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.

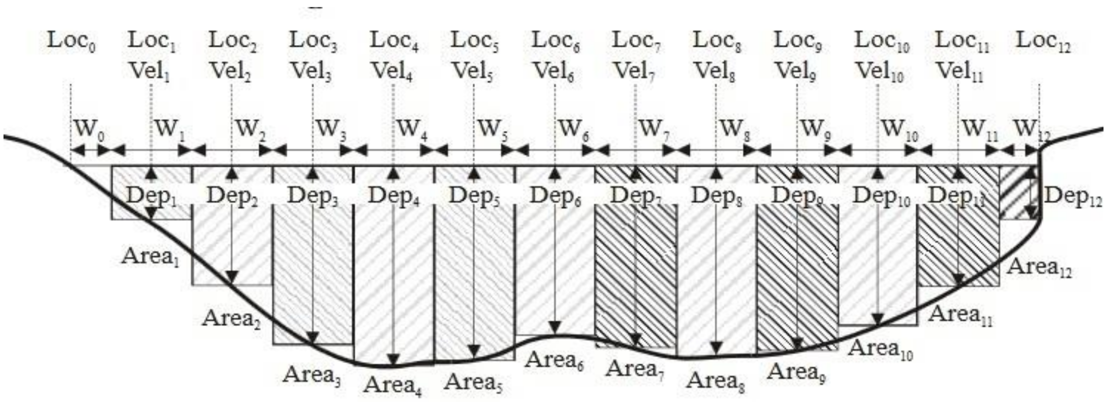

Figure 2-1: The FlowTracker's mid-section discharge equation (SonTek 2007)

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 $148*LTMAD^{-0.36}$ (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 ≥ 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.