagan Lake at West Kelowna, B.C. The Powers Creek watershed has an area of approximately 145 km^2 (Associated 2016) and the total stream length is 29.5 km (Lukey & Louie 2015). Powers Creek drains a gently sloping plateau in the upper reaches before flowing through a deeply incised canyon and through a terrace of thick glacial sediments, before flowing across a large alluvial fan. A summary of creek characteristics is found in Table 3-39 and additional stream-specific data is provided in Appendix B13.

The lowest 1 km reach of Powers Creek is impaired by heavy urban encroachment and corresponding loss of riparian vegetation. Intermediate reaches have moderate riparian cover and impacts (Lukey & Louie 2015). The stream is known to support populations of Kokanee (spawning) and Rainbow (Associated 2016). Powers Creek has been recognized previously for its significant current and potential future Kokanee and Rainbow producing capabilities (Anonymous 1969; Wightman & Taylor 1978; Tredger 1988). The maximum reported Kokanee escapement was 35,000 in 1985 (Tredger 1988). A small (passable) chute is located approximately 0.7 km from the mouth (Tredger 1988) and a potential barrier to fish migration is located at Highway 97 (~ 2.7 km from the mouth) where there is a series of cascades and a culvert. A permanent barrier is located upstream at the water treatment facility of the Westbank Irrigation District (~ 7.5 km from the mouth; Lukey & Louie 2015). Tredger (1988) notes the high quality of trout rearing habitat between the chute and the potential barrier at 2.7 km. During 2017 flooding the creek deposited significant amounts of mobile bed material in the lowest reach. This material was removed by dredging and the flood conveyance capacity readjusted. Given the fact that the fan of Powers Creek where it flows into Okanagan Lake has been constrained by development, these deposits will continue to cause issues for flood capacity and Kokanee access into the creek.

At present there are 85 points of diversion and 4 pending water licence applications within the watershed (Associated 2019); however, the actual volume extracted annually is unknown. The City of West Kelowna is the main water user in the watershed and has developed headwater storage including Horseshoe Lake, Dobbin Lake, Paynter Lake, Jackpine Lake, Lambly Lake, and Tadpole Lake reservoirs (Associated 2016). Inter-basin water transfers into Powers Creek occur from Lambly (Bear) Creek and from Alocin Creek in the Nicola River watershed to supplement streamflows to the West Kelowna water intake on Powers Creek (Associated 2016; Lejbak pers. comm.). Powers Creek is considered fully recorded after June 30 unless storage is provided (Shepherd & Ptolemy 1999).

Since 1987, the B.C. MOE has held a water licence on Powers Creek for instream (conservation) use for the maintenance of 0.085 m^3/s within the creek throughout the year (Shepherd & Ptolemy 1999). Further, MOE placed a Water Act Reserve on Powers Creek (and all its tributaries) on June 15, 1989 (Dobson 2010), requiring that 0.13 m^3/s be maintained within the creek to meet current and projected angling demands for recreational fisheries (Lejbak pers. comm. 2019). Powers Creek is ‘flow sensitive’ during the winter but not the summer season as flows are above 20% LTMAD (Table 3-40). Water losses or gains across the alluvial fan near the mouth are unknown.

Naturalized flow data were provided by Associated (2019) with an estimated data quality rating of C (data error between 25% and 50%); residual and maximum licensed flows were not available at the time of reporting. Okanagan Tennant EFNs for Powers Creek were developed in accordance with the methods outlined in Section 2.2. No WUW data was collected in Powers Creek. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. The exception was Kokanee spawning, for which the EFN was set to the median naturalized flows during the spawning period. A summary of EFNs for Powers Creek is provided in Table 3-41 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-28, Figure 3-29 and Appendix B13, and flow sensitivities in Table 3-40. Further information on EFN setting in Powers Creek is provided at the end of this section.

Table 3-39: Powers Creek description

Drainage Area	145 km^2
Median Elevation	1242 m
WSC station	No active stations 08NM136 (historic) Lambly Lake Diversion to Powers Creek (1965-1972) 08NM033 (historic) Powers Creek above Westbank Diversion (1920-1974) 08NM034 (historic) Powers Creek Westbank Diversion (1920-1931) 08NM059 (historic) Powers Creek below Westbank Diversion (1924-1987) 08NM157 (historic) Powers Creek at the Mouth (1969- 1982)
MOE station (Epp 2008b)	08NM570 (historic) Powers Creek at Gellatly Road (2004-2009)
LTMAD	0.643 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, Eastern Brook Trout, Sculpin (general) (ESSA & Solander 2009)
Land use	Forestry in upper watershed, and agriculture and urban development in the lower watershed (Associated 2016)

Table 3-40: Flow sensitivities in Powers Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.137	21%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.113	18%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-41: EFN summary table for Powers Creek

Species & life stage	Time period	Okanagan Tennant Recommended EFN				Critical flow	
		Median (m^3/s)	% LTMAD	Min (m^3/s)	Max (m^3/s)	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.141	22%	0.129	0.486	0.032	5%
Rainbow spawning	May 20 – Jul 10	1.12	174%	0.574	3.80	0.321	50%
Kokanee spawning	Sep 4 – Oct 3	0.141	22%	0.141	0.141	0.064	10%
Rainbow overwintering	Nov 1 - March 31	0.143	22%	0.120	0.160	0.032	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

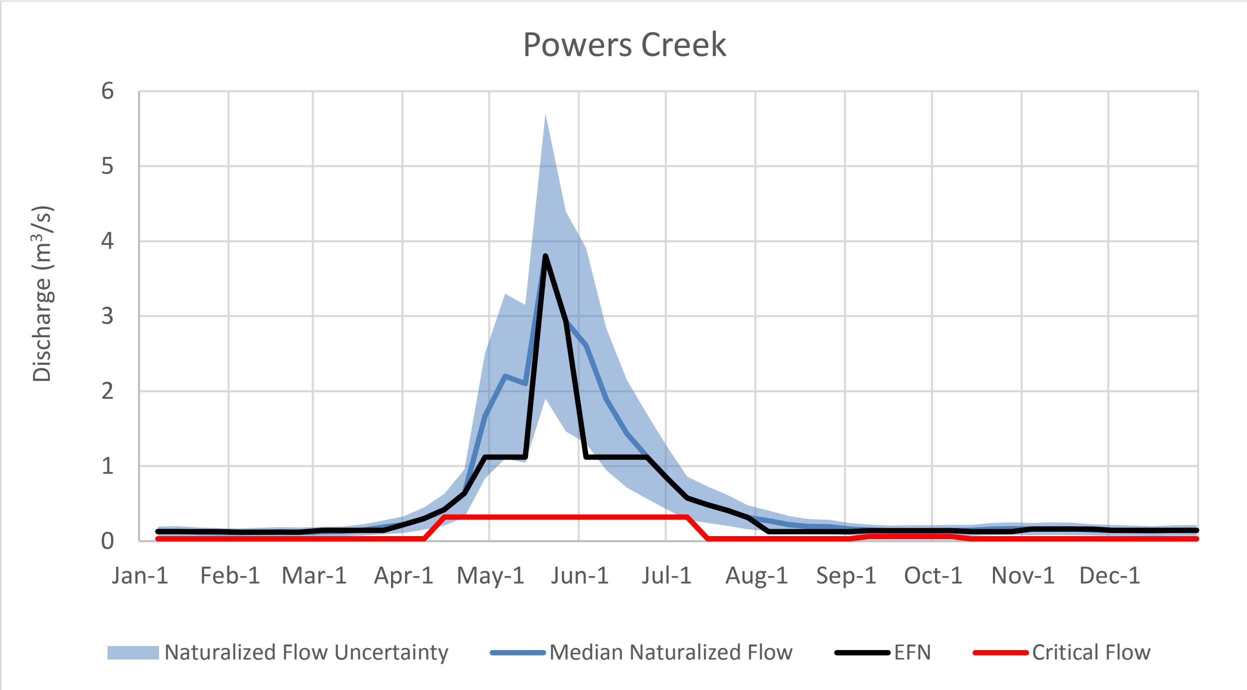


Figure 3-28: Weekly EFNs, critical flow and streamflows in Powers Creek

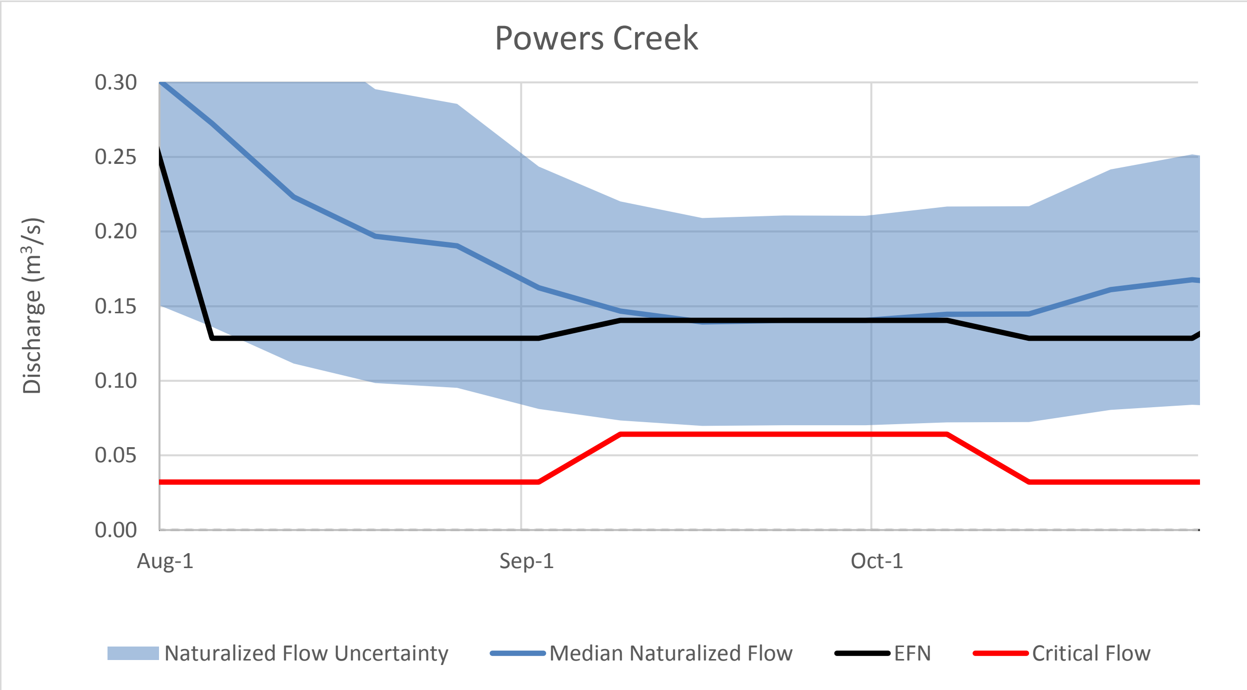


Figure 3-29: Weekly EFNs, critical flow and streamflows during the summer and fall period in Powers Creek

Rainbow parr rearing

The recommended EFN for Rainbow rearing is 0.129 m^3/s which is equal to the flow standard of 20% LTMAD. No WUW data was collected in Powers Creek for this project. Historical EFN recommendations made for Rainbow parr rearing were 0.11 m^3/s (Koshinsky 1972b) and 0.4-0.6 m^3/s (ESSA & Solander 2009). The recommended critical flow for Rainbow rearing is 0.0.32 m^3/s (5% LTMAD) based on the LTMAD criterion (Table 2-7).

Naturalized weekly flows during the mid-July to late September period are slightly higher than the recommended EFN (median 0.141 m^3/s, Table 3-41). Historical residual flows recorded at the WSC hydrometric station 08NM157 (Powers Creek at the Mouth, Figure B13-1 Appendix B13) from 1969 - 1982 during the same period were 0.218 m^3/s which suggests flow supplementation from storage. Historical WUW information (Tredger & Wightman 1988) shows modest gains in Rainbow parr rearing capacity between the recommended EFN and the residual flows. The authors recommend a flow of 0.14 m^3/s for Rainbow rearing based on field observations. More recent flow data collected by Epp (2008b) from 2004 - 2008 (Figure B13-1, Appendix B13) show residual rearing flows near the recommended EFN, with large annual differences and some years well below the recommended EFN.

Rainbow spawning

The recommended Okanagan Tennant EFN for Rainbow spawning is 1.12 m^3/s (Table 3-41), which is equal to the flow standard of 174% LTMAD. The recommended critical flow for Rainbow spawning is 0.321 m^3/s (50% LTMAD) based on the LTMAD criterion (Table 2-7). Estimated naturalized flows and residual flows recorded at the WSC hydrometric station 08NM157 (Powers Creek at the Mouth, Figure B13-1, Appendix B13) from 1969 - 1982 are above the recommended EFN for most of the spawning period, therefore EFNs for Rainbow spawning are considered achievable. A previous EFN recommendation by ESSA & Solander (2009) was approximately 1.75 m^3/s.

Kokanee spawning

The recommended Okanagan Tennant EFN for Kokanee spawning is 0.141 m^3/s (22% LTMAD, Table 3-41) which is equal to median naturalized flows during the spawning period. No WUW data was collected in Powers Creek for this project but historical information is available. According to Tredger (1988), there were no large gains in Kokanee spawning capacity at flows greater than 0.12 m^3/s; however, large decreases were observed below that. They suggest that 0.13 m^3/s is a suitable flow for Kokanee spawning. Data from Epp (2008b) indicate that WUW at the recommended EFN is approximately 60% of the maximum WUW, which is equal to or greater than the WUW available at the recommended EFN flows in other study streams. Historical minimum discharge recommendations for Kokanee spawning are generally in the range from 0.12-0.14 m^3/s (Koshinsky 1972b; Tredger 1988). The recommended critical flow for Kokanee spawning is 0.064 m^3/s (10% LTMAD) based on the LTMAD criterion (Table 2-7).

Median flows at the WSC hydrometric station 08NM157 (Powers Creek at the Mouth, Figure B13-1, Appendix B13) from 1969 - 1982 were 0.241 m^3/s, which is substantially greater than the Okanagan Tennant EFN presented above. However, more recent flow data collected by Epp (2008b) from 2004 - 2008 documented spawning flows at or well below the Okanagan Tennant EFN (Figure B13-1, Appendix B13). Meeting EFNs for Kokanee spawning is considered achievable in conjunction with improved flow management.

3.14 *Trepanier Creek*

Trepanier Creek flows from the west side of the Okanagan Basin into Okanagan Lake at Peachland, B.C. The Trepanier Creek watershed is approximately 260 km^2 with two main tributaries. MacDonald and Lacoma Creeks (Associated 2016). The total stream length is 28 km (Lukey & Louie 2015). The creek drains a gently sloping plateau and enters a steep canyon section below Highway 97 before flowing through the community of Peachland (Associated 2016). In the upper reaches the main land use is forestry, with agriculture and urban development within the lower portions of the watershed. Brenda Mine, located in the headwaters, has not been operational since 1990 (Associated 2016). A summary of creek characteristics is found in Table 3-42 and additional stream-specific data is provided in Appendix B14.

A waterfall and a series of cascades are located 1 km from the mouth and are considered a barrier to fish passage (Grainger & Streamworks 2010). The accessible reach is impaired by riparian vegetation removal and encroachment of residential land-use (Lukey & Louie 2015). There is also evidence of past channelization, which has reduced the availability of holding pools and habitat diversity, and has reduced available gravel for Rainbow and Kokanee spawning (Wightman & Taylor 1978).

The stream is known to currently support populations of Kokanee (spawning) and Rainbow spawning and rearing. Juvenile Burbot were also captured upstream of Highway 97 (Wightman & Taylor 1978). Kokanee habitat is considered marginal due to large substrate size, short accessible length and high gradient (Tredger 1989b; Shepherd & Ptolemy 1999). In the 1970s, Kokanee spawning was prevented during dry years by lack of flow in the lower reaches resulting from water abstraction (Pearson 1977). More recently, Kokanee enumeration reports indicate that crowding in the limited spawning gravels is an issue during years with higher escapement (Webster 2017).

At present, there are 160 points of diversion and 11 pending water licence applications within the Trepanier Creek watershed (Associated 2019); however, the actual volume extracted is unknown. The District of Peachland is the main water supplier in the watershed with developed water storage at Wilson Lake and Silver Lake reservoirs (Associated 2016). Inter-basin water transfers do occur from Trepanier Creek into Peachland Creek (Associated 2016). As of 1976, Trepanier Creek is considered fully recorded (except for domestic purposes) unless storage is provided (MELP 2000). Further, MOE requested a Water Act Reserve on Trepanier Creek on June 15, 1989 (Shepherd & Ptolemy 1999), but the status is unknown. Trepanier Creek is 'flow sensitive' during the winter but not the summer season as flows are at 20% LTMAD (Table 3-43). The Trepanier Creek Operating Strategy was drafted in 2006 following close to zero flows in Lower Trepanier Creek in August of 2003 and 2005. The strategy is not a formal operating agreement but is intended to guide the District of Peachland to maintain close to natural flow levels during periods of flow (Epp 2010b). Estimated naturalized flows (Associated 2019) are generally quite high in comparison to other Okanagan streams; however, historical reports indicate low flows resulting from water use may limit Kokanee spawning (Pearson 1977, Tredger 1989b). Streamflow losses and gains across the alluvial fan near the mouth are unknown but the stream was assumed to be losing water to groundwater for the flow naturalization exercise (Associated 2019).

Okanagan Tennant EFNs for Trepanier Creek were developed in accordance with the methods outlined in Section 2.2. No WUW data was collected in Trepanier Creek. Naturalized flow data were provided by Associated (2019) with an estimated data quality rating of B (data error between 10% and 25%); residual and maximum licensed flows were not available at the time of reporting. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the naturalized flow or flow standard. A summary of EFNs for Trepanier Creek is provided in Table

3-44 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-30, Figure 3-31 and Appendix B14, and flow sensitivities in Table 3-43. Further information on EFN setting in Trepanier Creek is provided at the end of this section.

Table 3-42: Trepanier Creek description

Drainage Area	260 km^2
Median Elevation	1228 m
WSC station	08NM041 (historic) Trepanier Creek near Peachland (1919-2014) 08NM013 (historic) Jack Creek at the Mouth (1919-1919) 08NM155 (historic) Trepanier Creek at the Mouth (1969-1981)
MOE station	08NM572 Trepanier Creek at Highway 97 (2006-2009) 08NM573 Trepanier Creek downstream Highway 97 (2006-2007) 08NM574 Trepanier Creek upstream of Highway 98 (2006-2008)
LTMAD	1.283 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, Burbot, Largescale Sucker, Sucker spp., Prickly Sculpin, Sculpin spp. (ESSA & Solander 2009)
Land use	Forestry in the upper watershed, agriculture and urban development in lower watershed. Brenda Mine (no longer in operation) is located in the headwaters (Associated 2016)

Table 3-43: Flow sensitivities in Trepanier Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.263	20%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.213	17%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-44: EFN summary table for Trepanier Creek

Species & life stage	Time period	Okanagan Tennant Recommended EFN				Critical flow	
		Median (m^3/s)	% LTMAD	Min (m^3/s)	Max (m^3/s)	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.257	20%	0.257	0.968	0.064	5%
Rainbow spawning	May 20 – Jul 10	1.73	135%	1.15	7.66	0.642	50%
Kokanee spawning	Sep 4 – Oct 4	0.257	20%	0.257	0.257	0.128	10%
Rainbow overwintering	Nov 1 – Mar 31	0.257	20%	0.229	0.257	0.064	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

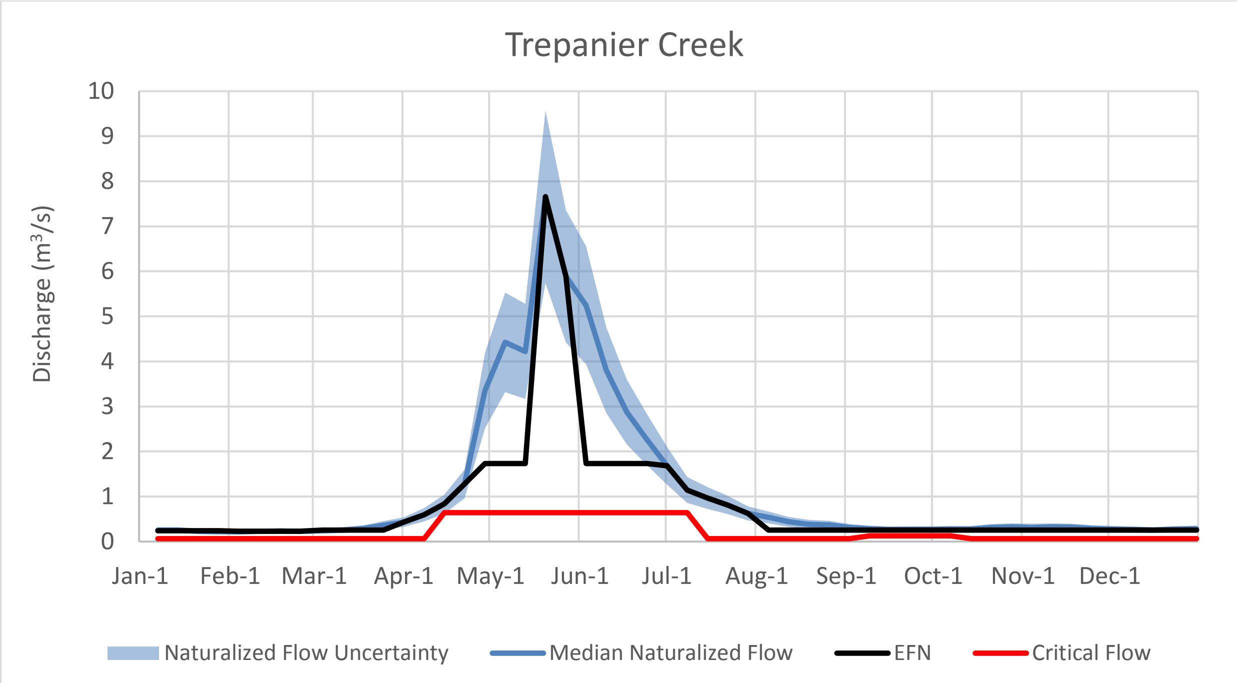


Figure 3-30: Weekly EFNs, critical flow and streamflows in Trepanier Creek

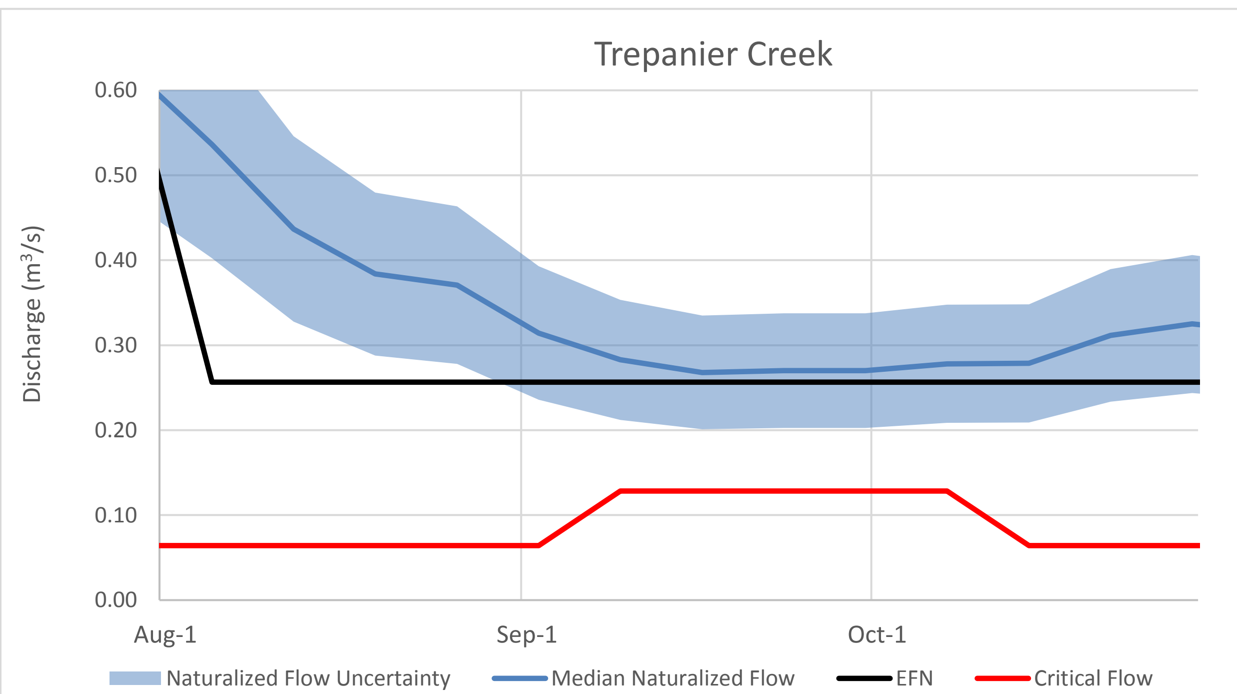


Figure 3-31: Weekly EFNs, critical flow and streamflows during the summer and fall period in Trepanier Creek

Rainbow parr rearing

The median recommended Okanagan Tennant EFN for Rainbow rearing is 0.257 m^3/s (Table 3-44) which is equal to the flow standard of 20% LTMAD. No WUW data was collected in Trepanier Creek for this project. Previous EFN recommendations have ranged from a low of 0.057 m^3/s (Hunter 1978) to 0.328 m^3/s (Dobson 1990), with intermediate values of 0.14 m^3/s (Cairns 1992) and 0.165 m^3/s (Shepherd & Ptolemy 1999). The Trepanier Creek Operating Strategy recommends that flows in the lower reaches should be maintained at close to natural levels as possible during lower flow periods (<0.30 m^3/s) as useable fish habitat is directly proportional to flow at lower levels, and states that there is very little useable habitat when flows in lower Trepanier Creek are below 0.10 m^3/s (Epp 2010b). The recommended critical flow for Rainbow parr rearing is 0.064 m^3/s (5% LTMAD) based on the LTMAD criterion (Table 2-7).

