GEOMORPHIC
CONSULTING

Xwulqw’selu Sta’lo (Koksilah River)
Environmental Flow Assessment

Prepared For:
COWICHAN WATERSHED BOARD
4335 Riverside Drive
Duncan, BC Canada
V9L 6M8

Prepared By:
GEOMORPHIC CONSULTING
3961 Pioneer Place
Smithers, BC Canada
V0J 2N0
+1-250-643-2043

March 30, 2022

CWB – 2022 – 1 – R1

Executive Summary

Water holds a prominent place in culture, science, policy, community values and recreational pursuits. Yet, it remains under valued in comparison to the role that it plays in society and in the cycle of life in the Cowichan Valley, British Columbia. To explore the importance of water in the Xwulqw'selu Sta'lo (Koksilah River), an *Environmental Flow Assessment* (EFA) was performed.

To investigate the environmental flows of the Koksilah River, several assessments, each complementing one another, were conducted between April and October of 2021. The three assessments included (i) an evaluation of channel condition, (ii) an evaluation of water supply, and (iii) an evaluation of instream habitat-flow relationships for rearing Coho and Steelhead fry in addition to looking at Chinook passage through riffles.

Chapter 1 provides an overview of environmental flows to contextualize the three components of the EFA that were performed. This chapter frames *environmental flows* first in the global context with the establishment of the *Brisbane Declaration* (2007), then by the Global Call to Action on *Environmental Flows* (2017), and finally, by their history and application in riverine environments.

Chapter 2 presents the first component of the EFA which was an assessment of channel and riverscape condition. This assessment was accomplished through a Meso-Habitat Evaluation (MHE) for the lower Koksilah River, a 5,775 m segment upstream of the Island Highway bridge. The MHE characterized riverscape condition within this segment of the Koksilah River.

The main outcome of the MHE was defining the evolutionary stages of the stream channel and recognizing the associated ecological value (current conditions) is very low. These degraded / ecologically depleted evolutionary stream stages are the legacy of land-use.

Chapter 3 presents the second component of the EFA which was a desktop scoping exercise to investigate water supply and current *environmental flow needs (EFN)*. The EFA was conducted using five different hydrologic (historic), *standard-setting,* EFN methods. Each method relied on Water Survey of Canada (WSC) hydrometric data (1960-2021). To contextualize water supply impacts a low-flow assessment of the Koksilah River was performed. Low-flow conditions were investigated with the use of the Canadian Climate Normal Windows for potential changes in the timing or magnitude of peak flows due to climate change.

The main finding of the EFN scoping exercise was the sheer magnitude of water supply deficits. The scoping exercise focused on the life history needs of summer rearing Coho and Steelhead fry. Results from the assessment identified profound EFN deficits in the Koksilah River between April and November. Water deficits in the Koksilah River ranged between 250% and 950%.

Chapter 4 presents the third component of the EFA which is a field-based Instream Flow Incremental Methodology (IFIM) employed to explore instream habitat-flow relationships for rearing Coho and Steelhead fry along with passage of adult Chinook through riffles.

Using the habitat-hydraulic model, five main investigations were made that included: (i) max rearing potential for Coho fry, (ii) max rearing potential for summer Steelhead fry, (iii) insect production in riffles, (iv) fine sediment deposition in glides, and (v) adult chinook passage through riffles. From these five investigations a multi-value environmental flow range was presented.

To maximize aquatic health, and to plan for sustainable salmon and Steelhead populations in the Koksilah River, meeting or exceeding the following summer baseflows could be considered as essential:

1. Coho fry: 0.25 - 0.75 m3/s | 2.5 - 7.5% MAD
2. Steelhead fry: 0.25 - 0.7 m3/s | 2.5 - 7% MAD
3. Insect production: 1 - 6 m3/s | 10 - 60% MAD
4. Siltation of glides: >0.3 m3/s | >3% MAD
5. Chinook passage: >1.0 m3/s | >10% MAD

Chapter 5 presents a synthesis of each chapter and recommends next steps. The most notable outcome from the Meso-Habitat Evaluation was revealing the degraded evolutionary stage(s) the lower Koksilah River. These findings are sharply contrasted by the historical knowledge of healthy ecosystems and thriving salmon runs in the Koksilah River. Therefore, this speaks towards the need to restore the riverscape [floodplain, riparian, stream] to increase the available *environmental water / environmental flows*.