Naturalized weekly flows during the mid-July to late September period are greater than the recommended EFN (0.268 - 0.968 m^3/s, Figure 3-31). Median daily residual flows recorded at the WSC hydrometric station 08NM041 (Trepanier Creek near Peachland, 1919-2014; Figure B14-1, Appendix B14), which is located above the District of Peachland water intake, were generally at or above the recommended EFN. However, median daily residual flows at the WSC hydrometric station near the mouth (08NM155 Trepanier Creek at the Mouth, 1969-1981, Figure B14-1, Appendix B14), were well below the recommended EFN from late July through the winter, reaching as low as 0.045 m^3/s (4% LTMAD). Achieving EFNs for Rainbow parr rearing near the mouth may thus be problematic. WUW information collected by Tredger (1989b) up to a discharge of 0.165 m^3/s demonstrated increasing capacity for parr rearing beyond the flows measured. WUW information collected by Epp (2008) indicates that parr rearing WUW increases rapidly up to approximately 100% LTMAD in the channelized sections near the mouth. In a natural channel reach further upstream near Highway 97C, WUW increased rapidly between approximately 0.25 to 0.5 m^3/s and then levelled off.

Rainbow spawning

The median recommended Okanagan Tennant EFN for Rainbow spawning is 1.73 m^3/s (Table 3-44), which is equal to the flow standard of 135% LTMAD. The recommended critical flow for Rainbow spawning is 0.642 m^3/s (50% LTMAD) based on the LTMAD criterion (Table 2-7).

Estimated naturalized flows (Figure 3-30) are greater than the EFN from mid-April to late June, whereas residual flows (particularly at the mouth) drop below the recommended EFN in early June (WSC 08NM155 Trepanier Creek at the Mouth, 1969-1981, Figure B14-1, Appendix B14). Achieving Rainbow spawning EFNs is considered feasible with improved flow management. A previous EFN recommendation by ESSA & Solander (2009) was approximately 2 m^3/s.

Kokanee spawning

The recommended Okanagan Tennant EFN for Kokanee spawning is 0.257 m^3/s (Table 3-44), which is equal to the flow standard of 20% LTMAD. WUW information collected by Tredger (1989b) up to a discharge of 0.165 m^3/s demonstrated increasing capacity for Kokanee spawning beyond the flows measured. Their estimated capacity of 4,000 spawners at 0.165 m^3/s was below the maximum escapement on record (9,300 in 1971; MELP 2000). WUW information collected by Epp (2008) indicates that Kokanee spawning WUW increases rapidly up to approximately 0.8 m^3/s (62% LTMAD) in the accessible reaches near the mouth. The Trepanier Creek Operating Strategy recommends that flows in the lower reaches should be maintained at close to natural levels as possible during lower flow periods (<0.30 m^3/s) as useable fish habitat is directly proportional to flow at lower levels (50% of maximum spawning WUW at <0.30 m^3/s), and states that there is very little useable habitat when flows in lower

Trepanier Creek are below 0.10 m^3/s (Epp 2010b). Historical EFN recommendations for Kokanee spawning range from 0.14-0.28 m^3/s (Koshinsky 1972b; Dobson 1990; Cairns 1992; Shepherd & Ptolemy 1999). The recommended critical flow for Kokanee spawning is 0.064 m^3/s (10% LTMAD) based on the LTMAD criterion (Table 2-7).

Naturalized weekly flows during the Kokanee spawning period are just above the recommended EFN (Figure 3-31). Median daily residual flows recorded at the WSC hydrometric station 08NM041 (Trepanier Creek near Peachland, 1919-2014; Figure B14-1, Appendix B14), which is located above the District of Peachland water intake, are generally very close to the recommended EFN. However, flows near the mouth (WSC 08NM155, Trepanier Creek at the Mouth, 1969-1981, Figure B14-1, Appendix B14), were on average 0.086 m^3/s which is well below the recommended EFN, reaching as low as 0.045 m^3/s (4% LTMAD), indicating that low flows near the mouth are likely severely reducing the Kokanee spawning capacity of Trepanier Creek. Achieving the Kokanee spawning EFN near the mouth is thus considered problematic.

3.15 Naramata Creek

Naramata Creek flows from the east side of the Okanagan Basin into Okanagan Lake 11 km north of Penticton, B.C. The Naramata Creek watershed is approximately 41.8 km^2 (Associated 2016) and the stream length is 13 km (Lukey & Louie 2015). The creek drains a gently sloping plateau and then enters a steep canyon section before flowing over two terraces with orchards and residences in the town of Naramata near Okanagan Lake (Associated 2017). A summary of creek characteristics is found in Table 3-45 and additional stream-specific data is provided in Appendix B15.

Naramata Creek is known to currently support populations of Kokanee (spawning) and Rainbow (Associated 2016). There is a fish passage barrier located 3.4 km from the mouth. Kokanee spawning conditions have been impacted by water storage and effluent discharges into the creek (Pearson 1977), and fish habitat in general has been degraded by past channel straightening and dredging activities (Wightman & Taylor 1978) in the lower reaches as recently as 1990. The original streambed was much narrower with greater habitat complexity and more pools (Shepherd & Ptolemy 1999). A number of habitat improvements were completed in the creek since 1995 by the local community, including efforts to build Kokanee spawning beds and restoration of riparian areas along the creek.

At present, there are 13 points of diversion within the watershed (Associated 2019); however, the actual volume extracted is unknown. Naramata Creek was used as the community water supply as early as 1905 (Summit 1995) by the Regional District of Okanagan Similkameen (RDOS). The stream is currently fully recorded except during freshet (FLNRORD 2016).

Though there are no developed storage reservoirs in the watershed, a series of ditches store diverted water. Streamflows in Naramata Creek are augmented by the highline diversion, a wooden flume system that diverts water from Chute and Robinson creeks into Naramata Creek to support irrigation and water supply for Naramata. Three storage reservoirs exist within the Chute and Robinson Creek watersheds. Though some of the water is used by licensees, streamflows have historically been augmented during the summer and fall period (Matthews 2002). In 2007, the RDOS switched their water supply to Okanagan Lake and abandoned their use of Naramata Creek. However, the highline diversion is still operational between July and October (Lejbak pers. comm. 2019) and FLNRORD is currently evaluating whether continued operation would be worthwhile to maintain the Kokanee stock (White pers. comm. 2019 as natural flows are considered insufficient to maintain the population (Matthews 2002). Historical information indicates that insufficient flow has always been a limiting factor to fish production in Naramata Creek (Matthews 2002), and fish kills have been reported during periods of reduced flow augmentation (Shepherd & Ptolemy 1999). Naramata Creek is ‘flow sensitive’ in the summer and winter as low flows are below 20% LTMAD and reach as low as 5% LTMAD (Table 3-46). Water losses and gains across the alluvial fan near the mouth are unknown.

Naturalized, residual and maximum licensed flow estimates were provided by Associated (2019) with an estimated data quality rating of C for naturalized flows (data error between 25% and 50%) and D for residual flows (data error greater than 50%). Estimated maximum licensed flows indicate that the creek would be dry from mid-June to mid-September if licensed withdrawal and storage volumes were maximized.

Table 3-45: Naramata Creek description

Drainage Area	41.8 km^2
Median Elevation	1330 m
WSC station	No active or historic WSC stations
LTMAD	0.157 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee (ESSA & Solander 2009)
Land use	Forestry in upper watershed, agriculture and urban development in lower watershed (Associated 2016)

The approach for recommending Okanagan Tennant EFNs for Naramata Creek differed from other creeks due to the history of flow augmentation from the highline diversion. Local fish populations have adapted to the augmented flows and thus, residual flows were used as the upper bound of the Okanagan Tennant EFN instead of naturalized flows. No WUW data was collected in Naramata Creek. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the residual flow or flow standard. During the summer and fall low flow period, recommended EFNs are equal to the weekly median residual flows to maintain current levels of Rainbow parr rearing and Kokanee spawning habitat capacity, and recommended overwintering EFNs are 50% of spawning flows to protect incubating eggs. A summary of EFNs for Naramata Creek is provided in Table 3-47 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-32, Figure 3-33 and Appendix B15, and flow sensitivities in Table 3-46. Further information on EFN setting in Naramata Creek is provided at the end of this section.

Table 3-46: Flow sensitivities in Naramata Creek based on naturalized flows

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.012	7%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.009	5%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-47: EFN summary table for Naramata Creek based on residual flows

Species & life stage	Time period	Okanagan Tennant Recommended EFN				Critical flow	
		Median (m^3/s)	% LTMAD	Min (m^3/s)	Max (m^3/s)	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.090	52%	0.055	0.139	0.009	5%
Rainbow spawning	May 20 – Jul 10	0.492	285%	0.150	0.830	0.086	50%
Kokanee spawning	Sep 17 – Oct 10	0.056	32%	0.029	0.059	0.017	10%
Rainbow overwintering	Nov 1 – Mar 31	0.028	16%	0.028	0.028	0.009	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

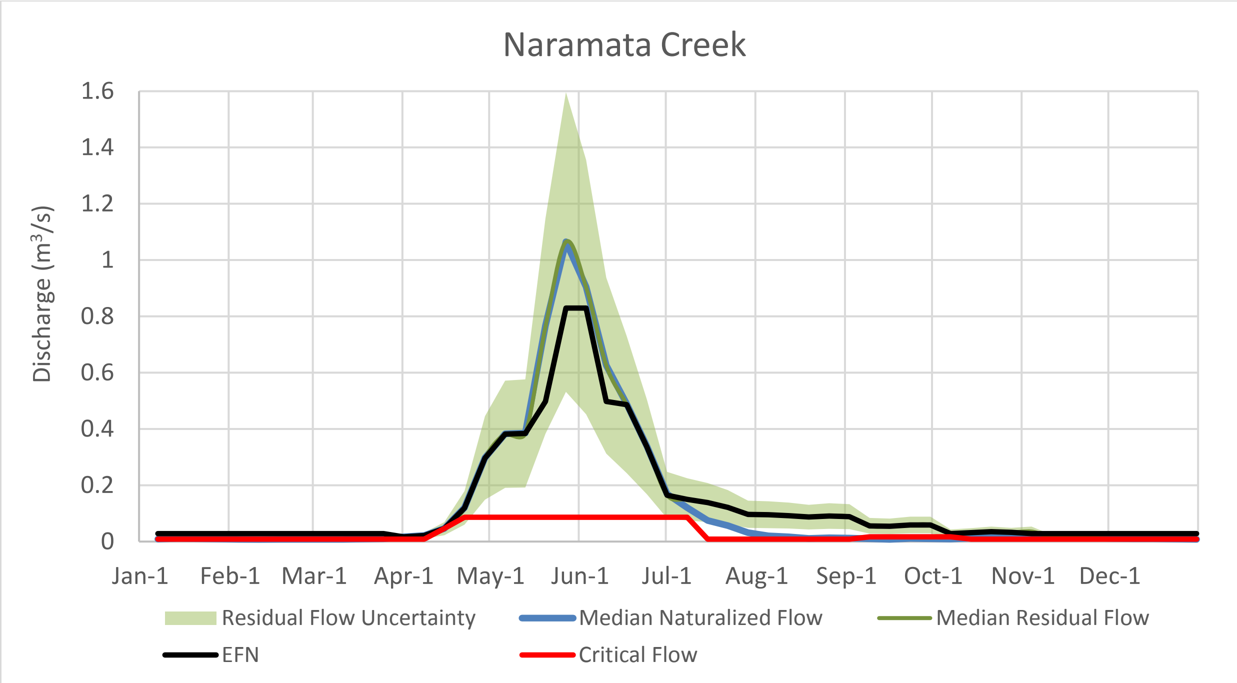


Figure 3-32: Weekly EFNs, critical flow and streamflows in Naramata Creek

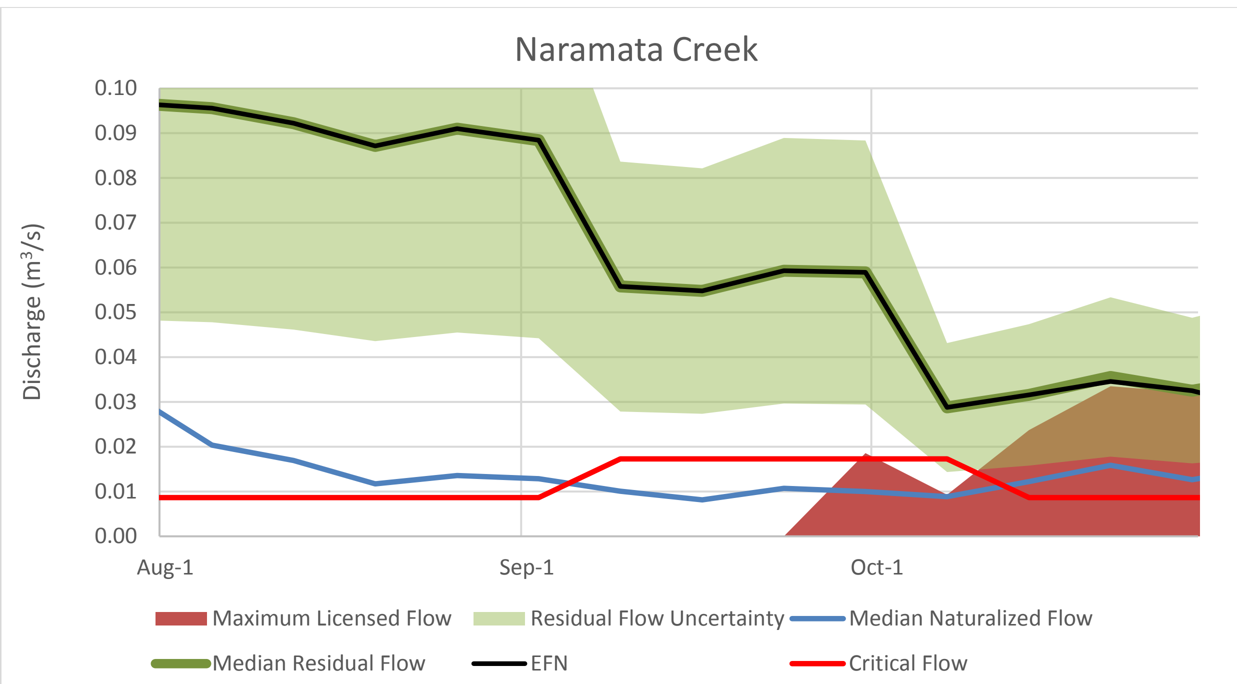


Figure 3-33: Weekly EFNs, critical flow and streamflows during the summer and fall period in Naramata Creek

<u>Rainbow parr rearing</u>

The median recommended Okanagan Tennant EFN for Rainbow rearing is 0.090 m^3/s (57% LTMAD) (Table 3-47) which is equal to the estimated median residual flows during the mid-July to late September period. No recorded hydrometric data is available for comparison. Estimated naturalized weekly flows during the mid-July to late September period are well below the recommended EFN, indicating that continued flow supplementation is required to sustain current levels of parr rearing in the creek and to achieve the EFN (Figure 3-33). No WUW data was collected but past channel widening for flood control likely necessitates the comparatively high EFN. The recommended critical flow for Rainbow rearing is 0.009 m^3/s (5% LTMAD) based on the LTMAD criterion (Table 2-7).

Judging from WUW curves for Rainbow parr rearing in other creeks of similar size (e.g., McDougall Creek), it is likely that Rainbow parr WUW increases rapidly between the naturalized flow estimates (approximately 0.015 m^3/s during the summer low flow period) and our recommended EFN. Given the absence of actual habitat data underlying this EFN, it is recommended to confirm habitat conditions under late summer residual flows (up to approximately 0.1 m^3/s) to refine EFN recommendations and evaluate the potential for continued flow supplementation. The habitat assessments should be coupled with flow monitoring.

Previous EFN recommendations have ranged from a low of 0.085 m^3/s (visual observations from Wightman & Taylor 1978) to 0.255-0.55 m^3/s (ESSA & Solander 2009), the former being almost equivalent to our EFN and the latter being unachievable even with flow augmentation.

Rainbow spawning

The recommended Okanagan Tennant EFN for Rainbow spawning is 0.492 m^3/s (314% LTMAD, Table 3-47). Estimated naturalized and residual flows are greater than the EFN from late-May to late June (Figure 3-32). A previous EFN recommendation by ESSA & Solander (2009) was approximately 0.6 m^3/s. The recommended critical flow for Rainbow spawning is 0.086 m^3/s (50% LTMAD) based on the LTMAD criterion (Table 2-7).

Kokanee spawning

The current level of Kokanee production from Naramata Creek is maintained through flow augmentation from the highline diversion (Matthews 2002). It is likely that Kokanee production under naturalized flows would be severely diminished, as indicated by a fish kill in 1993 that resulted from the temporary interruption of the highline diversion inflows during the Kokanee spawning period (Inkster 1993). EFNs for Kokanee spawning were set to estimated residual flows for the spawning period as stocks have adapted to the augmented flow regime (Associated 2019). The median of the recommended weekly EFNs is 0.056 m^3/s (36% LTMAD, Table 3-47). However, historical EFN recommendations for Kokanee spawning based on visual inspection of the creek were greater at 0.085 m^3/s (Wightman & Taylor 1978) and 0.23 m^3/s, as well as 0.11 m^3/s over the winter for incubation (Shepherd & Ptolemy 1999). Estimated residual flows are much lower and it is unknown whether EFNs could be achieved through management of storage in the Robinson and Chute Creek watersheds. Estimated residual flows prior to the Kokanee spawning period are much greater than those during the Kokanee spawning period (Figure 3-33). If possible, it is recommended to reduce releases during mid-summer to increase supplementation during the Kokanee spawning period. Field investigations of Kokanee spawning habitat conditions under a range of expected flows, coupled with flow monitoring, should be completed to refine EFN recommendations and evaluate the potential for continued flow supplementation. The recommended critical flow for Kokanee spawning is 0.017 m^3/s (10% LTMAD) based on the LTMAD criterion (Table 2-7).

Overwinter incubation flows are recommended at 50% of the Kokanee spawning flows (0.028 m^3/s, 18% LTMAD) but cannot be augmented by the highline diversion as it does not operate in the winter. Estimated naturalized flows in the winter range from 0.008-0.016 m^3/s, which is well below the recommended EFN. Since there was no winter flow augmentation in the past it is expected that maintaining the current residual flow regime will maintain current production levels of Kokanee.

3.16 Trout Creek

Trout Creek is the second largest tributary to Okanagan Lake, flowing from the west side of the Okanagan Basin to its mouth at Summerland, B.C. The Trout Creek watershed is approximately 762 km^2 (NHC 2003) and has a number of main tributaries including North Trout, Camp, Bull, Isintok, and Darke creeks (Associated 2016). From the forested headwaters, Trout Creek flows through deeply incised canyon sections before flowing onto a large alluvial fan at Okanagan Lake (Associated 2017). The lowest reaches flow through orchards and residential areas near the town of Summerland. A summary of creek characteristics is found in Table 3-48 and additional stream-specific data is provided in Appendix B16.

Trout Creek supports populations of Kokanee (spawning) and Rainbow (Associated 2016). The lowest section of the creek below the canyon was entirely channelized for flood control purposes in the 1970s. With additional impacts including removal of streamside vegetation and high water demand, the once relatively large Kokanee and Rainbow populations in the creek have been have almost entirely eliminated (Hinton 1972). The channelized section has large substrate because of resulting high water velocities that provides only marginal spawning habitat. Access to upstream sections is blocked by seven fish migration barriers that occur within the lower 8.8 km of Trout Creek. Upstream of the lowest 2 km is an unstable canyon that contributes significant amounts of suspended sediment into the lower reaches (NHC 2003). The lower 11 km of Trout Creek and particularly the lowest 2 km experience acute low flows due to irrigation diversions (Wightman & Taylor 1978) and typically experienced dry streambed conditions in the summer months (Koshinsky & MacDonald 1971). Historical hydrometric records show low flows in particular years with unnatural down-ramping rates due to flow regulation.

At present, there are 127 points of diversion and three pending water licence applications within the Trout Creek watershed (Associated 2019); however, the actual volume extracted is unknown. The stream is currently fully recorded except for domestic licences (FLNRORD 2016). The District of Summerland is the main water supplier, and has developed water storage at Thirsk Reservoir (Associated 2016). There are eight more additional reservoirs in the watershed including Crescent, Whitehead, Tsuh, Isintok, and four headwater reservoirs. Serious impairment of fish populations resulting from low flows in the lower reaches of Trout Creek have been documented in numerous reports over the years. A summary of the Trout Creek streamflow and Kokanee spawning data was undertaken by Keystone Environmental and Columbia Environmental Consulting Ltd. (Martins 2003). Concerns were brought up regarding the lack of flow data available. Flow monitoring and WUW investigations in the mid-2000s contributed to development of a Water Use Plan for Trout Creek. In the plan, EFNs were set to the lesser of WUW-derived conservation flows and a multiplier of an unregulated tributary to Trout Creek (WSC station 08NM134 Camp Creek) that represents largely natural streamflow conditions (NHC 2005). Naturalized flow data provided by Associated (2019) indicates that the lower reaches of Trout Creek are naturally 'flow sensitive' during the winter as naturalized flows are below 20% LTMAD (Table 3-49). Water losses or gains across the alluvial fan near the mouth are unknown since no field measurements were collected; however, the stream was assumed to lose flow to groundwater on the fan based on information from the Water Use Plan (Associated 2019).

Naturalized flow data were provided by Associated (2019) with an estimated data quality rating of B (data error between 10% and 25%); residual and maximum licensed flows were not available at the time of reporting. Okanagan Tennant EFNs for Trout Creek were developed in accordance with the methods outlined in Section 2.2. No WUW data was collected. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. Weekly Okanagan Tennant EFNs were set to the lower of the residual flow or flow standard. However, Kokanee spawning flows were set to naturalized flows to conform to the current

Water Use Plan. A summary of EFNs for Trout Creek is provided in Table 3-50 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-34, Figure 3-35 and Appendix B16, and flow sensitivities in Table 3-49. Further information on EFN setting in Trout Creek is provided at the end of this section.

Table 3-48: Trout Creek description

Drainage Area	747 km^2
Median Elevation	1330 m
WSC station	08NM134 (active) Camp Creek at Mouth near Thirsk (1965-present) 08NM238 (historic) Thirsk Lake near the Outlet (1979-1987) 08NM238 (historic) Trout Creek Below Thirsk (1979-1986) 08NM133 (historic) Bull Creek near Crump (1965-1986) 08NM023 (historic) Darke Creek Northwest Fork (1921-1922) 08NM025 (historic) Darke Creek at Meadow Valley (1921-1922) 08NM055 (historic) Trout Creek Summerland Diversion (1922-1931) 08NM054 (historic) Trout Creek near Faulder (1922-1954) 08NM042 (historic) Trout Creek near Summerland (1920-1922) 08NM158 (historic) Trout Creek at the Mouth (1969-1982)
MOE station	08NM042-HDS (2004-2009)
LTMAD	2.17 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, Eastern Brook Trout, Mountain Whitefish, Largescale Sucker, Longnose Dace, Prickly Sculpin, Sculpin (general), Redside Shiner, Peamouth Chub (ESSA & Solander 2009)
Land use	Forestry and livestock grazing in upper watershed, and agriculture and urban development in lower watershed (Associated 2016). The lowest reach was once within the Penticton Indian Band reserve

Table 3-49: Flow sensitivities in Trout Creek

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.512	24%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.401	18%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-50: EFN summary table for Trout Creek

Species & life stage	Time period	Okanagan Tennant Recommended EFN				Critical flow	
		Median (m^3/s)	% LTMAD	Min (m^3/s)	Max (m^3/s)	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.435	20%	0.435	1.57	0.109	5%
Rainbow spawning	May 20 – Jul 10	2.44	112%	1.88	9.74	1.09	50%
Kokanee spawning	Sep 1 – Oct 20	0.520	24%	0.520	0.520	0.217	10%
Rainbow overwintering	Nov 1 – Mar 31	0.441	20%	0.420	0.547	0.109	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

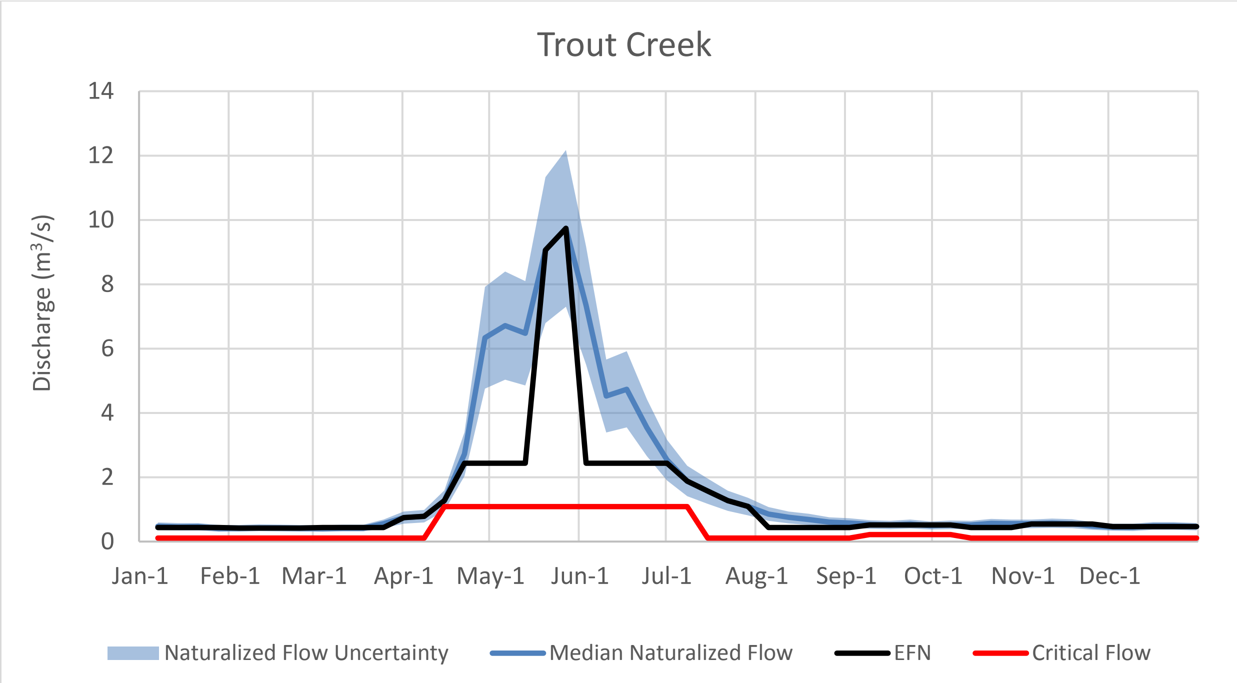


Figure 3-34: Weekly EFNs, critical flow and streamflows in Trout Creek

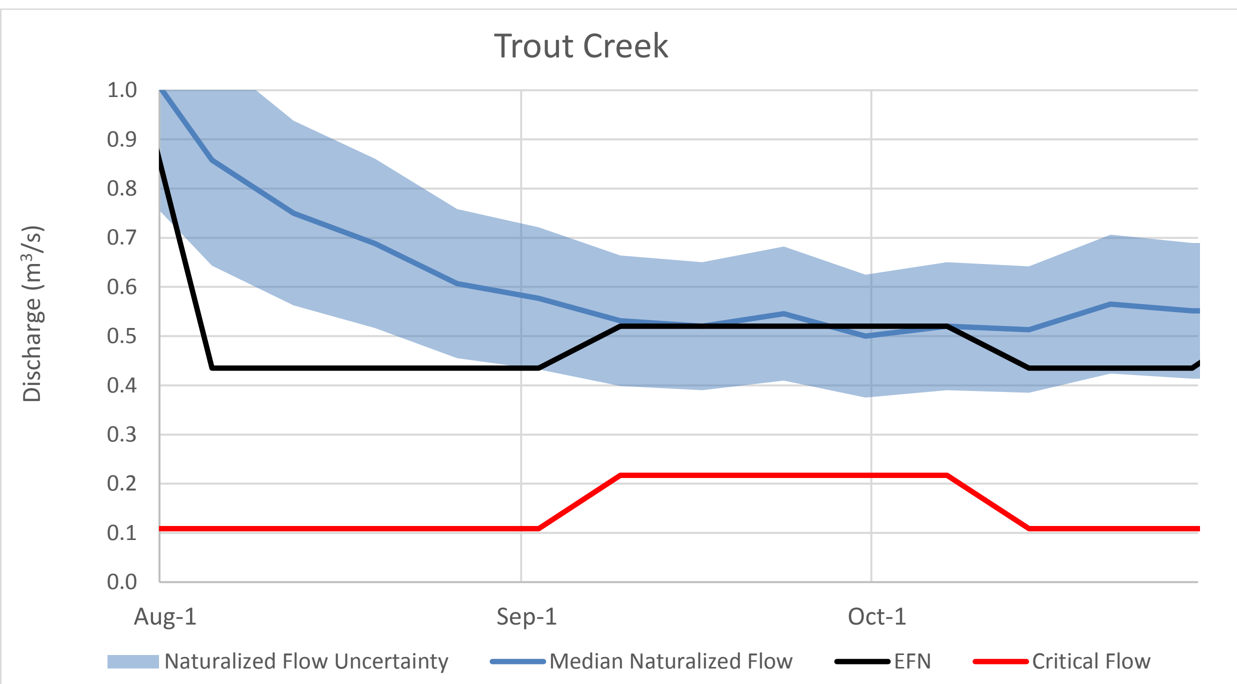


Figure 3-35: Weekly EFNs, critical flow and streamflows during the summer and fall period in Trout Creek

Rainbow parr rearing

The recommended Okanagan Tennant EFN for Rainbow parr rearing is 0.435 m^3/s (20% LTMAD); however, the median Okanagan Tennant EFN for the mid-July to late September period in Trout Creek is 0.520 m^3/s (24% LTMAD) due to higher flow requirements for Kokanee spawning in the fall (Table 3-50). Estimated weekly naturalized flows (Associated 2019) range from 0.500 – 1.568 m^3/s (median 0.647 m^3/s) during the mid-July to late September period. The EFN is lower than naturalized flow estimates throughout the summer (Figure 3-35). Previous WUW investigations indicate approximately 60% of maximum parr rearing WUW remaining at the recommended EFN (NHC 2005). The recommended critical flow for Rainbow rearing is 0.109 m^3/s (5% LTMAD) based on the LTMAD criterion (Table 2-7).

Historical EFN recommendations for Rainbow parr rearing ranged from 0.075 m^3/s (Associated 1997) to 1 m^3/s (ESSA & Solander 2009). Maximum incremental benefits are achieved between 0.4 and 0.5 m^3/s (NHC 2004) and optimum flows are at 1.2 m^3/s (NHC 2005). The lowest monthly conservation flow from the Water Use Plan is 0.54 m^3/s and occurs in October, though the operational flow release during a drought year would be much lower as it would default to 4x Camp Creek real-time flows. Due to the rapid increase in WUW between the recommended EFN and approximately 1.2 m^3/s (NHC 2005), there is significant benefit in sustaining flows greater than the recommended EFN during wetter years.

Median residual flows recorded at the WSC hydrometric station 08NM158 (Trout Creek at the mouth, 1969-1982; Figure B16-1, Appendix B16) were well below the recommended EFN from mid-July to September, and below the EFN for the remainder of the fall. More recent data from the MOE station 08NM042-HDS (2004-2009) shows median weekly summer flows at the recommended EFN though flows during individual weeks dropped below the EFN at times (Figure B16-1, Appendix B16). Meeting EFNs for Rainbow rearing near the mouth is thus considered possible but requires careful management of releases and withdrawals.

Rainbow spawning

The median recommended Okanagan Tennant EFN for Rainbow spawning is 2.44 m^3/s (Table 3-50), which is equal to the flow standard of 112% LTMAD. Estimated naturalized flows (Figure 3-34) are greater than the EFN from mid-April to late June. A previous EFN recommendation by ESSA & Solander (2009) was approximately 4 m^3/s. The recommended critical flow for Rainbow spawning is 1.09 m^3/s (50% LTMAD) based on the LTMAD criterion (Table 2-7).

Median residual flows recorded at the WSC hydrometric station 08NM158 (Trout Creek at the mouth, 1969-1982; Figure B16-1, Appendix B16) were above the recommended EFN during the spawning period from mid-May to late July. More recent data from the MOE station 08NM042-HDS (2004-2009) shows median weekly flows below the recommended EFN from late May onwards (Figure B16-1, Appendix B16). Meeting EFNs for Rainbow spawning in Trout Creek is possible but requires careful management of water storage activities to avoid disrupting spawning EFNs.

Kokanee spawning

The recommended Okanagan Tennant EFN for Kokanee spawning is 0.520 m^3/s (24% LTMAD, Table 3-44), which is equal to the median weekly naturalized flows during the Kokanee spawning period (Figure 3-35) and slightly greater than the flow standard of 20% LTMAD. Previous WUW investigations indicate approximately 85% of maximum Kokanee spawning WUW remaining at the recommended EFN in the lower accessible reaches of Trout Creek (NHC 2005). Historical EFN recommendations for Kokanee spawning range from 0.28-2 m^3/s (Associated 1997; CBCOBA 1974; NHC 2004; ESSA & Solander 2009).

The recommendation from the Water Use Plan of approximately 0.54-0.68 m^3/s during an average year is in close agreement with the recommended EFN. Operational flow releases during a drought year would be much lower as they would default to 4x Camp Creek real-time flows.

The recommended critical flow for Kokanee spawning is 0.217 m^3/s (10% LTMAD) based on the LTMAD criterion (Table 2-7). Historical recommended minimum discharges range from 0.28 m^3/s (Koshinsky & MacDonald 1971) to 0.618 m^3/s (MOE 2000) with a note that flows of 0.14 m^3/s were "probably disastrous" for salmon (Koshinsky & MacDonald 1971). Optimum flows of 0.8 m^3/s were recommended by NHC (2005).

Median residual flows recorded at the WSC hydrometric station 08NM158 (Trout Creek at the mouth, 1969-1982; Figure B16-1, Appendix B16) were below the recommended EFN during the Kokanee spawning period. More recent data from the MOE station 08NM042-HDS (2004-2009) shows median weekly flows at or just below the recommended EFN though flows during individual weeks dropped below the EFN at times and near critical flows on occasion (Figure B16-1, Appendix B16). Meeting EFNs for Kokanee spawning is thus considered possible but requires careful management of releases and withdrawals.

3.17 Penticton Creek

Penticton Creek flows from the east side of the Okanagan Basin into Okanagan Lake just upstream and east of the Okanagan Lake outlet dam at Penticton, B.C. The Penticton Creek watershed is approximately 180 km^2 and has a number of main tributaries including James, Reed, Municipal, Harris, and Steward Creeks (Associated 2016). From its headwaters, Penticton Creek flows through a deeply incised canyon and onto an alluvial fan at the City of Penticton (Associated 2017). A summary of creek characteristics is found in Table 3-51 and additional stream-specific data is provided in Appendix B17.

Historically, Penticton Creek supported a large run of Kokanee; however, channelization for flood control purposes in the 1950s essentially eliminated the run (Pearson 1977). The lower reaches within the city of Penticton were partially lined in concrete and 39 drop structures were installed to reduce the gradient. As a result, Penticton Creek is highly impaired in terms of fish habitat (Lukey & Louie 2015; Mould 2017). The channelization of Penticton Creek combined with the concrete substrate installed in the 1950s has led to considerable increases in water velocities that also prove to be migration barriers for fish. The largest barrier to fish migration is located 4.46 km from the mouth at "Penticton Dam #2" with a number of partial barriers existing downstream along with a series of fish ladders for mitigation. A recent effort to restore Penticton Creek has resulted in a detailed restoration plan for the lower reaches (Mould 2017) and restoration of a short demonstration section in 2015.

The creek has had support for populations of Kokanee in the form of several constructed spawning beds but there are no longer annual Kokanee fry releases (Askey pers. comm. 2019). Juvenile Rainbow have also been observed in the lower reaches and the stream is available to adfluvial Rainbow spawning, though the habitat is drastically impaired. Stream temperature data is not available for the lower reaches of Penticton Creek; however, water temperature was taken during field discharge surveys by ONA on August 30, 2016, which showed an average water temperature of 17.3°C.

Penticton Creek has a long history of supplying water for the City of Penticton. At present, there are 35 points of diversion within the watershed (Associated 2019); however, the actual volume extracted is unknown. The stream is currently fully recorded (FLNRORD 2016). The City of Penticton is the main water supplier, and has developed water storage at Greyback Reservoir (Associated 2016). They release a minimum of 0.230 m^3/s at the water treatment plant throughout the year to limit sedimentation at their intake (Lejbak 2019). Penticton Creek is not 'flow sensitive' during summer or winter under residual flows but would be under naturalized flows (Table 3-52). No field measurements were available to estimate groundwater gains or losses on the alluvial fan and they are therefore unknown.

Due to the highly modified nature of the lower reaches of Penticton Creek, it is not suitable for conventional flow estimation procedures (Shepherd & Ptolemy 1999). Nonetheless, Okanagan Tennant EFNs for Penticton Creek are provided with the exception that residual flows were used in place of naturalized flows as the altered channel requires much higher flows to maintain fish habitat. Naturalized and residual flows were provided by Associated (2019) with an estimated data quality rating of B (data error between 10% and 25%); maximum licensed flows were not available at the time of reporting. Naturalized summer low flow estimates for Penticton Creek were lower than expected for the stream size. No WUW data were collected. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. A summary of EFNs for Penticton Creek is provided in Table 3-53 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-36, Figure 3-37 and Appendix B17 and flow sensitivities in Table 3-52. Further information on EFN setting in Penticton Creek is provided at the end of this section.

Table 3-51: Penticton Creek description

Drainage Area	180 km^2
Median Elevation	1282 m
WSC station	08NM240 (active) Two Forty Creek near Penticton (1983-present) 08NM241 (active) Two Forty-One Creek near Penticton (1983-Present) 08NM242 (active) Dennis Creek near 1780 Meter Contour (1985-present) 08NM169 (historic) Greyback Lake at the Outlet (1970-1987) 08NM168 (historic) Penticton Creek Above Dennis Creek (1970-1999) 08NM068 (historic) Howard Creek near Penticton (1930-1930) 08NM069 (historic) Reed Creek near Penticton (1930-1930) 08NM170 Penticton Creek Below Harris Creek (1970-1981) 08NM063 (historic) Penticton Creek Lot 19 Diversion (1926-1954) 08NM076 (historic) Penticton Creek Above Diversion (1936-1941) 08NM032 (historic) Penticton Creek main Diversion (1919-1966) 08NM031 (historic) Penticton Creek Below Diversion (1919-1921) 08NM118 (historic) Penticton Creek at the Mouth (1950-1972)
Other hydrometric stations	Penticton Creek at Nanaimo Ave (2001-2016)
LTMAD	1.159 m^3/s (Associated 2019)
Fish species expected	Rainbow, Kokanee, Eastern Brook Trout, Longnose Dace (ESSA & Solander 2009)
Land use	Forestry in upper watershed, agriculture and urban development in lower watershed (Associated 2016)

Table 3-52: Flow sensitivities in Penticton Creek based on naturalized flow

Species & life stage	1-in-2 yr 30-day summer low flow		1-in-2 yr 30-day winter low flow	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
Rainbow rearing	0.104	9%		
Insect production				
Kokanee spawning				
Rainbow overwintering			0.086	7%
Kokanee egg incubation				

Source: Associated (2019)

Table 3-53: EFN summary table for Penticton Creek based on residual flows

Species & life stage	Time period	Okanagan Tennant Recommended EFN				Critical flow	
		Median (m^3/s)	% LTMAD	Min (m^3/s)	Max (m^3/s)	Flow (m^3/s)	% LTMAD
Rainbow rearing & insect production [a]	April 1 – Oct 31	0.497	43%	0.369	0.733	0.058	5%
Rainbow spawning	May 20 – Jul 10	1.63	142%	0.864	5.20	0.576	50%
Kokanee spawning	Sep 6 – Oct 7	0.417	36%	0.369	0.486	0.115	10%
Rainbow overwintering	Nov 1 – Mar 31	0.373	32%	0.331	0.526	0.058	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

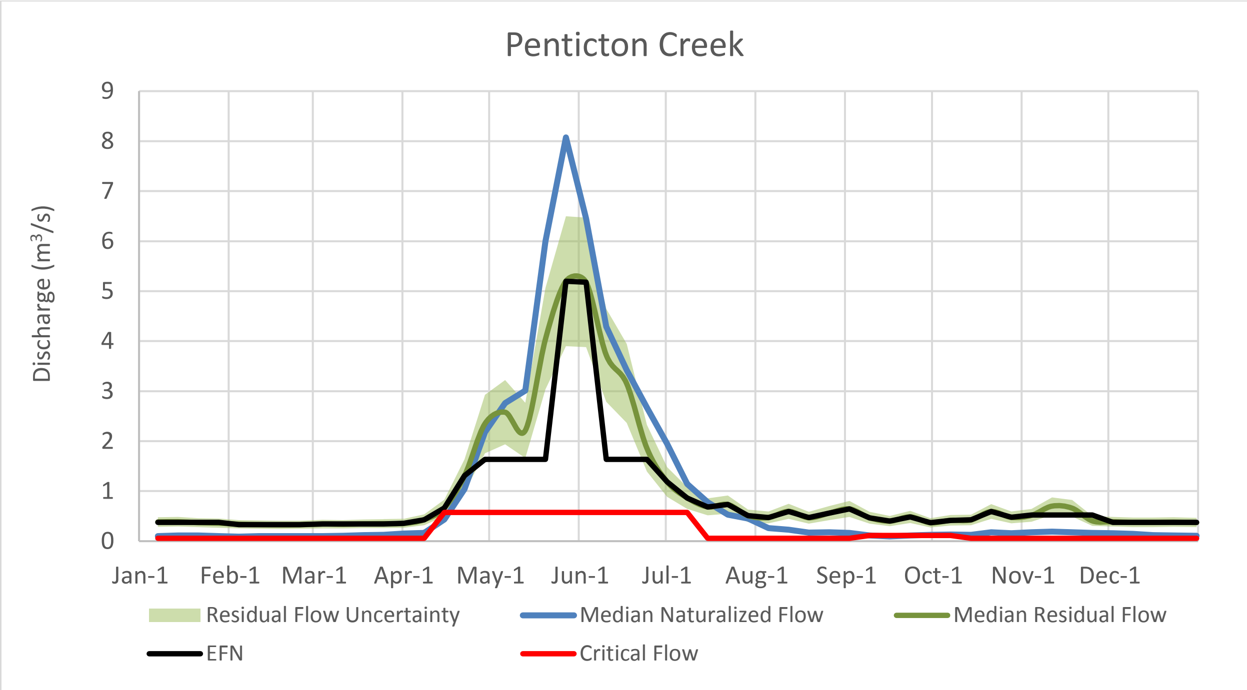


Figure 3-36: Weekly EFNs, critical flow and streamflows in Penticton Creek

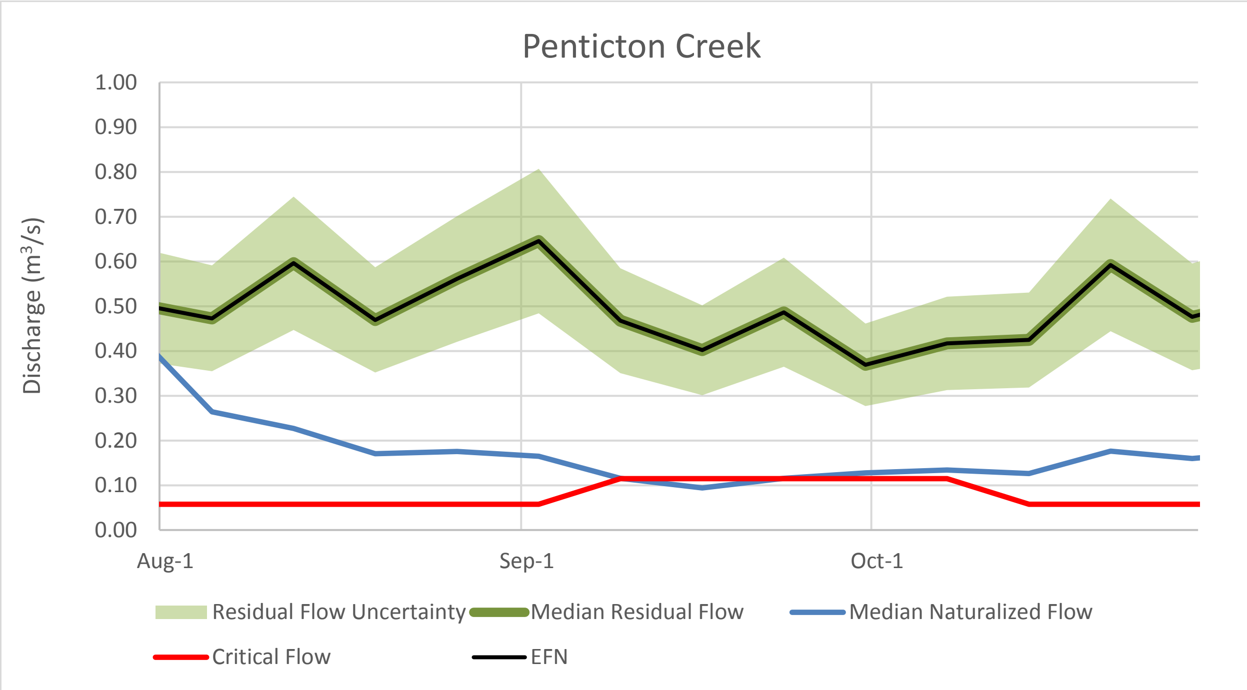


Figure 3-37: Weekly EFNs, critical flow and streamflows during the summer and fall period in Penticton Creek

Rainbow parr rearing

The median recommended Okanagan Tennant EFN for summer Rainbow rearing is 0.497 m^3/s (43% LTMAD, Table 3-53) which is equal to the median residual flows during the mid-July to late September period (Figure 3-37). While the minimum flow releases from the City of Penticton of 0.230 m^3/s are equal to the 20% LTMAD flow standard that would typically constitute the Okanagan Tennant EFN, limited information on current habitat conditions in the lower reaches presented in Mould (2017) suggests that water depths (0.06 m) at this flow rate are poorly suited for Rainbow parr rearing. Therefore, the EFN recommended here is equal to the median estimated residual flows (Associated 2019), which are higher than the minimum flow release throughout the year. Field verification of the EFN is recommended. The restoration plan (Mould 2017) is designed to provide suitable habitat conditions at the minimum flow of 0.23 m^3/s; therefore, EFNs should be reviewed periodically and adjusted based on measured habitat conditions as sections of the creek are restored. Previous EFNs set BCIFN thresholds (minimum risk) between ~0.6 m^3/s and ~1.3 m^3/s (ESSA & Solander 2009). The recommended critical flow for Rainbow parr rearing is 0.058 m^3/s (5% LTMAD) based on the LTMAD criterion (Table 2-7).

Median residual flows recorded at the WSC hydrometric station 08NM118 (Penticton Creek at the Mouth, 1950-1972; Figure B17-1, Appendix B17) were well below the recommended EFN from late June for the remainder of the summer and fall, and fell below the critical flow during mid-summer. Flows further upstream were substantially greater, indicating that water management was leading to the low flows recorded near the mouth (Figure B17-1, Appendix B17). More recent data from the City of Penticton station near the mouth (2001-2016) shows median weekly summer flows slightly below the recommended EFN but much higher than historically observed (Figure B17-1, Appendix B17). Meeting EFNs for Rainbow rearing near the mouth is thus considered possible but requires careful management of releases and withdrawals.

Rainbow spawning

The recommended Okanagan Tennant EFN for Rainbow spawning is 1.63 m^3/s, which is equal to the flow standard of 141% LTMAD (Table 3-53). Estimated residual flows (Figure 3-36) are above the recommended EFN for most of the spawning period. Limited information on current habitat conditions in the lower reaches presented in Mould (2017) suggests that flows of at least 2 m^3/s are required to maintain suitable spawning conditions. Future restored sections will be designed to provide suitable habitat conditions for Rainbow spawning at approximately 1 m^3/s (Mould 2017); therefore, EFNs should be reviewed periodically and adjusted based on measured habitat conditions as sections of the creek are restored. A previous EFN recommendation by ESSA & Solander (2009) was approximately 1.4 m^3/s. The recommended critical flow for Rainbow spawning is 0.576 m^3/s (50% LTMAD) based on the LTMAD criterion (Table 2-7).

Historically, median residual flows recorded at the WSC hydrometric stations were above the EFN from mid-April to late July (Figure B17-1, Appendix B17). More recent data from the City of Penticton station near the mouth (2001-2016) shows median weekly flows above the EFN from early May to mid-June (Figure B17-1, Appendix B17).

Kokanee spawning

The recommended Okanagan Tennant EFN for Kokanee spawning is 0.417 m^3/s (36% LTMAD), which is equal to the median residual flows during the Kokanee spawning period (Table 3-53). Limited information on current habitat conditions in the lower reaches presented in Mould (2017) suggests that water depths (0.06 m) at the minimum flow release of 0.230 m^3/s are poorly suited for Kokanee spawning and a minimum of 0.5 m^3/s is required to provide sufficient depth. Field verification of the EFN is recommended. Future restored sections will be designed to provide suitable habitat conditions for Kokanee spawning at approximately the minimum flow release (Mould 2017); therefore, EFNs should be reviewed periodically and adjusted based on measured habitat conditions as sections of the creek are restored. Historical EFN recommendations for Kokanee are 0.7-1.132 m^3/s (ESSA & Solander 2009; Shepherd & Ptolemy 1999; Shepherd 1993), with minimum flow recommendations between 0.32 m^3/s (Mould 2002) and 0.556 m^3/s (Shepherd & Ptolemy 1999). The recommended critical flow for Kokanee spawning is 0.115 m^3/s (10% LTMAD) based on the LTMAD criterion (Table 2-7).

Median residual flows recorded at the WSC hydrometric station 08NM118 (Penticton Creek at the Mouth, 1950-1972; Figure B17-1, Appendix B17) were well below the recommended EFN during the Kokanee spawning period. More recent data from the City of Penticton station near the mouth (2001-2016) shows median weekly flows at the recommended EFN (Figure B17-1, Appendix B17). Meeting EFNs for Kokanee spawning is thus considered possible but requires careful management of releases and withdrawals.

3.18 McLean Creek

McLean Creek flows from the east side of the Okanagan Basin into Skaha Lake just north of the town of Okanagan Falls, B.C. It is the only significant tributary to Skaha Lake other than the Okanagan River (Matthews & Bull 2003). From the headwaters McLean Creek flows through an agricultural plateau for approximately 2 km before discharging into Skaha Lake (Associated 2016). The McLean Creek watershed has an area of approximately 63 km^2 (Associated 2016). A summary of creek characteristics is found in Table 3-54 and additional stream-specific data is provided in Appendix B18.

The stream is known to support populations of fluvial and adfluvial Rainbow (Associated 2016) and dense areas of juvenile Rainbow rearing upstream of Eastside Road were observed during snorkel surveys (OBMEP 2017). The stream is also available to salmon species that include Kokanee, anadromous Steelhead, Sockeye, Chinook and Coho. The lowest permanent barrier to fish migration is a waterfall approximately 2.2 km from the mouth (OBMEP 2019). This represents the extent of anadromous salmon habitat.

The lowest reach of McLean Creek experiences a varying degree of riparian habitat impairment and hydro-modification. From the confluence with Skaha Lake upstream to Eastside Road, the creek has undergone significant riparian habitat impairment and hydro-modification. In this lowest section, banks have been armoured and yards are maintained right up to the creek. However, upstream of Eastside Road to the upstream fish migration barrier (2.2 km from the mouth) the riparian habitat is very good with minimal hydro-modification. In this upper section, the stream meanders well and there is a complex of riparian vegetation and large woody debris. A number of endangered wildlife species have been observed in this section.

McLean Creek contains some of the coolest summer water temperatures in the southern portion of the Canadian Okanagan basin. Water temperatures are generally within preferred ranges for salmonid life histories in summer months and generally remain lower than 20°C.

At present, there are 65 points of diversion and one pending water licence application within the watershed (Associated 2019); however, the actual volume extracted annually is unknown. FLNRORD (2016) registered a possible water shortage for McLean Creek in 1967. There is no main water user in the watershed and there is no developed water storage (Associated 2016). Upper reaches go dry immediately following freshet and there are a high number of withdrawals above the waterfall. McLean Creek has considerable groundwater inputs from wetland areas in the mid-elevation reaches that augment winter flows. Many of the water licences are above the wetland reach and the lower reaches have flow year-round. No field measurements were collected for this project and groundwater gains and losses across the alluvial fan are unknown. McLean Creek is naturally ‘flow sensitive’ during summer and winter as flows are below 20% LTMAD (Table 3-55).

Naturalized flows were provided by Associated (2019) with an estimated data quality rating of C (data error between 25% and 50%); residual and maximum licensed flows were not available at the time of reporting. Okanagan Tennant EFNs for McLean Creek were developed in accordance with the methods outlined in Section 2.2. No WUW data was collected. Fish periodicity and flow standards described in Table 2-2 to Table 2-6 were used. A summary of EFNs for McLean Creek is provided in Table 3-56 including the median EFN and the range of weekly EFNs, with weekly details in Figure 3-38, Figure 3-39 and Appendix B18, and flow sensitivities in Table 3-55. Further information on EFN setting in McLean Creek is provided at the end of this section.

Table 3-54: McLean Creek description

Drainage Area	63.2 km^2
Median Elevation	1243 m
WSC station	08NM005 (historic) Mclean Creek near OK Falls (1921-1926)
LTMAD	0.167 m^3/s (Associated 2019)
Fish species expected	Rainbow (Matthews & Bull 2003)
Land use	Agriculture

Table 3-55: Flow sensitivities in McLean Creek

Species & life stage	**1-in-2 yr 30-day summer low flow**		**1-in-2 yr 30-day winter low flow**	
	Flow (m^3/s)	% LTMAD	Flow (m^3/s)	% LTMAD
O. mykiss rearing	0.023	14%		
Insect production				
Kokanee spawning				
O. mykiss & Chinook overwintering			0.017	10%
Kokanee & Chinook egg incubation				

Source: Associated (2019)

Table 3-56: EFN summary table for McLean Creek

Species & life stage	**Time period**	**Okanagan Tennant Recommended EFN**				**Critical flow**	
		Median (m^3/s)	% LTMAD	Min (m^3/s)	Max (m^3/s)	Flow (m^3/s)	% LTMAD
O. Mykiss parr rearing & insect production [a]	April 1 – Oct 31	0.032	19%	0.021	0.125	0.008	5%
Steelhead spawning	April 1 – Jun 25	0.428	256%	0.035	0.980	0.084	50%
Rainbow spawning	May 20 – Jul 10	0.471	282%	0.180	0.980	0.084	50%
Kokanee spawning	Sep 1 – Oct 20	0.026	15%	0.021	0.033	0.017	10%
Salmonid overwintering	Nov 1 – Mar 31	0.021	13%	0.019	0.033	0.008	5%

a while EFNs apply to the entire period, median values are presented for the summer low flow period from Jul 15-Sept 30.

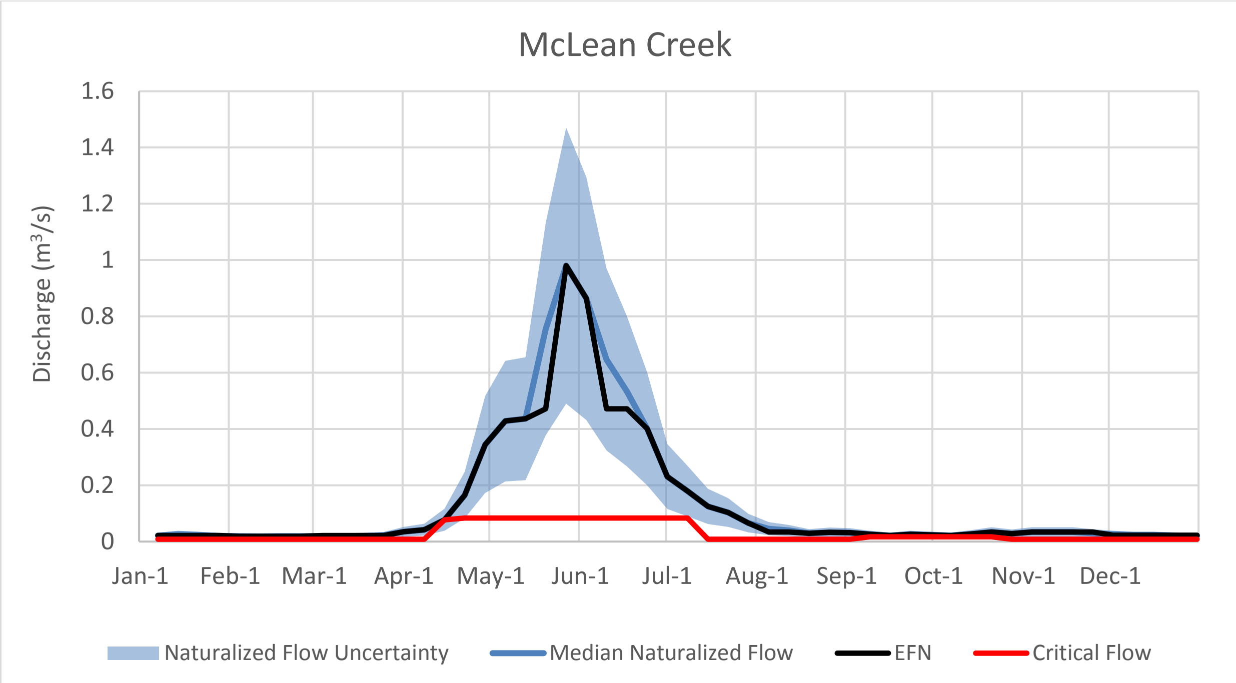


Figure 3-38: Weekly EFNs, critical flow and streamflows in McLean Creek

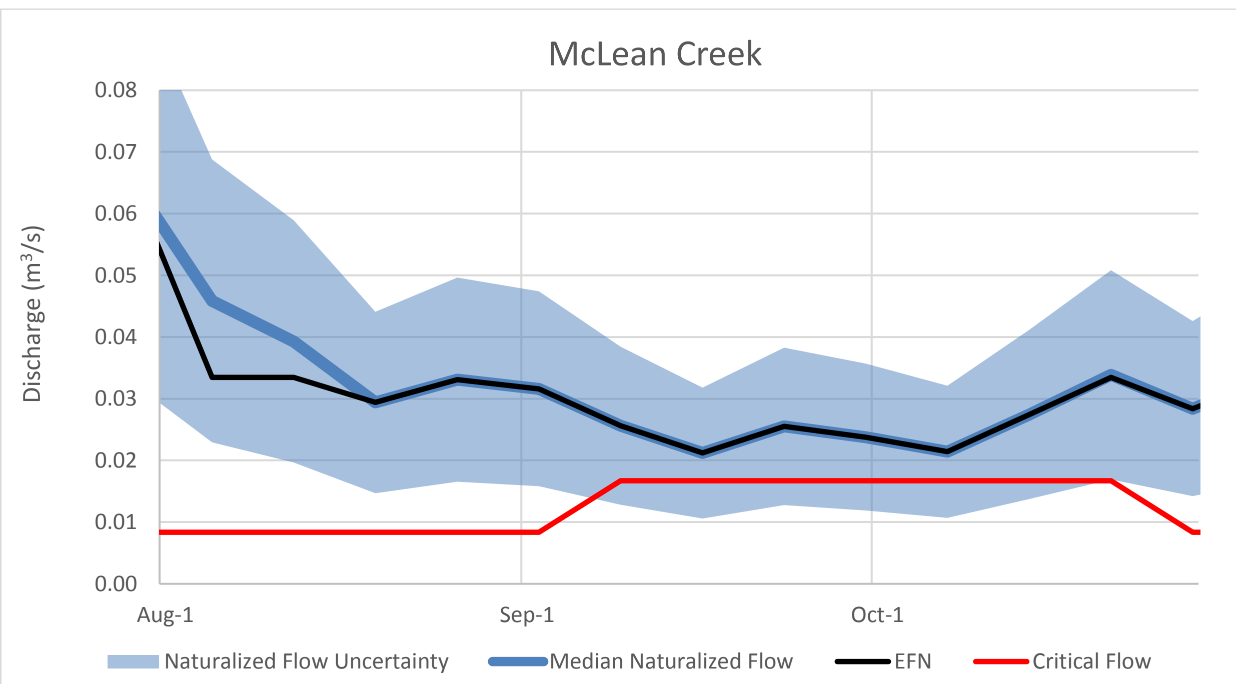


Figure 3-39: Weekly EFNs, critical flow and streamflows during the summer and fall period in McLean Creek

O. mykiss parr rearing

The recommended Okanagan Tennant EFN for Steelhead and Rainbow (*O. mykiss*) parr rearing is 0.032 m^3/s (19% LTMAD), which is equal to the median weekly naturalized flows during the mid-July to late September period (Table 3-56, Figure 3-39). The recommended critical flow for *O. mykiss* parr rearing is 0.008 m^3/s (5% LTMAD) based on the LTMAD criterion (Table 2-7). Historical recorded flows at the WSC hydrometric station 08NM005, which operated seasonally from 1921-1926, document flows much below the recommended EFN from early July onwards (Figure B18-1, Appendix B18). However, mapping by Associated (2017) indicates that the hydrometric station was located high in the watershed in the reaches above the wetland discharge and thus flows were likely lower than in the reaches at the mouth. No historical EFN recommendations have been made for McLean Creek

Steelhead spawning

The recommended Okanagan Tennant EFN for Steelhead spawning is 0.428 m^3/s (256% LTMAD), which is slightly lower than the flow standard of 282% LTMAD (Table 3-56) due lower naturalized flows in the beginning of the spawning period. The recommended critical flow for Steelhead spawning is 0.084 m^3/s (50% LTMAD) based on the LTMAD criterion (Table 2-7). Estimated naturalized flows are typically greater than the EFN during the later part of the spawning period from early May to late June (Figure 3-38). Median historical recorded flows at the WSC hydrometric station 08NM005 were above the recommended EFN during only a small portion of freshet (Figure B18-1, Appendix B18); however, mapping by Associated (2017) indicates that the station was located high in the watershed above several tributaries and thus likely experienced lower peak flows than reaches near the mouth.

Rainbow spawning

The recommended Okanagan Tennant EFN for Rainbow spawning is 0.471 m^3/s, which is equal to the flow standard of 282% LTMAD (Table 3-56). The recommended critical flow for Rainbow spawning is 0.084 m^3/s (50% LTMAD) based on the LTMAD criterion (Table 2-7). Estimated naturalized flows are typically greater during the spawning period from mid-May to late June (Figure 3-38). Median historical recorded flows at the WSC hydrometric station 08NM005 were at the recommended EFN during only a small portion of freshet (Figure B18-1, Appendix B18); however, mapping by Associated (2017) indicates that the station was located high in the watershed above several tributaries and thus likely experienced lower peak flows than reaches near the mouth.

Kokanee spawning

The recommended Okanagan Tennant EFN for Kokanee spawning is 0.026 m^3/s (15% LTMAD), which is equal to the median naturalized flows during the Kokanee spawning period (Table 3-56). The recommended critical flow for Kokanee spawning is 0.017 m^3/s (10% LTMAD) based on the LTMAD criterion (Table 2-7). It is likely that fall rain events play an important role for Kokanee access in McLean Creek. Median historical recorded flows at the WSC hydrometric station 08NM005 during early September were below the recommended EFN (~0.01 m^3/s) (Figure B18-1, Appendix B18); however, mapping by Associated (2017) indicates that the station was located high in the watershed in the reaches above the wetland discharge and thus flows were likely lower than in the reaches at the mouth.

4.0 SUMMARY AND RECOMMENDATIONS

EFNs were recommended for 18 Okanagan streams using the Okanagan Tennant method and for 10 of those streams, were further refined using the Okanagan WUW method (Associated 2016). These EFNs were developed through an extensive collaborative effort including experts and stakeholders, are robust and realistic in the context of naturally available flows, and are based on the best available information at this time. In addition, critical flows were recommended for all streams based on a proportion of the LTMAD or fish habitat data, where available. The process of applying the EFN setting methods recommended in the Phase I report (Associated 2016) to the 18 streams created a deeper understanding of each stream's distinct biological, hydrological, and physical characteristics as well as history of human use and modifications, and EFNs were developed under careful consideration of each.

This section provides a review and summary of applying the prescribed methods, recommendations for adjustments, as well as considerations for EFN implementation. Further, a summary of EFNs and critical flows is provided as well as a discussion on data quality and data needs. This section concludes with recommendations for EFN setting initiatives specific to the Okanagan and in general, and a description of next steps.

4.1 Review of EFN Setting Methods and Data Sources

Okanagan Tennant EFNs were to be calculated for each stream as the lower of the highest flow standard or the median naturalized weekly flow for a given time step. They were to be further refined using the WUW information collected in 10 of the streams. Okanagan Tennant EFNs and final recommended EFNs are presented for all 18 streams in Appendices B1-B18. The EFN setting procedure generally followed the methods outlined in the Phase I report (Associated 2016). Refinement of the methods following their application was anticipated in the Phase I report and several adjustments to the methods, as well as sources of uncertainty, are discussed below. Further, stream-specific information on EFN setting methods, uncertainties, considerations for EFN implementation and recommendations are made in Table 4-1.

- **Naturalized and Residual Flow Data.** The EFN setting approach prescribed by the Phase I report relies heavily on naturalized or natural streamflow data (from proxy streams) to recommend EFN flows that are naturally feasible. Naturalized and residual flows for the study streams were estimated by Associated (2019) both on a weekly and on an annual basis (LTMAD), representing the most comprehensive and current estimates generated to date. Despite the significant effort and expertise devoted recently, considerable uncertainty remains resulting from a lack of historic and current hydrologic data that form the basis of naturalized flow estimation. In particular, there are no active and few historical hydrometric stations that represent natural and unmanaged flows in lower elevation stream reaches that were of particular interest for EFN setting because they contain the greatest variety of fish species, show the greatest cumulative flow diversions, and experience the greatest water use pressures. As a result, naturalized flows were derived from relatively few "natural" hydrometric stations typically at higher elevations, which required extrapolation and scaling between different watersheds and elevations, and in time. Local conditions (e.g., channel modifications, surface water - groundwater interactions, water use) can be highly variable particularly in the lower stream reaches where most human settlement occurs, and generalization from one watershed to another can be difficult for this reason.

  Accurate water use information was required for residual flow estimation. However, the lack of water use and diversion monitoring required that the assessment rely upon water use estimates generated from the Okanagan Water Demand Model (OWDM) (for a detailed description of the model see Associated 2019). Note that the OWDM is a GIS-based model that estimates water use from climate information and land-use (e.g., crop types) and soil characteristics for inventoried areas. The model provides an estimate of water use in the absence of actual records. However, review of estimated water use for some watersheds made apparent that the model was not capturing large offstream diversions since the model only estimates water use based on an inventoried land-base alone. Thus, further investigation regarding water diversions and their impact on flows would be prudent to better understand the impact of current water use on streamflows and the ability to meet EFN flows. Stream-specific recommendations are made in Table 4-1.

Also, considerable uncertainty exists in the naturalized flows with estimated data errors in approximately half of the 18 EFN streams between 10% and 25%, and the other half between 25% and 50% due to limited watershed-specific flow information. Some residual flow datasets have error estimates greater than 50% due to the lack of available water management information. Many naturalized flow estimates, particularly for summer and early fall low flows that were often most constraining on EFNs, appeared relatively low in comparison to both long-term and recent streamflow data recorded at hydrometric stations. Consequently, the EFN setting approach considered naturalized flows in the context of other available data and other stream-specific information, rather than a definitive upper limit to EFNs. This approach is described in the Phase I report as incorporation of “expert judgement” and amounts to a weight of evidence approach. In most cases, EFNs fall within the uncertainty range of the naturalized flows.

- **Flow Augmentation.** Many streams in the Okanagan are heavily regulated via headwater reservoirs or diversion of flows from other watersheds. The main purpose is typically for water supply during the irrigation season; but in some cases regulation is intended to benefit fish. Regulation typically involves storage of a portion of the freshet flows and subsequent release during the irrigation season. In some watersheds, regulation has resulted in flow augmentation over naturalized flows during the summer and early fall low flow period. Flow augmentation in those creeks has occurred over many years and fish populations have adapted to and likely benefited from the augmented flows. Since flows are naturally limiting during this time, a reduction over present flow conditions would likely reduce available fish habitat and may lead to future losses in fish production. Therefore, in streams with a history of flow augmentation EFNs were constrained by the higher residual flows rather than naturalized flows (i.e., Equesis Creek, Naramata Creek, Penticton Creek, and Mission Creek).

- **Critical Flows.** The Okanagan WUW method assesses habitat changes between the critical flow and the Okanagan Tennant EFN to determine the risk of flows lower than the Okanagan Tennant EFN. Therefore, critical flows are needed for each species/life stage to complete the analysis. The Phase I report recommended the commonly used value of 5% LTMAD as a starting point and identified the possibility of using WUW data from the study riffles to estimate critical flows based on minimum passage depths. Thus, a critical flow setting method was added to the EFN setting procedure. Critical riffle analysis was completed for the 10 streams with WUW data. In the remaining streams, critical flows were set using %LTMAD-based criteria commonly used by FLNRORD.

  Some of the streams maintained relatively high flows throughout the duration of the study so there were no WUW measurements at critical flow levels. This required extrapolation of low flow WUW measurements beyond the range of observed data to estimate critical flows. Where extrapolation was deemed too uncertain, the %LTMAD criteria were used instead. Where measurements existed reasonably close to critical conditions, extrapolations beyond the data range were made and results closely inspected for plausibility and consistency with other streams. Extrapolated critical flows deemed plausible over-ruled critical flows set using the %LTMAD criteria, due to the use of field-based information in the critical riffle analysis, which is superior to office-based information. Extrapolation was not required for Rainbow or Chinook spawning, which require relatively high flows for riffle passage.

- **WUW Analysis.** WUW information proved very useful in many streams to inform EFN setting, in particular those that either had unusual flow patterns or heavily modified channels. The relationship between LTMAD and channel conditions (and consequently, fish habitat characteristics) that forms the basis of the Tennant approach to EFN setting holds true in general. Nevertheless, local variations in channel and flow conditions greatly influence fish habitat conditions and are much better characterized by WUW data. WUW was calculated in a standard approach using depth and velocity measurements at the study transects with species and lifestage-specific HSI curves. The curves were not Okanagan-specific but discussion among the project team concluded that they were reasonably applicable to local streams. Two refinements were undertaken:

    - No HSI curve for Sockeye spawning was initially supplied and none were readily available from the literature. As a result, an Okanagan-specific HSI curve for Sockeye spawning was created from habitat data collected at Sockeye redds in the Okanagan River. The river is larger than all streams included in this study and it was not clear if resulting HSIs would be applicable in smaller streams with inherently shallower water depths. Resulting WUW curves, however, appeared reasonable at naturally available flows in the study streams and the project team supported using the Sockeye HSI curve for Okanagan EFN development.

    - The originally-provided Chinook spawning HSI curve for summer Chinook, who spawn in large river mainstems, was not considered representative of habitat preferences for the smaller-bodied spring Chinook that spawn in the study streams. Spawning HSI curves from the Nicola River were used instead to reflect the smaller body size of Okanagan spring Chinook and the small stream size of the study streams. However, the Nicola River is still larger than all of the study streams and it became evident during analysis that the curves may not be applicable to the smaller tributaries included in this study because estimated WUWs often appeared very low at naturalized flows. While there is uncertainty in the naturalized flow estimates, it is recommended to construct a spring Chinook spawning HSI curve for small streams to better characterize the habitat-flow relationship of local populations.

Since average WUW curves were created from combined transect data for a given stream, there was considerable scatter in some of the WUW curves. Standardizing WUW data between transects by scaling the WUW relative to the peak of the curve was useful because it communicates the relative decline in habitat with flows. Further, it greatly reduced scatter in the transect data caused by different transect widths, and many of the resulting curves fit to standardized WUWs have relatively narrow error bands. Higher uncertainty existed in WUW curves for streams with a low number of field observations, highly variable habitat conditions between transects, or multi-year observations. Multi-year WUW data is rarely consistent between years due to channel changes during high freshet flows and we recommend focusing data collection over one season (spring freshet flows to fall low flows). However, while individual WUW transect geometry may change annually, the fundamental channel morphology in a given reach will rarely change. Selecting WUW transects with average channel conditions (e.g., width, depth) ensures that WUW-flow curves will remain representative of the channel in future seasons as long as there are no significant changes in dominant morphology characteristics.

Some streams maintained relatively high flows throughout the study period (e.g., Coldstream and Equesis creeks) and as a result, the lower end of the WUW curves in the flow range of interest for EFN setting was poorly defined. Those cases required extrapolation beyond the observed data range to characterize the decline in WUW at low flows. Due to the greater uncertainty, EFNs were set conservatively near the lowest observed data points where possible, under consideration of Okanagan Tennant EFNs and naturalized flows.

Upon review of WUW curves in relation to naturalized flows and critical flows, it was found that calculation of the WUW Index as described in the Phase I report was not particularly informative for EFN setting in some cases. Frequently, the critical flow (Index 0) and the Okanagan Tennant EFN (Index 1) were very close together, in particular for summer and fall periods with low flows. The difference in WUWs between the two points was sometimes very small (e.g., 5-10% WUW) and it was considered more informative to review the absolute change in WUW than to produce a scaled index over such a small WUW range. WUWs had already been scaled relative to their peak to standardize between transects, resulting in relative WUWs between 0% and 100%, which made it easy to assess relative changes between two points on the curve. Nonetheless, the WUW Index is useful for comparison of impacts between naturalized, residual and maximum licensed hydrographs. Residual and maximum licensed datasets are not yet available for all streams and the WUW Index percentile plots, as described in the Phase I report, should be prepared when all datasets are complete. An example of the WUW Index for McDougall Creek Rainbow spawning is provided in (Figure 4-1).

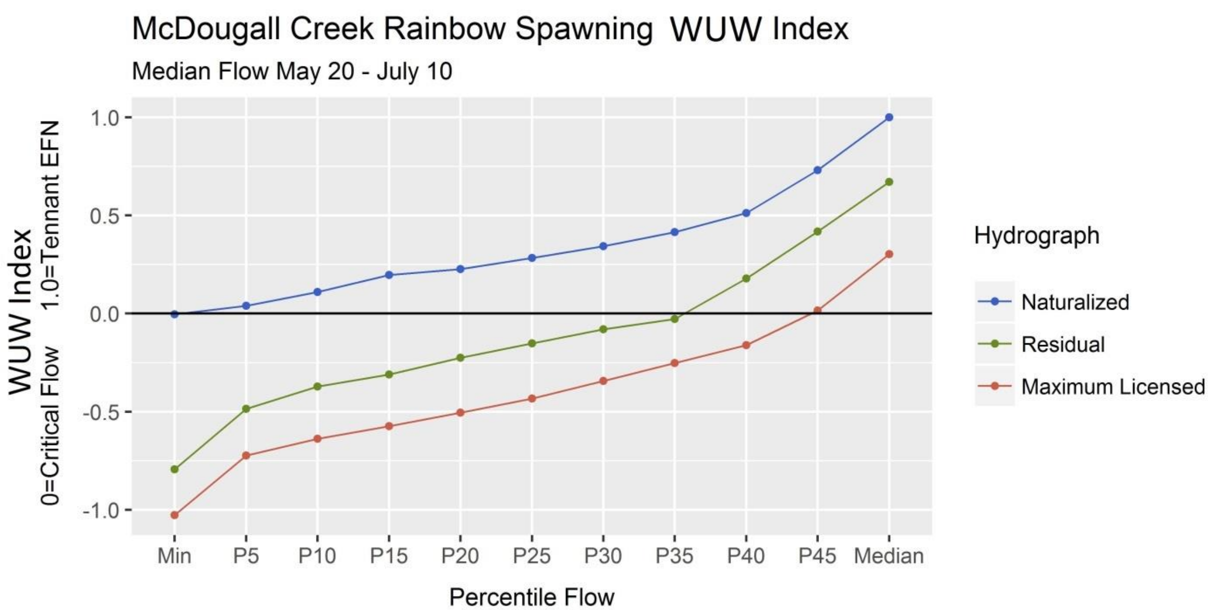


Figure 4-1: WUW Index Plot of Rainbow spawning in McDougall Creek

- **SEFA Analysis.** SEFA modeling was trialed in Coldstream Creek to determine if it could provide the necessary information on habitat-flow relationships to support EFN setting. Further, it was assessed whether SEFA could fill gaps in the data due to a lack of low flow measurements, which complicated critical riffle analysis and critical flow recommendations (Section 3.1.1). SEFA modelling was completed for Rainbow rearing and Kokanee spawning by FLNRORD (Appendix C). The modelled parameters differed slightly between SEFA and WUW analysis: for parr rearing EFNs, SEFA only utilized information on invertebrate production whereas WUW analysis also used parr rearing HSIs. Critical flow analysis used the same parameters between the two modelling approaches. SEFA produced similar, though not identical, information on the habitat-flow relationships as the WUW analysis. SEFA predicted a slightly more rapid decline in insect production with dropping flows. Similarly, Kokanee spawning WUW peaked at higher flows and declined slightly more rapidly than the curve produced by the WUW analysis; however, differences in the lower flow range that EFNs would actually be focused on were very small. Overall, EFN recommendations resulting from the two analytical approaches would have been similar in this case. SEFA modelling produced similar critical flows for Rainbow rearing but higher critical flows for Kokanee spawning. Application of the SEFA model is most useful where field surveys can be obtained over the full range of flows (low, moderate, and high) but where resource constraints prevent the number of field visits typically required for full WUW analysis (8-10). The utility of SEFA to fill data gaps beyond the range of measured observations could be re-assessed for a dataset with low flow data that allows for validation of predicted EFN and critical flows, though extrapolation beyond the range of measured data is generally fraught with high degrees of uncertainty.

- **Benthic Macroinvertebrate Monitoring.** Through the Environment and Climate Change Canada Okanagan Ecosystem Initiative, the ONA trialed a parallel project to assess biological indicators in relation to streamflow conditions and collect stream habitat attributes that could be integrated into fish habitat capacity modeling (Enns et al. 2020). Biological indicators included benthic macroinvertebrate community sampling, which was analyzed under the framework set out in the EFN methods, specifically using %LTMAD and the Okanagan Tennant Model. Results showed that the magnitude of low flows (expressed as %LTMAD) were a significant predictor of Ephemeroptera, Plecoptera, and Tricoptera richness (EPT Richness; taxa richness of mayflies, stoneflies, and caddisflies per sample), which are important prey for juvenile salmonids. For the stream reaches assessed, hydromodification and riparian function were also significant predictors of EPT Richness. These methods could be developed further to monitor the effectiveness of stream management decisions as benthic macroinvertebrate sampling is much less expensive than other methods and does not rely on intrusive sampling of juvenile salmonids.

Table 4-1: Summary of EFN setting approach, uncertainties and data needs by stream

Stream	EFN setting approach	Uncertainties	Considerations for EFN implementation	Recommendations
Coldstream	• Kokanee spawning and Rainbow rearing: used WUW data to adjust EFNs upwards from Okanagan Tennant EFNs because naturalized flows are much greater than flow standards and WUW declines rapidly; critical flows based on %LTMAD and reflecting naturally high baseflows • Rainbow spawning: set EFN just below Okanagan Tennant EFN; critical flows based on riffle analysis	• Lack of low flow WUW data. Greater uncertainty in low end of WUW curve for Kokanee spawning and Rainbow rearing. EFNs were set conservatively just below the lowest WUW measurement but well below naturalized flows and residual flows	• Significant groundwater contributions produce higher baseflows than most other streams; however, the water balance completed for this EFN did not consider withdrawals from hydraulically connected aquifers. The demands from this and other wells could be considered in future water balance work • EFNs and critical flows are relatively attainable due to comparatively high naturalized and residual flows • Large amount of high quality fish habitat remains due to low degree of channel modifications • Highly important Kokanee stream	• Collect low flow WUW data from riffle transects to confirm critical flow recommendations • Obtain residual and maximum licensed flow data estimates • Continue operating the hydrometric station near McClounie Road and upgrade to real-time to provide flow information in high quality fish habitats • Consider protecting available water resources and fish habitat
Equesis	• Kokanee spawning and Rainbow rearing: used WUW data to adjust EFNs upwards from Okanagan Tennant EFNs because of long-term flow augmentation from Pinaus Lake; critical flows set based on %LTMAD • Rainbow spawning: set EFN at Okanagan Tennant EFN; critical flows based on riffle analysis	• Naturalized LTMAD and summer low flow estimates were considered low • Lack of low flow WUW data. Greater uncertainty in low end of WUW curve for Kokanee spawning and Rainbow rearing. EFNs were set conservatively just below the lowest WUW measurement, greater than naturalized flows but no greater than residual flows	• EFNs and critical flows are relatively attainable due to flow augmentation from Pinaus Lake • Relatively large amount of high quality fish habitat remains • Highly important Kokanee stream • Stream would be dry from late July to mid-September if licensed withdrawal and storage volumes were maximized	• Collect low flow WUW data from riffle transects to confirm critical flow recommendations • Continue operating the hydrometric station near Westside Road • Confirm OKIB reservoir management to ensure it is consistent with previous management and/or assumptions included in Associated (2019) • Develop an operating plan for Pinaus Lake to meet EFN and water use needs • Monitor ditch diversions upstream and downstream of Westbank Road
Naswhito	• Kokanee spawning and Rainbow rearing: used WUW data to adjust EFNs upwards from Okanagan Tennant EFNs because: (1) naturalized flow estimates that confined the Okanagan Tennant EFN were low compared to measured flows (2) WUW at	• Lack of historical hydrometric records • Naturalized flow estimates for the summer and fall period were considered uncertain because they are lower than those recorded by the hydrometric station from 2016-2018.	• High quality fish habitat remains • August flows fall below the Rainbow rearing EFN sometimes • September flows fall below Kokanee spawning EFNs in some years • Actual water use is uncertain and individual points of diversion may have a large cumulative impact on streamflows	• Continue operating the hydrometric station near the mouth to reduce uncertainty regarding residual and naturalized flows at the mouth • Identify large points of diversion and determine their cumulative impact on flows

Stream	EFN setting approach	Uncertainties	Considerations for EFN implementation	Recommendations
	naturalized flows was extremely low; • Kokanee critical flows based on median naturalized flows and riffle analysis • Rainbow rearing critical flows based on riffle analysis • Rainbow spawning: set EFN at Okanagan Tennant EFN; critical flows based on riffle analysis	• Residual flow estimates may underestimate the magnitude of large diversions observed during field visits	• Stream would be dry from early August to mid-September if licensed withdrawals were maximized • Migratory access for Kokanee spawners is susceptible to riffle passage constraints. Maintenance of critical flows during the spawning period is crucial to spawning success. Fall rain events likely play an important role in providing spawner access.	• Explore streamflow restoration opportunities. This creek is a prime candidate because of: (1) rapidly increasing WUW for Kokanee spawning and Rainbow rearing with small increases in flow, (2) large diversions observed, (3) frequent failure to meet EFNs in August and September
Whiteman	• Kokanee spawning and Rainbow rearing set to Okanagan Tennant EFNs • Kokanee critical flows based on %LTMAD • Rainbow rearing critical flows based on riffle analysis • Rainbow spawning: set EFN slightly below Okanagan Tennant EFN; critical flows based on riffle analysis	• lack of recent hydrometric records from the mouth • Residual flow estimates indicate near zero water withdrawal but this needs confirming through field surveys	• High quality fish habitat remains • Low fall flows are a known problem during the Kokanee spawning season and EFNs may not be met during some years. • Migratory access for Kokanee spawners is susceptible to riffle passage constraints. Maintenance of critical flows during the spawning period is crucial to spawning success. Fall rain events likely play an important role in providing spawner access. • High quality Rainbow rearing habitat is susceptible to naturally low flows during summer and fall. • Flows would be below the EFN throughout the summer and below critical flows during the Kokanee spawning period if licensed withdrawals were maximized.	• Continue operating the hydrometric station near the mouth to obtain more recent flow data in key Kokanee spawning habitats • Identify points of diversion and determine their impact on flows • Explore streamflow restoration opportunities. This creek is a prime candidate because of: (1) rapidly increasing WUW for Rainbow rearing with small increases in flow, (2) diversions observed, (3) frequent failure to meet EFNs in August and September
Mission	• Kokanee spawning and Rainbow rearing: used WUW data to adjust EFNs upwards from Okanagan Tennant EFNs because of long-term flow augmentation stipulated by Water Use Plan. Residual flows used for EFN setting. Critical flows based on riffle analysis. Passage conditions highly variable due to the wide range of channel modifications	• Channel conditions highly variable due to channelization • Moderate scatter in some WUW curves because of varying transect characteristics (i.e., lower gradient near the mouth to higher gradient near the canyon) • Some transects unsuitable for critical riffle analysis due to lack of measurements over the required range of flows	• Highly important Kokanee and adfluvial Rainbow stream • Habitat availability in the lower reaches impacted by channel modifications • EFNs and critical flows are relatively attainable due to extensive headwater storage • Water Use Plan implementation is lacking during some years • High water temperatures likely impair Rainbow rearing in the lower reaches	• Work with water managers to implement flow releases to meet EFNs • Continue operating the real-time hydrometric station near the mouth to monitor flows in key Kokanee spawning habitats • Re-establish real-time hydrometric station on Pearson Creek • Estimate maximum licensed flows

Stream	EFN setting approach	Uncertainties	Considerations for EFN implementation	Recommendations
	• Rainbow spawning: set EFN at Okanagan Tennant EFN; critical flows based on riffle analysis			• Develop safe ramping rates to provide protection to fish during adjustments in reservoir releases
McDougall	• Kokanee spawning and Rainbow rearing EFNs set to Okanagan Tennant EFNs • Kokanee critical flows based on %LTMAD • Rainbow rearing critical flows based on riffle analysis • Rainbow spawning EFNs set to Okanagan Tennant EFN; critical flows based on riffle analysis	• Lack of historical hydrometric records and lack of water management information • Complicated surface water-groundwater interactions including dry sections and extensive wetland areas • Naturalized flow estimates for the summer and fall period were considered uncertain because they were extremely low for the stream size • Residual flow estimates indicate flow augmentation which is highly unlikely given observed flow records. They likely underestimate the true magnitude of diversions	• No Kokanee population observed in recent history • Stream dewatering and Rainbow stranding was observed during field visits • Habitat quality impacted by channel modifications • High water temperatures likely impair Rainbow rearing in the lower reaches • Severely impacted by flow diversions and critically low flows are common • Low fall flows are a known problem and EFNs are not met during August and September in most years • Stream would be dry from late July to mid-September if licensed withdrawal and storage volumes were maximized	• Continue operating the hydrometric station near the mouth to obtain more recent flow data • Obtain information on the operation of Hayman Lake in the headwaters to meet downstream water use needs • Identify points of diversion and determine their impact on flows • Explore streamflow restoration opportunities. This creek is a prime candidate because of: (1) rapidly increasing WUW for Kokanee spawning and Rainbow rearing with small increases in flow, (2) numerous diversions observed, (3) frequent failure to meet EFNs in August and September
Lower Shingle	• Juvenile fish rearing, Rainbow spawning and Steelhead spawning EFNs set to Okanagan Tennant EFNs; critical flows based on riffle analysis • Chinook spawning EFNs set to naturalized flows (well below the Okanagan Tennant flow standard); critical flows also set to naturalized flows due to riffle passage concerns • Kokanee and Sockeye spawning EFNs set to Okanagan Tennant EFN; critical flows for Kokanee and Sockeye spawning set based on %LTMAD	• Limited recent and historical hydrometric records from the mouth • Naturalized flow estimates for the summer and fall period were low for stream size • Moderate scatter in the WUW curves for Kokanee spawning and juvenile fish rearing • Impact of water use on instream flows is not well known due to limited recent hydrometric data	• Juvenile fish rearing EFNs and critical flows were mostly met in years with recent hydrometric data near the mouth; historical records show flows much below EFNs • EFNs for Chinook spawning and particularly migration were not always met in recent years • Kokanee and Sockeye spawning EFNs were generally met in recent years • Habitat quality impacted by channel modifications • Water temperatures approach tolerance limits of juvenile fish and Chinook spawners • One of few Okanagan streams with documented use of spring Chinook	• Obtain residual and maximum licensed flow estimates • Continue operating the hydrometric station near the mouth to obtain more recent flow data • Determine the impact of water use on flows • Explore streamflow restoration opportunities. This creek is a prime candidate because of: (1) high flow needs for spring Chinook, (2) numerous diversions observed, (3) frequent failure to meet EFNs in July and August

Stream	EFN setting approach	Uncertainties	Considerations for EFN implementation	Recommendations
			• Flows above the EFN from July-October would greatly benefit all fish species in the creek in particular Chinook spawners	
Upper Shingle	• Juvenile fish rearing EFNs: used WUW data to adjust Okanagan Tennant EFN upward to naturalized flows because of very low WUW; critical flows based on riffle analysis • Rainbow spawning and Steelhead spawning EFNs: used WUW data to adjust Okanagan Tennant EFN upward to near naturalized flows providing near maximum WUW; critical flows based on riffle analysis • Chinook spawning EFNs set to naturalized flows which were well below the Okanagan Tennant flow standard; critical flows based on %LTMAD which is near naturalized flows	• Limited recent and historical hydrometric records • Moderate scatter in WUW curves for Chinook fry rearing • Extent of Chinook distribution in the system is unknown	• High quality fish habitat remains • Spring Chinook spawning is constrained by naturally low fall flows • Extensive water diversion results in dry streambed during some years and EFNs for juvenile fish rearing, Chinook migration and spawning are frequently not met • Water temperatures approach tolerance limits of juvenile fish and Chinook spawners • Flows greater than the EFN from July-October would greatly benefit all fish species in the creek through rapidly increasing WUW	• Obtain residual and maximum licensed flow estimates • Continue operating the hydrometric station in the Gabriel field to obtain more recent flow data • Determine the impact of water use on flows • Conduct surveys to determine the extent of Chinook distribution in Upper and Lower Shingle Creek • Explore streamflow restoration opportunities. This creek is a prime candidate because of: (1) high quality fish habitat, (2) observed incidents of dewatering from water diversion, (3) high flow needs for spring Chinook (4) frequent failure to meet EFNs from July-September
Shuttleworth	• Juvenile fish rearing EFNs set to Okanagan Tennant EFN; critical flows based on %LTMAD • Rainbow and Steelhead spawning EFNs set to Okanagan Tennant EFN; critical flows based on riffle analysis • Chinook spawning EFNs set to Okanagan Tennant EFN which is well below the Tennant flow standard; critical flows based on %LTMAD which is near naturalized flows • Sockeye spawning EFNs set to Okanagan Tennant EFN which is well below the Tennant flow	• Limited recent and historical hydrometric records • Moderate scatter in WUW curves for Chinook fry rearing • Summer naturalized low flow estimates were very low • Due to very limited information, residual flow estimates likely do not reflect the amount of observed water use at large-scale diversions in the lower reaches	• Medium quality fish habitat remains • Spring Chinook and Sockeye spawning is constrained by naturally low fall flows • Extensive water diversion results in dry streambed during many years and EFNs for juvenile fish rearing and fall spawning species are frequently not met. Juvenile Rainbow stranding observed during field visits. • Water temperatures exceed tolerance limits of juvenile fish and Chinook spawners • Flows greater than the EFN from July-October would greatly benefit all fish species in the creek through rapidly increasing WUW	• Continue operating the hydrometric station at Maple Street and install a station upstream of water diversion to obtain more recent flow data • Confirm groundwater- surface water interactions across the alluvial fan • Determine the impact of water use on flows and monitor withdrawals at large diversion • Explore streamflow restoration opportunities. This creek is a prime candidate because of: (1) quality fish habitat, (2) observed incidents of dewatering from water diversion, (3) high flow needs for spring

Stream	EFN setting approach	Uncertainties	Considerations for EFN implementation	Recommendations
	standard; critical flows based on %LTMAD which is near naturalized flows			Chinook (4) frequent failure to meet EFNs from July-September
Vaseux	• Juvenile fish rearing EFNs: used WUW data to adjust Okanagan Tennant EFN slightly downward from median naturalized flows; critical flows based on %LTMAD • Rainbow spawning and Steelhead spawning EFNs set to Okanagan Tennant EFNs; critical flows based on riffle analysis • Chinook spawning EFNs: used WUW data to adjust Okanagan Tennant EFN upward from median naturalized flows; critical flows based on %LTMAD • Sockeye spawning EFNs: used WUW data to adjust Okanagan Tennant EFN upward from median naturalized flows; critical flows based on %LTMAD	• Limited recent and historical hydrometric records near the mouth • Naturalized flow estimates for the summer and fall period were considered uncertain because they were extremely low • Residual flow estimates likely underestimate the magnitude of diversions	• EFNs for juvenile fish rearing, and Chinook and Sockeye spawning are rarely met due to stream dewatering most summers • One of few Okanagan streams with documented use of spring Chinook • Water temperatures exceed tolerance limits of juvenile fish and Chinook spawners • Re-establishment of summer and fall flows in the lower reaches is critical to recovery of fish populations • Flows greater than the EFN from July-October would greatly benefit all fish species in the creek and particularly Chinook spawners	• Continue operating the hydrometric station near the mouth and at the outlet of the canyon • Confirm groundwater - surface water interactions across the alluvial fan • Determine the impact of water use on flows and monitor withdrawals at the large diversions on the fan • Explore streamflow restoration opportunities. This creek is a prime candidate because of: (1) high quality fish habitat (2) observed major water diversions, (3) high flow needs for spring Chinook (4) frequent dry streambed and failure to meet EFNs from July-September • Explore potential for development of a Water Sustainability Plan (as defined under the WSA) • Conduct spawning ground surveys to confirm Sockeye and Chinook spawning activity
Inkaneep	• Juvenile fish rearing EFNs: used WUW data to adjust Okanagan Tennant EFN upward to naturalized flows because of very low WUWs; critical flows based on riffle analysis • Rainbow spawning and Steelhead spawning EFNs set to Okanagan Tennant EFN; critical flows based on riffle analysis • Chinook spawning EFNs set to naturalized flows which were greater than the Tennant flow	• LTMAD estimated is low due to the low freshet values compared to other watersheds of similar size, leading to very low Okanagan Tennant EFNs • Limited number of WUW measurements required modelling of WUW at intermediate flows	• EFNs for juvenile fish rearing and Chinook spawning are frequently not met • TEK indicates a historical use by spring Chinook • Water temperatures exceed tolerance limits of juvenile fish and Chinook spawners • Flows greater than the EFN from July-October would greatly benefit all fish species in the creek and particularly Chinook spawners	• Determine the impact of water use on flows • Explore streamflow restoration opportunities. This creek is a prime candidate because of: (1) high quality fish habitat, (2) high flow needs for spring Chinook (3) frequent very low flows and failure to meet EFNs from July-September

Stream	EFN setting approach	Uncertainties	Considerations for EFN implementation	Recommendations
	standard; critical flows also set to naturalized flows		• Stream would be dry from mid-July to mid-September if licensed withdrawal and storage volumes were maximized	
Shorts	• Rainbow rearing and Kokanee spawning EFNs: used WUW data from nearby Whiteman Creek and the literature to adjust Okanagan Tennant EFN upward from naturalized flows; critical flows based on %LTMAD • Rainbow spawning EFN set to Okanagan Tennant EFN; critical flows based on %LTMAD	• Naturalized flow estimates for the summer and fall period were quite low and residual flows estimated very little water use, which needs verification • Changing sediment deposition conditions on the alluvial fan near the mouth lead to extremely low flows during some years	• EFNs for Rainbow rearing and Kokanee spawning are frequently not met • Significant potential for Kokanee spawning if sufficient flows are maintained • Stream would be nearly dry from mid-August to mid-September if licensed withdrawals were maximized	• Continue operating the hydrometric station above Westside Road • Complete a thorough investigation of water diversion locations and use to verify estimates used for flow naturalization • Confirm groundwater - surface water interactions across the alluvial fan • Ground-truth the recommended EFNs by collecting field measurements at or near the recommended EFN • Explore streamflow restoration opportunities. This creek is a prime candidate because of: (1) high quality fish habitat, (2) frequent very low flows and failure to meet EFNs from July-September, (3) unknown impact of water diversion on the alluvial fan
Mill	• Rainbow rearing and Kokanee spawning EFNs: adjusted Okanagan Tennant EFNs upward to reflect naturally high baseflows; critical flows based on %LTMAD • Rainbow spawning EFN set to Okanagan Tennant EFN; critical flows based on %LTMAD	• Lack of recent hydrometric data	• Significant groundwater contributions support higher baseflows than most other streams • EFNs and critical flows are relatively attainable due to comparatively high naturalized and residual flows • High degree of flow regulation • Rainbow spawning EFN is not met during some years due to flow regulation during freshet • Stipulated conservation flows	• Obtain residual and maximum licensed flow estimates • Continue operating and/or install hydrometric stations along the Mill Creek valley floor to provide information on residual flows and groundwater contributions during low flows
Powers	• Rainbow rearing and spawning EFNs set to Okanagan Tennant	• Lack of recent hydrometric data from the mouth	• Significant potential for Kokanee spawning if sufficient flows are maintained	• Obtain residual and maximum licensed flow estimates

Stream	EFN setting approach	Uncertainties	Considerations for EFN implementation	Recommendations
	EFNs; critical flows based on %LTMAD • Kokanee spawning EFN: adjusted Okanagan Tennant EFNs upward to naturalized flows based on historical WUW data; critical flows based on %LTMAD	• Recent channel modification from sediment dredging in key spawning areas at the mouth	• EFNs for juvenile fish rearing and Kokanee spawning were usually met historically but not recently • Stipulated conservation flows • High degree of flow regulation	• Install a hydrometric station near the mouth to monitor residual flows • Conduct field visits to confirm recommended EFNs are appropriate in recently modified channel near the mouth • Improve flow management to meet conservation flows
Trepanier	• Rainbow rearing and spawning, and Kokanee spawning EFNs set to Okanagan Tennant EFNs; critical flows based on %LTMAD	• Lack of recent hydrometric data from the mouth	• History of not meeting EFNs for Rainbow rearing and Kokanee spawning as a result of water withdrawal	• Obtain residual and maximum licensed flow estimates • Install a hydrometric station near the mouth to monitor residual flows • Conduct field visits to confirm recommended EFNs • Explore streamflow restoration opportunities
Naramata	• Rainbow rearing and Kokanee spawning EFNs: adjusted Okanagan Tennant EFNs upward to residual flows; critical flows based on %LTMAD (Rainbow) and 50% of spawning flows (Kokanee) • Rainbow spawning EFN set to Okanagan Tennant EFN; critical flows based on %LTMAD	• Complete lack of historical and recent hydrometric data • Uncertainty over continued flow augmentation by the highline diversion from Robinson and Chute creeks (to be determined by FLNRORD) • Uncertainty over availability of winter flows for Kokanee incubation	• History of flow augmentation from adjacent watersheds • Past widening of channel for flood control • Kokanee population maintained solely through flow augmentation • Fish kills documented during low flow events	• Install a hydrometric station near the mouth • Monitor the highline diversion rates and document the actual diversion operation between Chute, Robinson and Naramata creeks • Collect WUW and flow data to refine Kokanee EFNs and critical flows if continued flow augmentation is to be pursued
Trout	• Rainbow rearing and spawning EFN set to Okanagan Tennant EFN; critical flows based on %LTMAD • Kokanee spawning EFN adjusted upward to median naturalized flows based on historical WUW information; critical flows based on %LTMAD	• Lack of recent hydrometric data from the mouth	• History of extremely low flows and not meeting EFNs for Rainbow rearing and Kokanee spawning as a result of water diversion • History of unnatural daily flow regime with large deviations from natural flow regime • Past channelization for flood control greatly reduced available habitat • Water Use Plan stipulates conservation flows	• Obtain residual and maximum licensed flow estimates • Install a hydrometric station near the mouth • Explore streamflow restoration opportunities

Stream	EFN setting approach	Uncertainties	Considerations for EFN implementation	Recommendations
Penticton	• Rainbow rearing and Kokanee spawning EFNs: adjusted Okanagan Tennant EFNs upward to residual flows; critical flows based on %LTMAD • Rainbow spawning EFN set to Okanagan Tennant EFN; critical flows based on %LTMAD	• Naturalized summer low flow estimates were lower than expected • Critical flows highly uncertain due to lack of WUW measurements and heavy channelization	• Past channelization for flood control greatly reduced available habitat; restoration efforts underway • Higher EFNs required due to low-flow channel widening • High degree of flow regulation • Early and mid-summer EFNs not met in recent years • Minimum flow releases for water utility infrastructure maintenance	• Obtain maximum licensed flow estimates • Collect WUW and flow data to confirm EFNs and determine critical flows • Review EFNs periodically as habitat restoration projects are implemented
McLean	• Juvenile fish rearing, Steelhead, Rainbow and Kokanee spawning EFNs set to Okanagan Tennant EFNs; critical flows based on %LTMAD	• General lack of hydrometric data	• High quality fish habitat remains and high density of rearing *O. mykiss* observed • Cool water temperatures indicate groundwater influence	• Obtain residual and maximum licensed flow estimates • Install hydrometric station to monitor flows near the mouth • Conduct streamflow monitoring to investigate the influence of groundwater on baseflows

4.2 Summary of recommended EFNs and Critical Flows

This section provides a summary of the EFN and critical flow recommendations as well as comments on general patterns observed. Recommended EFNs for the study creeks are provided in Table 4-2 and critical flows and flow sensitivities are provided in Table 4-3. Climate change will affect both the timing and magnitude of hydrographs and stream temperatures and the EFNs and critical flows in this report apply only to current climate conditions. They should be reviewed periodically in the future and adjusted, if warranted, to reflect changing climate conditions and any other stream changes or new information.

Okanagan streams are characterized by snowmelt-driven hydrographs with a large freshet peak in the spring and early summer and comparatively low flows during the remainder of the year. As a result, flows are most limiting to fish populations in the summer, fall and winter periods. The following general observations were made:

- Naturally available streamflows during freshet are generally sufficient to produce optimum conditions for **Rainbow** and **Steelhead** that spawn during the spring freshet. Okanagan Tennant EFNs were mostly set at the presumptive flow standards and were rarely constrained by naturally lower flows, except for some smaller streams. Okanagan Tennant flow standards typically produced near optimum WUWs and as a result, final recommended EFNs were not further adjusted. Water use during this time is usually relatively low and residual streamflows typically meet EFNs and critical migration flows in most years. However, caution is advised in heavily regulated systems with large storage capacity to ensure that water storage does not reduce streamflows below spawning EFNs. Where residual flows were available they did not indicate substantial infringement by water storage activities on springtime EFNs except in one stream (Mill Creek); however, residual flows or flow estimates were unavailable for approximately 40% of the streams, some known to be heavily regulated. While some hydrometric records exist from these systems and are discussed in the body of this report, residual flow estimates will provide a better understanding of any negative impacts that water storage has on Rainbow and Steelhead spawning EFN flows in these systems. Water regulation activities during freshet should ensure that a relatively natural flow pattern is maintained with appropriate timing of high flows as specified by the recommended EFNs, and that abrupt changes in flow are strictly avoided.

  Critical riffle analysis indicates that safe riffle passage ($\geq$25% of transect with depths $\geq$0.18 m) for Rainbow and Steelhead spawners would be achieved between 18% and 129% LTMAD and the %LTMAD required declines with increasing stream size (Figure 4-2). The relationship is similar to that of the large-bodied salmonid flow standard calculation used for Okanagan Tennant flow standards (Ptolemy & Lewis 2002; Section 2.2.2. and Table 2-5), which incorporated documented fish movement data (Ptolemy pers. comm.). Critical flows for Rainbow and Steelhead spawners are usually met in the study streams due to naturally high freshet flows during their spawning period.

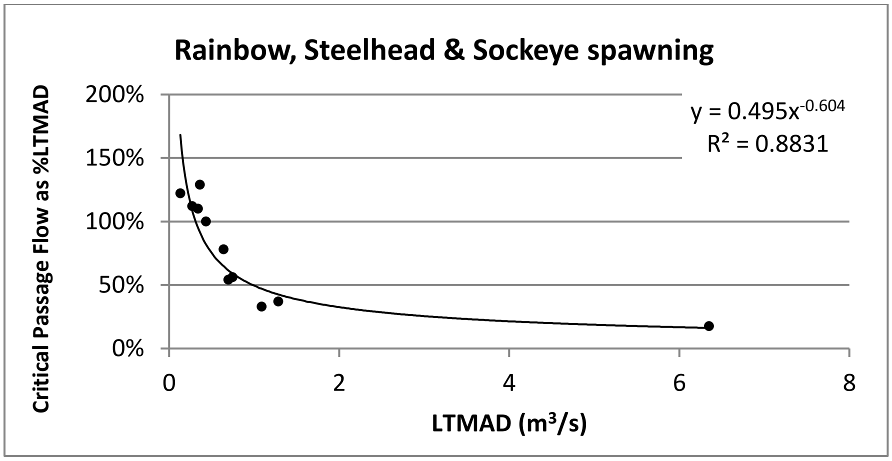


Figure 4-2: Rainbow, Steelhead and Sockeye spawner critical riffle passage flows vs. LTMAD for 11 Okanagan streams

- Streamflows are typically very low during later summer and early fall with a small increase in later fall following rain events. Thus, Okanagan Tennant EFNs for summer and early fall were generally most constrained by low naturalized flows and were mostly lower than presumptive flow standards. As a result, final EFNs were rarely further reduced based on WUW. In systems with a history of flow augmentation from storage, WUW information was used to increase EFNs from Okanagan Tennant EFNs to match residual flows to preserve the status quo. Specific observations for summer and fall EFNs include:

  - EFNs for **spring Chinook** migration and spawning in July-September were most constrained by naturally low flows during later summer as well as small stream size. The recommended EFNs were associated with relatively low WUWs (6%-28% of maximum) and riffle analysis indicated migration difficulties. Thus EFNs and, in some cases, critical flows, were set to naturalized flows in systems that are known or suspected to support spring Chinook to provide maximum available flows. Migration and spawning conditions for spring Chinook greatly improve at flows higher than the recommended EFNs.

    Critical riffle analysis indicates that commonly used %LTMAD-based migration (20%) and spawning (10%) critical flows do not produce safe riffle passage conditions ($\geq$25% of transect with depths $\geq$0.24 m) for Chinook in smaller streams due to shallow water depths and large body sizes. Safe riffle passage would be achieved between 91%-394% LTMAD and the %LTMAD required declines with increasing stream size (Figure 4-3). Rain events and associated flow increases are likely critically important in providing spawning migration access and should be protected. Due to their typical early-summer spawning migration, spring Chinook have an extraordinarily long holding period and maintaining suitable flows throughout the summer is of critical importance to their ability to successfully spawn. Stream temperatures were not explicitly considered in this analysis but it is likely that they further constrain habitat suitability for spring Chinook spawners in some of the streams as described in Table 4-1.

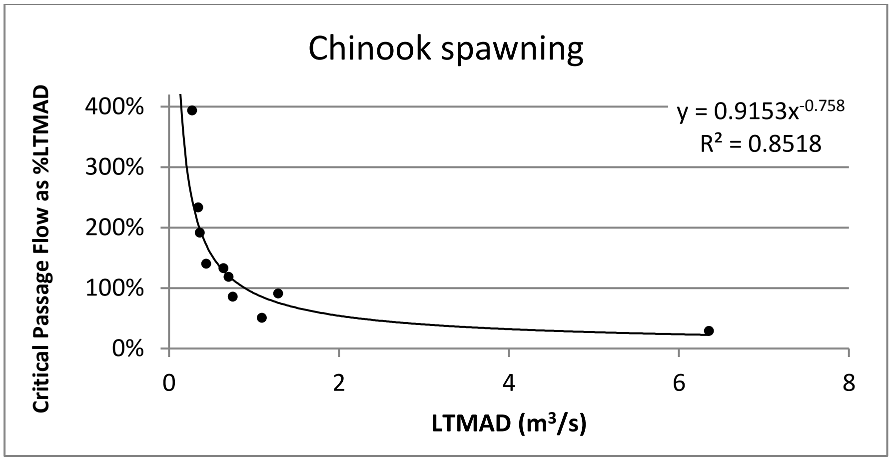


Figure 4-3: Spring Chinook spawner critical riffle passage flows vs. LTMAD for 11 Okanagan streams

- **Juvenile Rainbow and Chinook rearing** in most streams is naturally constrained by low flows through the summer and fall (July-September). As a result, many EFNs fall below the Tennant flow standard (20% LTMAD) during some portion of that period. There were a number of streams, however, with a history of flow augmentation or naturally higher baseflows, where recommended EFNs are at or greater than presumptive flow standards. WUWs at the recommended EFNs range from 25%-85% of maximum for O. mykiss parr, and from 35%-60% of maximum for Chinook fry. Optimum flows, indicated by the peak of the WUW curve, occur in all study streams at flows greater than naturally available in summer and fall. Rearing conditions improve rapidly at flows greater than the recommended EFNs. Stream temperatures were not explicitly considered in this analysis but it is likely that they further constrain suitable rearing habitats for cold water species in some of the streams as described in Table 4-1.

  Riffle width analysis (Table 2-7) produced critical flow recommendations for juvenile rearing that were slightly greater than those commonly applied by FLNRORD (5%) with a mean of 8% and a range of 3%-12% (Figure 4-4), excluding streams without WUW information and those lacking low flow measurements (Coldstream and Equesis). Recommended critical flows were always greater than or equal to 5% (Table 4-3). Unlike critical passage flows for spawners, there was no clear relationship with LTMAD.

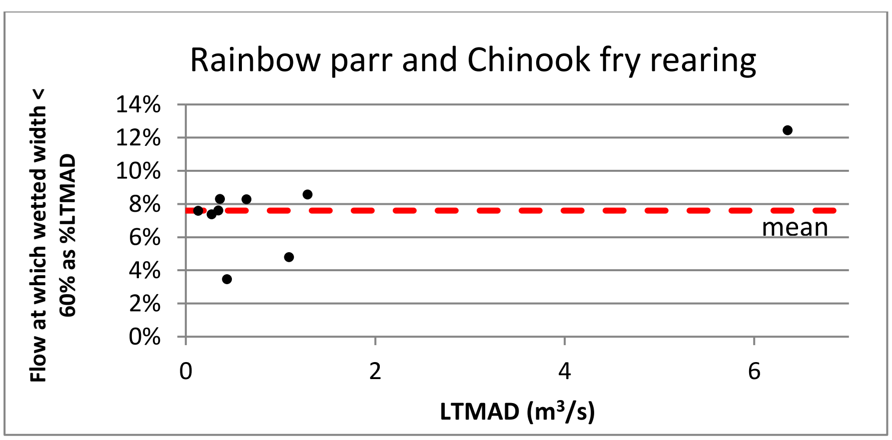


Figure 4-4: Rainbow parr and Chinook fry rearing critical riffle width flows vs. LTMAD for 11 Okanagan streams

- o **Kokanee** spawners, particularly the early fall spawning populations, are naturally constrained by low flows in September. Later spawning populations as well as **Sockeye** are less affected because flows often increase in October following rainfall events. WUWs at the recommended EFNs range from 30%-98% of maximum for Kokanee spawning, and from 30%-43% of maximum for Sockeye spawning with the exception of Shuttleworth Creek, where Sockeye access and spawning is likely limited to wet years due to small stream size and naturally low flows. Migration and spawning conditions greatly improve at flows higher than the EFNs.

  Critical riffle analysis indicates that commonly used %LTMAD-based critical flows (10%) do not produce safe riffle passage conditions (≥25% of transect with depths ≥0.12 m) for Kokanee in most of the study streams due to shallow water depths. Safe riffle passage for Kokanee would be achieved between 10%-82% LTMAD and the %LTMAD required declines with increasing stream size. Safe riffle passage for Sockeye would be achieved between 18% and 129% LTMAD (Figure 4-2) and flows are typically lower during the Sockeye spawning season. Rain events and associated flow increases are likely important in providing spawning migration access.

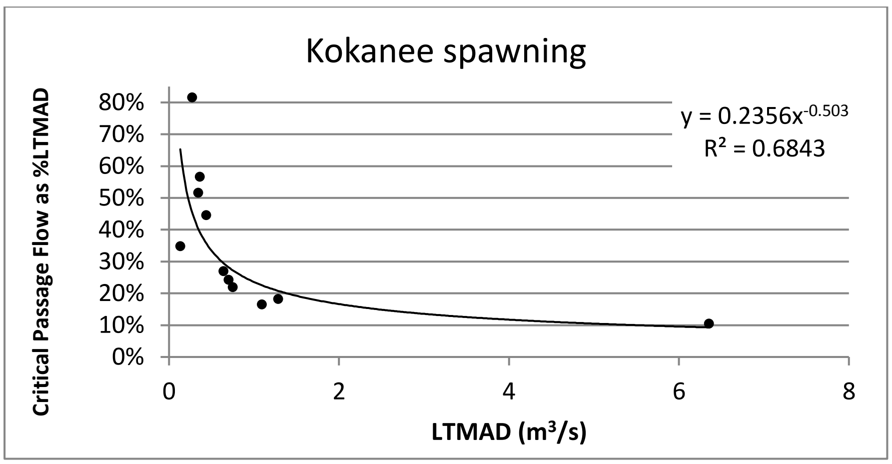


Figure 4-5: Kokanee spawner critical riffle passage flows vs. LTMAD for 11 Okanagan streams

- Most of the 18 study streams are naturally 'flow sensitive' during summer (Table 4-3) and without careful consideration of mitigation options (e.g., off-channel storage), any further water withdrawals may be detrimental to ecosystem health.

- Most of the 18 study streams are naturally 'flow sensitive' during winter (Table 4-3). Winter low flows have the potential to negatively affect egg incubation and overwintering habitats. Water demand is generally lower during the winter and streams for which maximum licensed flow estimates were produced did not indicate significant impacts on streamflows in the winter. However, care should be taken in highly regulated streams to ensure that sufficient winter flows are maintained. Measurement of flow under ice is fraught with error and introduces uncertainty in streamflow records as well as naturalized flow estimates during this period.

- In some streams, most or all migratory fish accessible low-gradient reaches are situated on valley-side alluvial fans (e.g., Shorts Creek). These transitional fan areas between steep valley side and valley bottom are naturally sensitive to low flows as they are often zones of groundwater recharge that lose some streamflow to the aquifers below. As a result, those creeks tend to experience extremely low base flows. Streams with long low-gradient valley-bottom reaches (e.g., Coldstream and Mill creeks) experience substantial groundwater inflows in those lower reaches and tend to have much higher baseflows than average.

- Streams for which maximum licensed flows were provided by Associated (2019) frequently showed extreme impacts of water use on summer and fall streamflows and five of nine creeks would dry up entirely from mid-July to mid-September under maximum licensed flow conditions. Coincidentally, the two streams showing little impact from licensed water use (Vaseux and Shuttleworth creeks) are known to dry up most summers and have large points of diversion above the dry reaches. Monitoring of actual water use is vital to understanding whether this is a natural phenomenon or whether licensed amounts are exceeded.

Table 4-2: Recommended EFNs for the 18 study streams

Stream	Drainage Area (km²)	LTMAD (m^3/s)	Median 30-Day summer naturalized low flow in m^3/s (%LTMAD)	Naturalized flow Data Quality Rating (Error Range)	**Median recommended EFNs** in m^3/s (%LTMAD)						
					Juvenile overwinter	Juvenile rearing	Steelhead spawning	Rainbow spawning	Chinook spawning	Kokanee spawning	Sockeye spawning
Coldstream	206	0.748	0.360 (48%)	B (>10% and ≤25%)	0.250 (33%)	0.250 (33%)	x	0.995 (133%)	x	0.250 (33%)	x
Equesis	204	0.700	0.059 (8%)	B (>10% and ≤25%)	0.137 (20%)	0.174 (25%)	x	1.10 (157%)	x	0.180 (26%)	x
Naswhito	87	0.363	0.045 (12%)	C (>25% and ≤50%)	0.054 (15%)	0.090 (25%)	x	0.774 (213%)	x	0.090 (25%)	x
Whiteman	203	1.09	0.108 (10%)	B (>10% and ≤25%)	0.138 (13%)	0.158 (14%)	x	1.10 (101%)	x	0.141 (13%)	x
Mission	845	6.35	1.10 (17%)	B (>10% and ≤25%)	0.925 (15%)	1.40 (22%)	x	4.83 (76%)	x	1.40 (22%)	x
McDougall	54	0.132	0.024 (18%)	C (>25% and ≤50%)	0.026 (20%)	0.026 (20%)	x	0.363 (274%)	x	0.028 (21%)	x
Lower Shingle	299	0.641	0.109 (17%)	B (>10% and ≤25%)	0.073 (11%)	0.128 (20%)	1.12 (174%)		0.125 (19%)	0.127 (20%)	0.126 (20%)
Upper Shingle	118	0.272	0.036 (13%)	B (>10% and ≤25%)	0.023 (9%)	0.064 (24%)	0.900 (331%)		0.041 (15%)	x	x
Shuttleworth	90	0.436	0.049 (11%)	C (>25% and ≤50%)	0.043 (10%)	0.080 (18%)	0.871 (200%)		0.060 (14%)	x	0.053 (12%)
Vaseux	294	1.29	0.042 (3%)	C (>25% and ≤50%)	0.070 (5%)	0.15 (12%)	1.50 (117%)		0.200 (16%)	x	0.150 (12%)
Inkaneep	179	0.362	0.081 (22%)	C (>25% and ≤50%)	0.082 (23%)	0.136 (38%)	0.771 (213%)		0.100 (28%)	x	x
Shorts	186	1.01	0.029 (3%)	B (>10% and ≤25%)	0.057 (6%)	0.100 (10%)	x	1.49 (148%)	x	0.140 (14%)	x
Mill	224	0.744	0.266 (36%)	C (>25% and ≤50%)	0.250 (34%)	0.250 (34%)	x	1.23 (165%)	x	0.250 (34%)	x
Powers	145	0.643	0.137 (21%)	C (>25% and ≤50%)	0.143 (22%)	0.141 (22%)	x	1.12 (174%)	x	0.141 (22%)	x
Trepanier	260	1.28	0.263 (20%)	B (>10% and ≤25%)	0.257 (20%)	0.257 (20%)	x	1.73 (135%)	x	0.257 (20%)	x
Naramata	42	0.157	0.012 (8%)	C (>25% and ≤50%)	0.028 (16%)	0.090 (52%)	x	0.492 (285%)	x	0.056 (32%)	x
Trout	747	2.17	0.512 (24%)	B (>10% and ≤25%)	0.441 (20%)	0.520 (24%)	x	2.44 (112%)	x	0.520 (24%)	x
Penticton	180	1.16	0.104 (9%)	B (>10% and ≤25%)	0.373 (32%)	0.497 (43%)	x	1.63 (142%)	x	0.417 (36%)	x
McLean	63	0.167	0.023 (14%)	C (>25% and ≤50%)	0.021 (13%)	0.032 (19%)	0.428 (256%)	0.471 (282%)	x	0.026 (15%)	x

x denotes fish species and life stages not present in the study stream

Table 4-3: Critical flows and flow sensitivities for the 18 study creeks

Stream	LTMAD (m^3/s)	1 in 2 yr 30-Day naturalized summer low flow %LTMAD (Sensitive if <20%)	1 in 2 yr 30-Day naturalized winter low flow %LTMAD (Sensitive if <20%)	Critical flows in m^3/s (%LTMAD)						
				Juvenile over-winter	Juvenile rearing	Steelhead spawning	Rainbow spawning	Chinook spawning	Kokanee spawning	Sockeye spawning
Coldstream	0.748	48%	33%	0.075 (10%)		x	0.419 (56%)	x	0.164 (22%)	x
Equesis	0.700	8%	7%	0.035 (5%)		x	0.380 (54%)	x	0.070 (10%)	x
Naswhito	0.363	12%	11%	0.031 (9%)		x	0.502 (138%)	x	0.06 (17%)	x
Whiteman	1.09	10%	9%	0.052 (5%)		x	0.361 (33%)	x	0.109 (10%)	x
Mission	6.35	17%	11%	0.662 (10%)		x	1.12 (18%)	x	0.662 (10%)	x
McDougall	0.132	18%	17%	0.010 (8%)		x	0.161 (122%)	x	0.013 (10%)	x
Lower Shingle	0.641	17%	10%	0.053 (8%)		0.493 (77%)		0.125 (19%)	0.064 (10%)	0.064 (10%)
Upper Shingle	0.272	13%	7%	0.020 (7%)		0.306 (113%)		0.027 (10%)	x	x
Shuttleworth	0.436	11%	6%	0.022 (5%)		0.445 (102%)		0.044 (10%)	x	0.044 (10%)
Vaseux	1.29	3%	0%	0.064 (5%)		0.477 (37%)		0.129 (10%)	x	0.129 (10%)
Inkaneep	0.362	22%	20%	0.030 (8%)		0.468 (129%)		0.100 (28%)	x	x
Shorts	1.01	3%	3%	0.050 (5%)		x	0.503 (50%)	x	0.101 (10%)	x
Mill	0.744	36%	35%	0.037 (5%)		x	0.372 (50%)	x	0.074 (10%)	x
Powers	0.643	21%	18%	0.032 (5%)		x	0.321 (50%)	x	0.064 (10%)	x
Trepanier	1.28	20%	17%	0.064 (5%)		x	0.642 (50%)	x	0.128 (10%)	x
Naramata	0.157	8%	6%	0.009 (5%)		x	0.086 (50%)	x	0.017 (10%)	x
Trout	2.17	24%	18%	0.109 (5%)		x	1.09 (50%)	x	0.217 (10%)	x
Penticton	1.16	9%	7%	0.058 (5%)		x	0.576 (50%)	x	0.115 (10%)	x
McLean	0.167	14%	10%	0.008 (5%)		0.084 (50%)		x	0.017 (10%)	x

x denotes fish species and life stages not present in the study stream

4.3 Recommendations

This section contains recommendations specific to this study and the Okanagan as well as for future EFN projects in general. Further, knowledge gaps and potential research topics are discussed.

Specific recommendations for the Okanagan EFN project are:

- **Collect hydrometric data**. Continue operation of existing hydrometric stations and install additional stations as outlined in Table 4-1. This information is useful for continued validation of naturalized flow estimates and EFNs, as well as monitoring the status of EFN implementation and alerting to potential flow problems.
- **Refine water use estimates and obtain information on reservoir management.** Water diversions and releases from reservoirs and their impact on flows should be documented through field observations (audit), particularly where there appears to be a mismatch between estimated and observed water use (Table 4-1). This has been trialed in Trout Creek where actual use was greater than projected use. Locations of water diversions should be confirmed prior to conducting field monitoring, followed by collection of the necessary streamflow and diversion information to help inform the streamflow naturalization process. Consider the requirement of diversion monitoring within the water licensing process.
- **Support development of operational plans for reservoirs.** Creating new or updating existing operational plans will permit inclusion of EFN needs and support meeting EFNs in the future.
- **Obtain residual and maximum licensed flow estimates**. Residual and maximum licensed flow datasets are not yet available for all 18 study streams. These datasets should be completed and the WUW Index percentile plots, as described in the Phase I report, should be prepared when all datasets are available. The impact of water use on fish habitat under residual and maximum licensed conditions can then be compared between streams which will help to identify problem areas and opportunities for streamflow restoration efforts.
- **Address over-allocation**. Over-allocation is evident in the maximum licensed flow estimates provided by Associated (2019), which indicate dry streambeds in five of nine creeks. Streamflow restoration efforts are needed to reduce the licensed amounts to realistic levels that balance the needs of water users and the ecosystem, or support the licensed amounts from off-channel storage. The increasing tendency for lower summer baseflows in recent decades revealed in the flow naturalization analysis should be considered during this exercise.
- **HSI curve for Okanagan spring Chinook.** An HSI curve should be developed for spring Chinook who spawn in small tributary streams. WUWs produced by the HSI curve from the Nicola River yielded WUWs so low that spring Chinook spawning EFNs were set to naturalized flows throughout the migration and spawning period. While it is likely that small stream sizes and naturally low flows do require Chinook spawning EFNs at or near naturalized flows, it is recommended to develop an HSI curve for spring Chinook that spawn in smaller streams. Okanagan spring Chinook spawners may currently be too low in abundance to derive HSI curves as few spawners are observed annually and monitoring is sporadic. Smaller streams with spring Chinook populations in nearby watersheds, such as Bessette Creek, Salmon River, and Coldwater River would serve as useful proxies. Similarly, confirmation of the Sockeye HSI curve in small tributaries would be useful.
- **Okanagan Lake tributaries.** EFNs and critical flows for Okanagan Lake tributaries should be determined for Sockeye and Chinook spawning. Fish passage at the outlet of Okanagan Lake was

implemented in the fall of 2019 and these species now have access to Okanagan Lake tributaries. Efforts should be focused on larger tributaries with potential to support these large-bodied species.

- **Temperature analysis**. Stream temperature data were collected at hydrometric stations operated by the ONA, however they were not explicitly analyzed due to resource and technique/method limitations, but were considered during EFN and critical flow setting. Streams with problematic thermal conditions were noted in the results section and in Table 4-1. For these streams, it is recommended that the already-collected data be further analyzed, using methods such as quantile regression, to determine whether EFNs and critical flows warrant adjustment to mitigate the impact of high stream temperatures. However, possible EFN increases are likely very limited without exceeding naturally available flows.

- **Confirm critical flows and EFNs**. Critical flows and, in some cases, EFNs (specific recommendations in Table 4-1) should be confirmed with actual field-based fish observation data to assess the effectiveness of this approach. In particular, critical flows for juvenile fish rearing should be further investigated to confirm that the recommended critical flows are sufficient. Passage flows should be verified with fish movement information from the study streams to confirm they are appropriate.

- **Collect climate data**. Climate data in conjunction with hydrometric data will improve climate change modeling and provide information on the ability to meet EFNs in the future.

- **Restore and enhance fish habitats.** Many Okanagan streams have experienced physical impacts which have reduced the quantity and quality of available fish habitat. In addition, ongoing climate change may progressively restrict the ability of the managers of Okanagan Lake dam to provide flows to the Okanagan River that fully supply anadromous fish spawning needs, which in turn could negatively impact fish populations in streams throughout the Okanagan. Accordingly, instream work to restore physical and biological functioning in areas of degraded fish habitat should be a priority throughout the Okanagan - particularly where the degradation is most severe and in areas of potentially high fisheries value. In addition to stream restoration, enhancing fish habitat to provide greater benefits than currently exist should also be considered.

Additionally, the following recommendations are made for consideration in future EFN studies:

- Highly modified streams with high fisheries value or potential value should be prioritized for field-based EFN setting as habitat-flow relationships highly depend on channel configuration within each stream. Thus, highly altered streams should be prioritized for WUW analysis in future studies.
- Information on naturalized flows is useful for constraining EFNs to realistically achievable flows. However, uncertainty in naturalized flow estimation can be high and often habitat conditions change rapidly particularly at low flows. Thus, the reliance on naturalized flows as a constraint on EFNs should be examined on a stream-by-stream basis. In the absence of recent field data, historical information on channel conditions, fish populations, and flow regimes can provide useful context for verifying naturalized flows and EFNs.
- Early identification of potential flow augmentation and resultant effects on habitat suitability assists with focusing data collection and estimation efforts (e.g., development of naturalized vs. residual streamflow datasets).
- Traditional Ecological Knowledge (TEK) should be incorporated into naturalized hydrograph development where available. TEK on historical ecosystem flow characteristics (predominantly wetland or side channel inundations levels) and the magnitude of the flow standards needed, as well

as summer and fall low flows, could provide useful contributions and context to naturalized flow development and EFNs.

- Collaborative projects such as this, with representatives from the provincial government, regional water stewardship agencies, First Nations organizations, and local experts, are likely to lead to increased support for recommended EFNs and success in future EFN implementation.
- Where resources are limited, focusing WUW assessments on moderate and low flows is a reasonable adjustment because in the B.C. Interior, summer low flows are typically most limiting to EFNs and occur when water demand is highest. Springtime migration, spawning and rearing EFNs were not typically limited by low flows; thus, setting those EFNs with the Okanagan Tennant approach carries relatively low risk except in highly regulated watersheds. Potential transects should be selected pre-freshet, and WUW measurements should be focused on moderate (~75% LTMAD) to very low flows from post-freshet to early fall. Capturing the lowest flows is key to properly define the bottom of the WUW curve and to determine critical flows.
- It is recommended to collect all WUW measurements in one season; minor channel geometry changes during freshets can bias the habitat-flow relationship leading to uncertainty. However, average conditions in a given stream or reach should persist between years if representative transects are chosen.
- Conduct analysis of stream temperatures and flows to guide EFN and critical flow setting.
- The impacts of very short term (i.e., days or hours) flow fluctuations within the weekly EFN time steps cannot be addressed within the EFN setting exercise, but could / should be considered in licensee-specific operating plans to make better use of water supplies (Associated 2016). This is a serious issue in some regulated streams or those experiencing very high water use.
- Habitat types selected for analysis should be carefully defined to ensure consistency when it comes to transect positioning within a habitat unit (e.g., glide). For instance, habitat conditions at a pool tailout may be different than mid-glide though both may be used for spawning by certain species. During this study, care was taken to position transects in the center of each habitat unit (e.g., mid-riffle, mid-glide) to ensure consistency between transects and represent average conditions.
- The number of study transects on each stream was chosen from stream length, variability between reaches, logistics and time constraints. While some authors recommend a higher number of study transects (e.g. 18-20, Payne et al. 2004), there is a direct tradeoff between the number of streams that can be sampled and the number of transects on each stream when resources are limited. Conducting detailed habitat mapping to determine average conditions by habitat unit and reach, and then installing transects representative of average conditions, was expected to produce representative results even with a lower number of transects. Ideally, this assumption should be verified in future studies.

During the course of this project, several knowledge gaps were identified. More research is recommended in the following areas to better refine:

- **Flow ramping rates**. The EFNs presented herein do not contain specific ramping rates. Ramping guidelines for fish below hydroelectric facilities are provided by Knight Piesold (2005). Current ramping standards in B.C. are noted as ignoring several key stream functions and also need to be site specific. More research is recommended on ramping rates resulting from "point of diversion" withdrawals and water storage release rates at all times of the year. In addition, ramp down rates should be studied in relation to impacts on riparian vegetation rejuvenation (Richter & Richter 2000;

Mahoney & Rood 1998), in particular in Cottonwood ecosystems which are an endangered Okanagan ecosystems with very poor modern regeneration rates (BC MELP 1997; Lea 2008).

- **Fish life history information.** Further information on Kokanee juvenile migration timing in Okanagan streams should be compiled or collected to create a more robust and locally derived timing window. Further, research on locally-applicable flow standards is required for the following;
    - overwintering juvenile Steelhead, Chinook and Coho
    - all life stages of Sockeye, and
    - small bodied Rainbow Trout adult migration.
- **Confirm fish population health and abundance in contrast to summer baseflows and habitat models.** Fish population response to a variety of flows above and below the recommended EFNs and critical flows should be confirmed with actual fish abundance and/or health data. While the literature suggests increased fish abundance with greater minimum flows in some cases, the response is not unequivocal and local verification is recommended (Bradford & Heinonen 2008).
- **Groundwater-surface water interactions.** Groundwater-surface water interactions on alluvial fans, in particular losses to groundwater, should be quantified where possible to assist with naturalized flow estimation. Further, effects of channelization, groundwater pumping and urbanization of the lower reaches on these interactions should be considered.
- **Channel maintenance flows**. The flood stage where the stream reaches bankfull discharge is the dominant channel form flow (Newbury 2010, Leopold et al. 1964). These bankfull discharges maintain average rates of sediment transport, bankfull widths and depths, pool-riffle ratios, and the average rates of bank migration (Leopold et al. 1964), thus stable bed and bank erosion that creates fish habitat. The bankfull discharge is derived from a flood exceedance assessment and is always a greater number than the median spring flows calculated in the Okanagan Tennant method. More research is needed on;
    - testing the validity of estimates derived on channel stability and fish habitat, and
    - how to create flow estimates within the Okanagan Tennant method that protect channel forms.

4.4 Next steps

The goal of the Okanagan EFN Project was to produce defensible, transparent and robust EFN values for Okanagan streams. Following completion of this technical exercise, the initial next step is for the larger community to review the EFN and critical flow recommendations for each stream. This will include a review by ONA bands for creeks within their areas of responsibility. The Phase I Report (Associated 2016) should be updated with the changes to the methods described above and any changes identified during the review phase.

Upon agreement on this technical report, there will be a collaborative effort to set final EFNs that balance water demands with ecological needs within a socio-economic context. The focus of this next step will be to identify societal values, and allow for the ability to understand, identify, and make informed decisions as they relate to tradeoffs that exist between EFNs and societal demands (Associated 2016). The undertaking would conclude with the development of an implementation plan. On behalf of ONA, the ONA Natural Resource Council and Chiefs Executive Committee will be engaged in implementation planning with the long term goal of using EFNs for Okanagan water law development.

> kʷu‿yʕayʕát iʔ‿kʷu‿sqilxʷ kscpútaʔstm áłiʔ y̓lmixʷmtət iʔ‿siwłkʷ.
>
> Water must be treated with reverence and respect.
>
> áłiʔ íʔ n̓xʷl̓xʷl̓tan̓tət lut kstan̓músmn̓tm, áłiʔ ksctxt̓stim yʕayʕat iʔ‿stim.
>
> Our relationship with water is not taken lightly, we are responsible to ensure that our relation can continue to maintain the health and resiliency of our land and animals.
>
> *-Excerpt, Okanagan Water Declaration, July 31, 2014*

5.0 REFERENCES

Agrodev. 1994. Preliminary Design and Cost Estimates for Vaseux Creek Fish Passage Facilities. Prepared for the Okanagan Regional Wildlife Heritage Fund Society, Kelowna B.C.

Agrodev. 1996. Stream Assessment and Fishway Feasibility Study. Prepared for the Okanagan Indian Band. January 1996.

Amlin, N. and S. Rood. 2001. Inundation Tolerances of Riparian Willows and Cottonwoods. Journal of the American Water Resources Association. Vol 37, No. 6. pg 1709-1720.

Andrusak, H., S. Matthews, A. Wilson, G. Andrusak, J. Webster, D. Sebastian, … J. Stockner. 2006. Okanagan Lake Action Plan Year 10 (2005) Report. Province of British Columbia, Fisheries Project Report No. 115. Ecosystems Branch, Ministry of Environment, Province of British Columbia.

Annear, T., I. Chisholm, H. Beecher, A. Locke, P. Aarrestad, C. Coomer, … C. Stalnaker. 2004. Instream Flows for Riverine Resource Stewardship, Revised Addition. Instream Flow Council, Cheyenne, WY.

Annear, T., I. Chisholm, H. Beecher, A. Locke, P. Aarrestad, C. Coomer, … R. Wentworth. 2002. Instream Flows for Riverine Resource Stewardship. Instream flow council. 411p.

Anonymous. 1969. Equesis (6 Mile) Creek Fish Habitat Survey.

Aqua Resource Management Inc. 2001. Coldstream Creek Restoration Project Phase II: Shareholder Survey, Stream Habitat Analysis and Recommendations for Future Restoration Efforts in the Coldstream Creek Watershed. Penticton, B.C.

Arterburn, J. 2013a. Final EDT Okanogan Summer/Fall-run Chinook Salmon Life History Model Memo.

Arterburn, J. 2013b. OBMEP/EDT Life History Model Parameters for Okanogan/Okanagan Steelhead Memo.

Arterburn, J., K. Kistler, C. Fisher, and M. Rayton. 2007. Okanogan Basin Spring Spawner Report for 2007. Prepared by Colville Tribes Department of Fish and Wildlife. Omak, WA.

Associated Engineering. 1997. District of Summerland Water System Master Plan. Prepared for the District of Summerland, October 1997.

Associated Environmental Consultants Inc. (Associated). 2016. Collaborative Development of Methods to Set Environmental Flow Needs in Okanagan Streams. Working document, Current Version. Prepared for the Okanagan Basin Water Board, Okanagan Nation Alliance, and B.C. Ministry of Forests, Lands and Natural Resource Operations.

Associated Environmental Consultants Inc. (Associated). 2017. Recommended Methods for the Development of Streamflow Datasets to Support the Application of the Okanagan Tennant Method in Okanagan Streams. Prepared for the Okanagan Basin Water Board.

Associated Environmental Consultants Inc. (Associated). 2019. Streamflow Datasets to Support the Application of the Okanagan Tennant Method within the Okanagan Basin Priority Environmental Flow Needs Watersheds. Prepared for the Okanagan Basin Water Board, March 2019.

Audy, N. and R. Benson. 2011. q̓awsitkʷ (Okanagan River) Sockeye Spawner Enumeration and Biological Sampling 2009. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C. 128 pp.

B.C. Ministry of Environment (MOE). 1982. Coldstream and Vaseux Creek Watersheds: Analysis of Channel Stability and Sediment Sources. APD Bulletin 27.

B.C. Ministry of Environment (MOE). 2000. Draft: Profile of a Candidate Sensitive Stream under the Fish Protection Act Mission Creek

Basok, R.E. 2000. Okanagan River Rainbow/Steelhead Genetic Sampling. Submitted to B.C. Ministry of Water, Land and Air Protection.

Baty, F., C. Ritz, S. Charles, M. Brutsche, JP. Flandrois, and ML. Delignette-Muller. 2015. A Toolbox for Nonlinear Regression in R: The Package nlstools. Journal of Statistical Software, 66(5), 1-21. Retrieved from http://www.jstatsoft.org/v66/i05/

B.C. Government. Accessed 2019. Water Rights Databases. Retrieved from https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-licences-approvals/water-rights-databases

BC-MELP 1997. Cottonwood Ecosystems of the Southern Interior. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/species-ecosystems-at-risk/brochures/cottonwood_riparian_ecosystems_southern_interior.pdf

Becker, C.D. and D.A. Neitzel. 1983. Salmonid Redd Dewatering: What Do We Know? PNL-SA-11841.

Beecher, H.A., B.A. Caldwell, S.B. DeMond, D. Seiler, and S.N. Boessow. 2010. An Empirical Assessment of PHABSIM Using Long-Term Monitoring of Coho Salmon Smolt Production in Bingham Creek, Washington, North American Journal of Fisheries Management, 30:6, 1529-1543, DOI: 10.1577/M10-020.1.

Benson, R. 2010. Fish Water Management Tools (FWMT) - Sockeye Incubation Timing. Prepared for FWMT Committee. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C. 20 pp.

Benson, R. and M. Squakin. 2008. Steelhead Spawner Enumeration in the Okanagan River Mainstem and Tributaries: Inkaneep, Vaseux and Shuttleworth creeks 2007. Within the Okanagan Basin Monitoring and Evaluation Program (OBMEP). Prepared by the Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Benson, R. and N. Audy. 2012. Okanagan River Sockeye Spawner Enumeration and Biological Sampling 2010. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Benson, R. and R, Bussanich. 2016. q̓awst'ik'wt (Skaha Lake) Nerkid Spawner Enumeration and Biological Sampling 2014. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Benson, R. and R. Bussanich. 2014. q̓awst'ik'wt (Skaha Lake) Kokanee Spawner Enumeration and Biological Sampling 2012. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Benson, R., R. Bussanich, and A. Friesen. 2016. q̓awst'ik'wt (Skaha Lake) Nerkid Spawner Enumeration and Biological Sampling 2013. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Benson, R., R. Bussanich, and A. Stevens. 2013. q̓awstʼikʼwt (Skaha Lake) Kokanee Spawner Enumeration and Biological Sampling 2011. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Bolker, B.M. 2008. Deterministic Functions for Ecological Modeling, in Bolker, B.M. [ed.] Ecological Models and Data in R. Princeton University Press.

Booker, D.J. 2016. Generalized Models of Riverine Fish Hydraulic Habitat. Journal of Ecohydraulics, 1(1-2), pp.31-49.

Bovee, K.D. and T. Cochnauer. 1977. Development and Evaluation of Weighted Criteria, Probability-of-Use Curves for Instream Flow Assessments: Fisheries. Cooperative Instream Flow Service Group, Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, U.S. Department of the Interior.

Bradford, M.J. and J.S. Heinonen. 2008. Low Flows, Instream Flow Needs and Fish Ecology in Small Streams. Canadian Water Resources Journal, 33(2), pp.165-180.

Burge, L. 2009. Analysis of Sedimentation and Sediment Mitigation Strategies for Mission Creek. City of Kelowna Environment Division.

Burge, L. 2011. Shuttleworth Creek Preliminary Data Report One: Long Profile, Grain Size and Energy Characteristics. Prepared by Burge Ecohydraulics. Prepared for Okanagan Nation Alliance.

Bussanich, R., R Benson, and A. Friesen. 2013. q̓awstʼikʼwt (Skaha Lake) Kokanee Spawner Enumeration and Biological Sampling 2010. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Bussanich, R., R. Benson, N. Audy, and A. Warman. 2012. q̓awsitkʷ [Okanagan River] Sockeye Spawner Enumeration and Biological Sampling 2010. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Cairns, R. 1992. Trepanier Creek Investigation Report. Prepared for the Ministry of Environment, Lands and Parks. Victoria, B.C. April 1992.

California Department of Fish and Wildlife. 2017. Critical Riffle Analysis for Fish Passage in California. California Department of Fish and Wildlife Instream Flow Program Standard Operating Procedure CDFW-IFP-001, 25 p.

Canada-British Columbia Okanagan Basin Agreement (CBCOBA). 1974. Technical Supplement IX: Fisheries and Wildlife in the Okanagan. Office of the Study Director, Penticton, B.C., March 1974.

Canadian EarthCare Society. 1992. Mill Creek (Kelowna Creek) Enhancement Project. Environmental Impact Study. Diagnostic Phase. File 34560-20.

Cartwright, J. 1968. Stream Improvement - 83 Mile Creek.

Colville Confederated Tribes (CCT). 2004. Chief Joseph Dam Hatchery Program. Volume 1 Master Plan. Appendix D: Okanogan River Spring Chinook Salmon Hatchery Genetic Managemen Plan. Retrieved from https://www.nwcouncil.org/sites/default/files/Appendix_D.pdf.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2006. COSEWIC Assessment and Status Report on the Chinook Salmon Oncorhynchus tshawytscha (Okanagan population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 41 pp.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2008. Wildlife Species Search. Retrieved from http://www.cosewic.gc.ca/eng/sct1/index_e.cfm.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2017. COSEWIC Assessment and Status Report on the Chinook Salmon Oncorhynchus tshawytscha (Okanagan population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 62 pp.

Core Numbers and Traits (CNAT). 2018. Database for the Okanagan Fish-and-Water Management Tool Project. Contact Margot Stockwell or Dr. Kim Hyatt, DFO, Pacific Biological Station Nanaimo.

Davis, C, H. Wright, C. K. Long, and N. Audy. 2007. Okanagan River Chinook salmon (Oncorhynchus tshawytscha): 2006 Brood Year Summary Report. Okanagan Nation Alliance, Westbank, B.C.

Davis, C. 2009. Okanagan River Chinook salmon (Oncorhynchus tschawytscha) 2008 Stock and Habitat Assessment. Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Davis, C. 2010a. Okanagan River Chinook salmon (Oncorhynchus tschawytscha) 2009 Stock and Habitat Assessment. Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Davis, C. 2010b. Okanagan River Chinook Salmon (Oncorhynchus tschawytscha) Compilation Report 2006 - 2010. Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Davis, C., H. Wright, and K. Long. 2008. Okanagan River Chinook Salmon (Oncorhynchus tschawytscha) 2007 Stock and Habitat Assessment. Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Davis, C., M. Squakin, L. Wiens, and T. Kozlova. 2009. Okanagan River Sockeye Spawner Enumeration and Biological Sampling 2008. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Demarchi, D. A. 2011. An Introduction to the Ecoregions of British Columbia. Ministry of Environment, Victoria, British Columbia. March 2011.

Dill, P.A. 1991. Migration of Kokanee Salmon Adults into Mission Creek Spawning Channel and Estimate of Egg Disposition. Okanagan College, Kelowna, B.C.

Dobson Engineering Ltd. (Dobson). 1990a. Shorts Creek. Assessment of Alternatives to Enhance Okanagan Lake Fishery. September 1990. Canada-British Columbia Okanagan Basin Agreement. 1974. Technical Supplement IX: Fisheries and Wildlife in the Okanagan. Office of the Study Director, Penticton, B.C. March 1974.

Dobson Engineering Ltd. (Dobson). 1990b. Equesis Creek: Assessment of Alternatives to Enhance Okanagan Lake Fishery. September 1990. Canada-British Columbia Okanagan Basin Agreement. 1974. Technical Supplement IX: Fisheries and Wildlife in the Okanagan. Office of the Study Director, Penticton, B.C. March 1974.

Dobson Engineering Ltd. (Dobson). 1990c. Mission Creek Assessment of Alternatives to Enhance Okanagan Lake Fishery.

Dobson Engineering Ltd. (Dobson). 2004. Mission Creek Fish Flows and Black Mountain Irrigation District Releases. Letter to Ministry of Water, Land and Air Protection, March 2004.

Dobson Engineering Ltd. (Dobson). 2008. Phase 2 Okanagan Water Supply and Demand Study: Water Management and Use Study. Prepared for the OBWB, June 2008.

Dobson Engineering Ltd. (Dobson). 2010. Powers Creek Source Assessment Report.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W. H. Freeman and Company, New York.

Ecoscape Environmental Consultants Ltd. (Ecoscape) 2006. Sensitive Habitat Inventory and Mapping (SHIM) - Mill Creek and Bellevue Creek. Inventory Summary Report. Kelowna, British Columbia. Prepared by Kyle Hawkes, R.P. Bio for Ecoscape Environmental Consultants.

Ecoscape Environmental Consultants Ltd. (Ecoscape). 2010. Sensitive Habitat Inventory and Mapping (SHIM) – 2009 Survey Period. Inventory Summary Report and Comprehensive Watercourse Catalogue. 184pp. (incl. Brewer and Craster Creeks) – GPS Database also available.

Enns, J. 2015. Fish Passage at akłxʷminaʔ (Shingle Creek) Dam Construction Report 2014. Prepared for the Penticton Indian Band, Rocky Reach Habitat Conservation Plan Tributary Committee, and Wells Habitat Conservation Plan Tributary Committee. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Enns, J.D., Teather, M.J., and S.C. Davis. 2020. Okanagan Tributary Aquatic Habitat Project Report. Okanagan Ecosystem Initiative. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Epp, P. 2008a. 2007 Flow and Habitat Monitoring, Mission Creek. Working Report. Environmental Stewardship Division, British Columbia Ministry of Environment, Penticton, B.C.

Epp, P. 2008b. 2008 Flow & Habitat Monitoring Powers Creek.

Epp, P. 2009. 2008 Flow and Habitat Monitoring, Mission Creek. Working Report. Environmental Stewardship Division, British Columbia Ministry of Environment, Penticton, B.C.

Epp, P. 2010a. 2009 Flow and Habitat Monitoring, Mission Creek. Working Report. Environmental Stewardship Division, British Columbia Ministry of Environment, Penticton, B.C.

Epp, P. 2010b. Trepanier Creek Operating Strategy. Working Report. Environmental Stewardship Division, British Columbia Ministry of Environment, Penticton, B.C.

Epp, P. 2014. Environmental Flows and Hydrologic Assessment for the Bessette Creek Watershed 2011-2013. Prepared for the Ministry of Forests, Lands and Natural Resource Operations Kamloops, B.C.

Ernst, A. 1999. Okanagan Nation Fisheries Commission Dam Research. Prepared for the Okanagan Nation Fisheries Commission, Westbank, B.C.

Ernst, A. and A. Vedan. 2000. Aboriginal Fisheries Information within the Okanagan Basin. Vedan, A., (ed). Okanagan Nation Fisheries Commission: Westbank, B.C.

ESSA Technologies Ltd. and Solander Ecological Research. 2009. Instream Flow Needs Analysis for the Okanagan Water Supply and Demand Project. Prepared for the Okanagan Basin Water Board, November 2009.

Eyjolfson, Z. and K. Alex. 2018. Habitat Rapid Assessment and Preliminary Restoration Design for Trout Creek. Prepared for the Canadian Okanagan Basin Technical Working Group and the Okanogan Sub-Basin Habitat Improvement Program – Colville Confederated Tribes. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Eyjolfson, Z. and M. Dunn. 2016. Okanagan Sub-basin Habitat Improvement Program (OSHIP): 2015 – 16 Tributary Prioritization. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Fish & Wildlife Service U.S. (FWS). 2008. Endangered Species Program. Retrieved from http://www.fws.gov/endangered/.

Fish, F.F. and M.G. Hanavan. 1948. A Report upon the Grand Coulee Fish Maintenance Project 1939-1947 (No. 55). U.S. Fish and Wildlife Service.

Folks, S., M. Squakin, and T. Kozlova. 2009. Steelhead Spawner Enumeration in Inkaneep Creek – 2008. Within the Okanagan Basin Monitoring and Evaluation Program (OBMEP). Prepared by the Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

Galbraith, D.M. and G.D. Taylor. 1969. Fish Habitat Survey: Okanagan Tributary Streams. Unpublished Manuscripts. Fish and Wildlife Branch. Victoria, B.C.

Grainger & Associates Consulting Ltd. and Streamworks Unlimited (Grainger & Streamworks). 2010. Trepanier Creek Hydrological Risk Assessment. Prepared for the B.C. Ministry of Environment, February 2010.

Greenwell, B.M., and C.M. Schubert Kabban. 2014. investr: An R Package for Inverse Estimation. The R Journal, 6(1), 90-100. Retrieved from http://journal.r-project.org/archive/2014-1/greenwell-kabban.pdf.

Hinton, B.R. 1972. Task 163 Okanagan Basin Study. Salmonid Enhancement Feasibility Study. Vol. 1. Trout Creek.

Houston, C. n.d. Minimum Flow Estimates Mission Creek.

Hunter, H.I. 1978. Trepanier Creek Water Yield. Hydrology Division, Water Investigations Branch. June 16, 1978.

Hyatt, K., M. Stockwell, H. Wright, L. Wiens and P. Askey. 2010. Okanagan Fish and Water Management Tools Project Assessments: Brood Year 2009 Salmon (Oncorhynchus nerka) Abundance and Biological Traits. Report to file: JSIDS- SRe05-10. Salmon in Regional Ecosystems Program, Fisheries and Oceans Canada, Nanaimo, B.C. V9T 6N7. 28 p.

Hynes, H.B. 1970. The Ecology of Running Waters. The Blackburn Press ISBN 1-930665-33-4.

Inkster, G. 1993. Memorandum re: Enumeration Results and the Mortality Count of Naramata Creek due to Dewatering.

Jones, N.E., I.C. Petreman, and B.J. Schmidt. 2015. High Flows and Freshet Timing in Canada: Observed Trends. Ontario Ministry of Natural Resources and Forestry. Science and Research Branch, Peterborough, Ontario. Climate change Research Report CCRR-42.

Jowett, I.G and J. Richardson. 2008. Habitat Use by New Zealand Fish and Habitat Suitability Models. NIWA Science and Technology Series No. 55.

Keefer M.L., T.S. Clabough, M.A. Jepson, E.L. Johnson, C.A. Peery, and C.C. Caudill. 2018. Thermal Exposure of Adult Chinook Salmon and Steelhead: Diverse Behavioral Strategies in a Large and Warming River System. PLoS ONE 13(9): e0204274. Retrieved from https://doi.org/10.1371/journal.pone.0204274.

Kellerhals, R. and M. Church. 1989. The Morphology of Large Rivers: Characterization and Management. In D.P. Dodge [Ed.] Proceedings of the International Large Rivers Symposium. Canadian Fisheries and Aquatic Sciences Special Pub. 106. Ottawa, ON.

Knight Piesold Ltd. 2005. Fisheries and Oceans Canada Flow Ramping Study. Study of Flow Ramping Rates for Hydropower Developments (REF no V103-79/2-1). Vancouver, B.C.

Koshinsky, G.D. 1972a. Canada - British Columbia Okanagan Basin Agreement Task 66 Abstract on Fish Habitat Survey: Okanagan Tributary Streams, 1969.

Koshinsky, G.D. 1972b. Estimates of Minimum Flow Requirements for Okanagan Tributary Streams for the Propagation of Salmonid Fish Species Endemic to the Main Lakes. March 1972.

Koshinsky, G.D. and S.J. MacDonald. 1971. Trout Creek Pilot Study - Preliminary Evaluation of Limnology and Fisheries. Canada-British Columbia Okanagan Basin Agreement. November 1971.

Koshinsky, G.D. and T.J. Wilcocks. 1973. Fishery Potentials in the Okanagan Basin - Task 66D. Canada – B.C. Okanagan Basin Agreement. Rept. Prep. By Env. Canada, Fish. Serv., Winnipeg for Okanagan Study Comm., Penticton. 198p.

Lamouroux, N. and I.G. Jowett. 2005. Generalized Instream Habitat Models. Canadian Journal of Fisheries and Aquatic Sciences, 62(1), pp.7-14.

Larrat Aquatic. 2011. Source Assessment of the Regional District of North Okanagan - Greater Vernon Water Utility North Kalamalka Lake Intake.

Lawrence, S. 2003. Sockeye Egg and Alevin Development Summary 2003. Prepared for Douglas County PUD.

Lawrence, S. 2004. Sockeye Egg and Alevin Development Summary 2004. Prepared for Douglas County PUD.

Lea, T. 2008. Historical (Pre-Settlement) Ecosystems of the Okanagan Valley and Lower Similkameen Valley of British Columbia – Pre-European Contact to the Present. Davidsonia 19:1.

Leopold, L., G. Wolman, and J. Miller. 1964. Fluvial Processes in Geomorphology. Dover \press US.

Leviavsky, S. 1955. Introduction to Fluvial Hydraulics. Constable, Dover.

Lewis, A., T. Hatfield, B. Chilibeck, and C. Roberts. 2004. Assessment Methods for Aquatic Habitat and Instream Flow Characteristics in Support of Applications to Dam, Divert, or Extract Water from Streams in British Columbia. Prepared for: British Columbia Ministry of Sustainable Resource Management, and British Columbia Ministry of Water, Land, and Air Protection. Victoria, B.C.

Linnansaari, T., W.A. Monk, D.J. Baird, and R.A. Curry. 2013. Review of Approaches and Methods to Assess Environmental Flows across Canada and Internationally. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/039. vii + 75 p.

Long, K. 2005. History and Configuration of Okanagan Falls, B.C. Prepared by Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

Long, K. and E. Tonasket. 2005a. Kokanee Spawner Enumeration and Biological Sampling in 2004 in Penticton Channel. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Long, K. and E. Tonasket. 2005b. Skaha Lake Kokanee Spawner Enumeration and Biological Sampling 2004. Prepared for the Reintroduction of sockeye into Skaha Lake Monitoring and Evaluation 2003, Grant County Public Utility District. Westbank, B.C.

Long, K., M. Squakin, and C. Louie. 2006. Steelhead Spawner Enumeration in the Okanagan River Mainstem and Tributaries: Inkaneep, Vaseux and Shuttleworth Creeks – 2006. Within the Okanagan Basin Monitoring and Evaluation Program (OBMEP). Prepared by the Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

Louie. C. and R. Benson. 2011. q̇awst’ik’wt (Skaha Lake) Kokanee Spawner Enumeration and Biological Sampling 2009. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Louis, K. 2004. Kokanee Enumeration 2004. Whiteman Creek, Nashwito Creek and Equesis Creek. Prepared for the Okanagan Nation Alliance. Westbank, B.C.

Louis, K. 2008. Kokanee Enumeration 2008. Whiteman Creek, Nashwito Creek and Equesis Creek. Prepared for the Okanagan Nation Alliance. Westbank, B.C.

Louis, K. 2010. Kokanee Enumeration 2010. Whiteman Creek, Nashwito Creek and Equesis Creek. Prepared for the Okanagan Nation Alliance. Westbank, B.C.

Louis, K. 2012. Kokanee Enumeration 2012. Whiteman Creek, Nashwito Creek and Equesis Creek. Prepared for the Okanagan Nation Alliance Fisheries. Westbank, B.C.

Louis, K. 2016. Kokanee Enumeration 2016. Whiteman Creek, Nashwito Creek and Equesis Creek. Prepared for the Okanagan Nation Alliance. Westbank, B.C.

Lukey, N. and C. Louie. 2015. Okanagan Subbasin Habitat Improvement Program (OSHIP): 2013 – 15 Tributary Prioritization. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Lukey, N. and K. Alex. 2018. Whiteman, Nashwito, & Equesis Creeks: Emergency Sediment Operations Construction – Environmental Monitoring Report. Prepared by Okanagan Nation Alliance Fisheries Department for the Okanagan Indian Band. Westbank, B.C.

Mackinnon, G. 1988. An Optimum Flow Estimation for Kokanee Spawning for Kelowna (Mill) Creek.

Mahoney, J. and S. Rood. 1998. Streamflow Requirements for Cottonwood Seedling Recruitment - an Integrative Model. Wetlands, Vol 18, No. 4, pp 634-645.

Mahony, A., W. Challenger, D. Robichaud, H. Wright, R. Bussanich, and J. Enns. 2019 (in press). Recovery Potential Assessment for the Okanagan Lake Chinook Salmon (Oncorhynchus tshawytscha) (2019) DFO Can. Sci. Advis. Sec. Res. Doc. 2019/nnn. xi + 104 p.

Martins, G. 2003. Letter Sept 11, 2003 to District of Summerland.

Mathieu, C. and M. Squakin. 2009. q̓awst'ik'wt (Skaha Lake) Kokanee Spawner Enumeration and Biological Sampling 2008. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Mathieu, C. and T. Kozlova. 2009. q̓awst'ik'wt (Skaha Lake) Kokanee Spawner Enumeration and Biological Sampling 2007. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Matthews, S. 2002. Naramata Creek Flows Letter. Ministry of Water, Land, and Air Protection.

Matthews, S. and C. J. Bull. 2003. Selection of a Focal Watershed for the Protection and Restoration of Fish Stocks and Fish Habitat in the Okanagan Region.

McCullough, D.A. 1999. A Review and Synthesis of Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon (pp. 1-291). U.S. Environmental Protection Agency, Region 10.

McGrath, E., J. Pepper, and A. Warman. 2012. Kokanee Fry Enumeration in Vernon Creek. Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

McGrath, E., N. Lukey and S. Lawrence. 2014. Kokanee Fry Enumeration in Middle Vernon Creek 2012 and 2013. Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Merritt, W.S., Y. Alila, M. Barton, B. Taylor, S. Cohen, and D. Neilsen. 2006. Hydrologic Response to Scenarios of Climate Change in Sub Watersheds of the Okanagan Basin, British Columbia. Journal of Hydrology 326, pp 79-108.

Ministry of Environment, Lands and Parks (MELP). 2000. Profile of a Candidate Sensitive Stream under the Fish Protection Act. Trepanier Creek.

Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) and Ministry of Environment (MOE). 2016. Environmental Flow Needs Policy.

Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD). 2016. Water Allocation Restrictions. Ministry of Forests, Lands, Natural Resource Operations and Rural Development. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/water-rights/water_allocation_restrictions_may2016.pdf.

Mould Engineering. 2017. Penticton Creek Master Plan. Prepared for City of Penticton. Penticton, B.C. Retrieved from https://www.penticton.ca/assets/City~Hall/Master~Plans/2017-12-11-PCRI%20Master%20Plan%20Final%20Report.pdf#search=%22penticton%20creek%20master%20plan%22.

Neumann, N. 2018. Mission Creek Groundwater –Surface Water Interactions Project: Analysis of Discharge and Water Level Records. Water Science Series, WSS2018-06. Province of British Columbia, Victoria.

Neuman, H.R. and C.P. Newcombe. 1977. Minimum Acceptable Stream Flows in British Columbia: A Review. Fisheries Management Report No. 70. December 1977.

Newbury, R. 2010. Stream Restoration Hydraulics. Project Casebook. Prepared for the Canadian Rivers Institute. Second printing. Winfield, B.C.

Northcote, T. G., Halsey, T. G., and S. J. MacDonald. 1972. Fish as Indicators of Water Quality in the Okanagan Basin lakes, British Columbia. British Columbia Fish and Wildlife Branch Department of Recreation and Conservation. Victoria, B.C.

Northwest Hydraulic Consultants (NHC). 2001. Hydrology, Water Use, and Conservation Flows for Kokanee Salmon and Rainbow Trout in the Okanagan Lake Basin North Vancouver: B.C. Fisheries. B.C. Prepared for B.C. Fisheries, Fisheries Management Branch, August 2001.

Northwest Hydraulic Consultants (NHC). 2001. Hydrology, Water Use, and Conservation Flows for Kokanee Salmon and Rainbow Trout in the Okanagan Lake Basin, B.C. Prepared for B.C. Fisheries, Fisheries Management Branch, August 2001.

Northwest Hydraulic Consultants (NHC). 2003. Stream Summaries: Trepanier, Peachland, Powers, Lambly, and Mission Creeks (draft). Prepared for the Ministry of Water, Land and Air Protection, Fisheries Branch.

Northwest Hydraulic Consultants (NHC). 2005. Trout Creek Water Use Plan Fisheries Report. Overview of Fish and Fish Habitat Resources, and Aquatic Ecosystem Flow Requirements in Trout Creek. northwest hydraulic consultants ltd., Vancouver, B.C.

Northwest Hydraulic Consultants Ltd. (NHC). 2004. Naturalized and Fisheries Conservation Flows for Trout Creek near Summerland, B.C. Prepared for the Ministry of Water, Land and Air Protection

Northwest Power and Conservation Council (NPCC). 2004. The Okanogan Subbasin Management Plan.

OBMEP. 2014. Okanogan Basin Monitoring and Evaluation Program, 2013 Annual Progress Report. Colville Confederated Tribes Fish and Wildlife Department, Nespelem, WA. Report submitted to the Bonneville Power Administration, Project No. 2003-022-00.

OBMEP. 2015. Okanogan Basin Monitoring and Evaluation Program, 2014 Annual Progress Report. Colville Confederated Tribes Fish and Wildlife Department, Nespelem, WA. Report submitted to the Bonneville Power Administration, Project No. 2003-022-00.

OBMEP. 2016. Okanogan Basin Monitoring and Evaluation Program, 2015 Annual Progress Report. Colville Confederated Tribes Fish and Wildlife Department, Nespelem, WA. Report submitted to the Bonneville Power Administration, Project No. 2003-022-00.

OBMEP. 2017. Okanogan Basin Monitoring and Evaluation Program, 2016 Annual Progress Report. Colville Confederated Tribes Fish and Wildlife Department, Nespelem, WA. Report submitted to the Bonneville Power Administration, Project No. 2003-022-00.

OBMEP. 2018. Okanogan Basin Monitoring and Evaluation Program, 2017 Annual Progress Report. Colville Confederated Tribes Fish and Wildlife Department, Nespelem, WA. Report submitted to the Bonneville Power Administration, Project No. 2003-022-00.

OBMEP. 2019. Okanogan Basin Monitoring and Evaluation Program, 2018 Annual Progress Report. Colville Confederated Tribes Fish and Wildlife Department, Nespelem, WA. Report submitted to the Bonneville Power Administration, Project No. 2003-022-00.

Okanagan Nation Alliance (ONA). 2012. Unpublished Data for the Kokanee Spawner Enumeration and Biological Sampling in Shingle Creek in 2012.

Okanagan Nation Alliance (ONA). 2019. ONA Unpublished Data - ONA collects enumeration information on Okanagan River Chinook spawners annually and also has periodically collected fry outmigration information.

Okanagan Nation Alliance (ONA). 2020. Okanagan Nation Alliance Website. www.syilx.org

Payne, T.R., S.E. Eggers, and D.B. Parkinson. 2004. The Number of Transects Required to Compute a Robust PHABSIM Habitat Index. Hydroecol. Appl. 14:1. Pp. 27-53.

Pearson, G.A. 1977. Okanagan Sub-region - Southern Interior Region Technical Report. Degradation in the Production of Stream Spawning Kokanee in the Okanagan Lake System.

Peven, C. 2003. Population Structure, Status and Life Histories of Upper Columbia Steelhead, Spring and Summer/fall Chinook, Sockeye, Coho Salmon, Bull Trout, Westslope Cutthroat Trout, Non-migratory Rainbow Trout, Pacific Lamprey, and Sturgeon.

ptagis. 2018. PIT Tag Recoveries. Retrieved from http://www.ptagis.org

Ptolemy, R. 2019. B.C. Ministry of Environment, developed the database (HydroMaster) for calculating areal runoff, Mean Annual Discharge, and summer and winter monthly minimum flows by Ecoprovince and EcoRegion based on historic flow records published by the Water Survey of Canada.

Ptolemy, R. and A. Lewis. 2002. Rational for Multiple British Columbia Instream Flow Standards to Maintain Ecosystem Function and Biodiversity. Prepared for the Ministry of Water, LAND AND Air Protection, Ministry of sustainable Resource Management.

R Core Team. 2015. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from https://www.R-project.org/.

Rae, R. 2005. The State of Fish and Fish Habitat in the Okanagan and Similkameen Basins. Prepared for the Canadian Okanagan Basin Technical Working Group. Westbank, B.C.

Reiser, D.W and T.C. Bjornn. 1979. Influence of Forest and Rangeland Management on Anadromous Fish. Habitat in Western North America Habitat Requirements of Anadromous Salmonids. USDA Forest Service Anadromous Fish Habitat Program. Pacific Northwest Forest and Range Experiment Station.

Resources Information Standards Committee (RISC). 2018. Manual of British Columbia Hydrometric Standards, Version 2.0, December 2018. Knowledge Management Branch, B.C. Ministry of Environment and Climate Change Strategy, Victoria, B.C.

Richter, B. and H. Richter. 2000. Prescribing Flood Regimes to Sustain Riparian Ecosystems along Meandering Rivers. Conservation biology 14 (5).

Rivard-Sirois C., C. Louie, and N. Audy. 2012. Okanagan Sub-basin Habitat Improvement Program (OSHIP), 2010-2011 Surveys, Shuttleworth Creek, snʕax̌əlqaxʷiyaʔ (Vaseux Creek) and akskʷəkʷant (Inkaneep Creek). Prepared by the Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Rivard-Sirois, C. 2013. Fish Passage at Shingle Creek Dam. Scoping Conceptual Options. Prepared for the Penticton Indian Band and the Okanogan Sub-Basin Habitat Improvement Program – Colville Confederated Tribes. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Rivard-Sirois, C. and N. Audy. 2010. Okanagan Subbasin Habitat Improvement Program (OSHIP) – 2009 Results. Prepared by the Okanagan Nation Alliance Fisheries Department. Westbank, B.C. 133 pp.

Roberge, M., J.M.B. Hume, C.K. Minns, and T. Slaney. 2002. Life History Characteristics of Freshwater Fishes occurring in British Columbia and the Yukon, with Major Emphasis on Stream Habitat Characteristics. Fisheries and Oceans Canada. Marina Environmental and Habitat Science Division. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2611.

Robertson, I.J.M. 1983. Nashwito Creek Applications –File Nos. 80296, 80297. Regional Manager, Fish and Wildlife, Okanagan Region.

Scott, M., J. Friedman, and G. Auble. 1996. Fluvial Process and the Establishment of Bottomland Trees. Geomorphology 14 p. 327-339.

Shepherd, B.G. 1993. Letter re: Estimates of Fisheries Flow Requirements for Penticton Creek for Migration, Spawning and Incubation in 1993. Ecocat Report ID 44475

Shepherd, B.G. and R. Ptolemy. 1999. Flows for Fish: Requirements for Okanagan Lake Tributaries (Draft). B.C. Ministry of Environment, Lands and Parks, Penticton, B.C., 76 pp.

Snow, C., C. Frady, D. Grundy, B. Goodman, and A. Haukenes. 2018. Monitoring and Evaluation of the Wells Hatchery and Methow Hatchery Programs: 2017 Annual Report. Report to Douglas PUD, Grant PUD, Chelan PUD, and the Wells and Rocky Reach HCP Hatchery Committees, and the Priest Rapids Hatchery Subcommittees, East Wenatchee, WA.

Sontek. 2007. Flowtracker Handheld ADV Technical Manual. San Diego, CA, U.S.A.

SonTek. 2016. FlowTracker2 User’s Manual 1.1. Release 45-0120 Rev B. San Diego, CA, U.S.A.

Stalnaker, C. B., and J.L. Arnette. 1976. Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment,” U.S. Fish and Wildl. Serv., Off. Biol. Serv., Washington, D.C., 199 p.

Summit Environmental Consultants Ltd. (SECL). 1995. Naramata & Robinson Creeks Stream Assessment. Prepared for B.C. Ministry of Environment, Lands and Parks.

Summit Environmental Consultants Ltd. (SECL). 1996. Watershed Restoration Program. McDougall Creek Watershed Assessment. Prepared for Heartland Economics Ltd. and Westbank First Nation, March 1996.

Summit Environmental Consultants Ltd. (SECL). 2002. Okanagan River Sockeye Egg and Alevin Development Data Summary. Prepared for Okanagan Nation Fisheries Commission.

Sungaila, H. 2015. Shuttleworth Creek Sediment Basin Construction Report: 2015. Prepared for the Ministry of Forests, Lands and Natural Resource Operations and Okanagan Regional Wildlife Heritage Fund Society. Prepared by Okanagan Nation Alliance Fisheries Department. Westbank, B.C.

Swoffer Instruments, Inc. n.d. Model 2100 Series Current Velocity Meters: Instructions for Operation and Maintenance of 2100 Indicator. Seattle, WA, U.S.A. 1-8.

Tennant, D.L. 1976. Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources. Fisheries 1: 6-10.

Tharme, R. E. 2003. A Global Perspective on Environmental Flow Assessment: Emerging Trends in the Development and Application of Environmental Flow Methodologies for Rivers. River Research and Applications. 19: 397-441.

Thompson, K. 1972. Determining stream flows for fish life. In Proceedings, Instream Flow Requirement Workshop, Pac. Northwest River Basin Comm., Vancouver, Wash. p. 31-50.

Tonasket, E. 2007. Sockeye Egg and Alevin Development Summary 2006. Prepared for Douglas County PUD.

Tredger, C.D. 1976. Adult Kokanee Enumeration and Population Estimates for Some Streams tributary to Upper Okanagan Basin lakes, October 1976.

Tredger, C.D. 1988. Okanagan Lake Tributary Assessment: Progress in 1987. Ministry of Environment, Victoria, B.C. June 1988.

Tredger, C.D. 1989a. Fish Production Capacity of Mission Creek at 4 Modelled Discharge Levels. Ministry of Environment, Victoria, B.C. March 1989.

Tredger, C.D. 1989b. Fish Production Capacity Okanagan Lake Tributary Assessment: Progress in 1988. Ministry of Environment, Victoria, B.C. March 1989.

Tredger, C.D. and J.C. Wightman. 1988. Assessment of Powers Creek Rainbow Trout carrying capacity (August 1979). Ministry of Environment and Parks, Victoria B.C. June 1988.

Triton Environmental Consultants (Triton). 2009. Habitat Suitability for Small Bodied Chinook in the Thompson Nicola Watershed. Prepared by Triton Environmental Consultants, Richmond, B.C. for Fraser Basin Council, B.C. Ministry of Environment and Fisheries and Oceans Canada.

Turner, D., M.J. Bradford, J.G. Venditti, and R.M. Peterman. 2016. Evaluating Uncertainty in Physical Habitat Modelling in a High-Gradient Mountain Stream. River Research and Applications, 32(5), pp.1106-1115.

Walsh, M. and K. Long. 2006a. Survey of Barriers to Anadromous Fish Migration in the Canadian Okanagan Sub-basin. Prepared by the Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

Walsh, M. and K. Long. 2006b. Okanagan Basin Monitoring and Evaluation Program (OBMEP) 2005 Annual Report for Sites in Canada. Prepared by the Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

Walsh, M. and L. Wiens. 2006. Skaha Lake Kokanee Salmon Spawner Enumeration and Biological Sampling 2005. Prepared for Grant County Public Utility District and Chelan County Public Utility District.

Washington Department of Fish and Wildlife (WDFW). 2004. Instream Flow Study Guidelines: Technical and Habitat Suitability Issues. Washington Department of Fish and Wildlife.

Water Management Consultants. 2005. Trout Creek Water Use Plan Operating Agreement. Prepared for Trout Creek Water Use Plan Consultative Committee, c/o District of Summerland, Summerland, B.C.

Water Management Consultants. 2010. Mission Creek Water Use Plan. Prepared for: Mission Creek Watershed Partnership, c/o Black Mountain Irrigation District, Kelowna, B.C.

Water Survey of Canada (WSC). 2015. Measuring Discharge with Flowtracker Acoustic Doppler Velocimeters. Environment Canada, Ottawa, Ont. 1-29.

Water Sustainability Act (WSA). 2016. Retrieved from http://www.bclaws.ca/civix/document/id/complete/statreg/14015.

Webster, J. 2005. 2004 Kokanee Stream Spawner Enumeration of the Okanagan Valley's Main Lakes. EcoCat Report ID 9498.

Webster, J. 2008. 2008 Kokanee Stream Spawner Enumeration of the Okanagan Basin’s Main Lakes. Ecocat Report ID 16064.

Webster, J. 2010. 2009 Kokanee Stream Spawner Enumeration of the Okanagan Basin’s Main Lakes. EcoCat Report ID 17800.

Webster, J. 2011. 2010 Kokanee Stream Spawner Enumeration of the Okanagan Basin’s Main Lakes. EcoCat Report ID 20975.

Webster, J. 2012. 2011 Kokanee Stream Spawner Enumeration of the Okanagan Basin’s Main Lakes. EcoCat Report ID 25665.

Webster, J. 2012. 2012 Kokanee Stream Spawner Enumeration of the Okanagan Basin’s Main Lakes. EcoCat ID 37913.

Webster, J. 2014. Enumeration and Biological Sampling of Stream Spawning Kokanee from the Okanagan Basin's Main Lakes, 2013. EcoCat Report ID 41634.

Webster, J. 2015a. Enumeration and Biological Sampling of Stream Spawning Kokanee from the Okanagan Basin's Main Lakes, 2014. EcoCat Report ID 48651.

Webster, J. 2015b. Enumeration and Biological Sampling of Stream Spawning Kokanee from the Okanagan Basin's Main Lakes, 2015. EcoCat Report ID 52898.

Webster, J. 2016. Estimation of Adult Kokanee Escapement, Egg Deposition, Fry Abundance and Egg-to-Fry Survival at Mission Creek Spawning Channel, 2015 Brood. Prepared for Ministry of the Environment, Penticton, B.C.

Webster, J. 2017. Enumeration and Biological Sampling of Stream Spawning Kokanee from the Main Lakes of the Okanagan Basin, 2016. Prepared for Ministry of Forests, Lands and Natural Resource Operations. February 2017. EcoCat Report ID 52892.

White, T. and R. Ptolemy. 2011a. Map of Ecosections of Summer Low Flow Sensitivities in B.C. Fish & Wildlife Branch Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Thompson-Okanagan Region.

White, T. and R. Ptolemy. 2011b. Map of Ecosections of Winter Low Flow Sensitivities in B.C. Fish & Wildlife Branch Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Thompson-Okanagan Region.

Wickham, H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016.

Wightman, J.C. 1975. Enumeration of Rainbow Trout at the Smith-Alphonse Dam on Mission Creek, Near Kelowna, with Reference to Passage through an Alaskan Steep Pass Fishway. Fish and Wildlife Branch, Victoria, B.C.

Wightman, J.C. and G.D. Taylor. 1978. Overview and Rating of Production Capabilities and Enhancement Opportunities for Rainbow Trout and Kokanee in Tributaries to Upper Okanagan Basin Lakes. Fish Habitat and Improvement Section, Fish and Wildlife Branch. Ministry of Recreation and Conservation, Victoria, B.C.

Wildstone Resources Ltd. 1992. Okanagan Lake Tributaries Plan, Volume 1 Mission Creek Management Place, Includes Overview. Prepared for Planning and Assessment, Southern Interior Region, B.C. Environment.

Wildstone Resources Ltd. 1997. Overview Fish Habitat Assessment Procedure Equesis, Nashwito, Whiteman and Shorts Creeks. Prepared for Okanagan Indian Band, April 1997.

Wildstone Resources Ltd. 1999. Lower Mill Creek Channel Assessment. Prepared for Glenmore-Ellison Improvement District and the City of Kelowna.

Wodchyc, K., L. Wiens, and R. Benson. 2007. Skaha Lake Kokanee Spawner Enumeration and Biological Sampling 2006. Prepared for the Grant County Public Utility District and Chelan County Public Utility District. Westbank, B.C.

Yaniw, N. and R. Benson. 2017. q̓awst'ik'wt (Skaha Lake) Nerkid Spawner Enumeration and Biological Sampling 2015. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Yaniw, N. and R. Benson. 2018. q̓awst'ik'wt (Skaha Lake) Nerkid Spawner Enumeration and Biological Sampling 2016. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Yaniw, N. and R. Benson. in prep 2019a. q̓awst'ik'wt (Skaha Lake) Nerkid Spawner Enumeration and Biological Sampling 2017. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

Yaniw, N. and R. Benson. In prep 2019b. q̇awst'ik'wt (Skaha Lake) Nerkid Spawner Enumeration and Biological Sampling 2018. Prepared for the Skaha Lake Sockeye Re-Introduction Program. Westbank, B.C.

APPENDICES