Collectively, the results from the three components of the EFA speak towards the interplay between *environmental flows* stream restoration, as the study results indicate that during summer low-flow conditions, EFN are not being met for either people or nature. The concluding remarks in Chapter 5 are that the magnitude of these water supply deficits suggests the mechanisms are watershed scale. From this analysis it is suggested that a loss of watershed integrity has destabilised key ecological functions in the Koksilah Watershed. As such, both people and nature are in water deficit for 4+ months of the year.

Problems of this scale are best suited to larger scale processes such as watershed planning processes or watershed management plans that can address both the mechanisms and restoration solutions. In such processes goals and objectives around the restoration of watershed integrity, ecological function, and riverscape condition would be appropriate. Such a progression would build on the Forest Practices Board's (2018) findings that ‘watershed scale planning is both missing and essential’.

The Xwulqw'selu Sta'lo (Koksilah River) Environmental Flow Assessment was designed to investigate several objectives, including: (1) Coho fry rearing; (2) Steelhead fry rearing; and (3) adult Chinook passage. Next steps that can be taken to address each of the restoration goals presented in Chapters 2-4 include:

1. **Meso-habitat mapping** – Mapping in key tributaries can advance restoration planning and deepen the understanding of geomorphic condition and recovery potential in those tributaries.
2. **Peak-flow analysis** – Performing a peak flow analysis to understand the mechanisms behind these flow events will be critical piece of the picture towards restoring ecosystem functions and riverscape health.
3. **Precipitation analysis** – Performing a regional analysis would provide an opportunity to compare how different watersheds are responding to precipitation events as compared to the Koksilah. Such an analysis may confirm whether the increase 1:2 return periods are due to climate variability or due to land-use changes.
4. **Historical aerial photo analysis** – Reviewing historical aerial photographs can assist with restoration planning by identifying risks and opportunities for restoration design and implementation.
5. **Expanding the Tier 1 EFA -** Adding Indigenous, agricultural and community flow needs would enhance a 'whole of watershed' approach and provide a platform to understand water needs.
6. **Expanding the Tier 2 EFA –** Both validating HSI's and adding bioenergetics suite of tools would each strengthen the scientific understanding of limiting factors in the Koksilah River.
7. **Watershed Restoration Plan** – The vast extend of habitat degradation revealed in the lower Koksilah River speaks clearly towards the need for watershed-scale restoration and management. As a watershed restoration plan is formed it is suggested that plan be based on: (i) a credible framework that can (ii) integrate process-based restoration.
8. **Process-Based Restoration Team** – It is self-evident that the Koksilah River and its tributaries will require on-going, process-based restoration / ecological restoration. Process-based restoration embraces a 'whole of watershed' approach and lends itself to being implemented through local capacity - such as Guardians, Technicians, youth, or community / stream keeper volunteers. Taking initial steps to put several summer jobs in place and supply training for a 'stream team' would reap rewards at many levels.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

LIST OF APPENDICES

Acknowledgments

Geomorphic wishes to thank the Cowichan Watershed Board and Cowichan Tribes for the opportunity to work on the Twinned Watershed Project. CWB contractors and staff Cheri Ayers, Melissa Evans, Jill Thompson and Tom Rutherford made this a wonderful experience - thank you.

Khowutzun Forest Services (KFS) technicians were the engine behind the project and deserve a shout out for working through the heat wave and providing rigorous field data. Cowichan Tribes biologist Tim Kulchyski helped to ground the project and provided welcomed guidance and wisdom on the Koksilah River.

Miranda Smith at MC Wright and Associates did a wonderful job in translating the riverscape data into a series of online Habitat Atlas maps that tell a wonderful story. Many thanks for your guidance on this.

This project would not have been possible without the generosity of the many landowners who provided the field crews access to the river. A big thank you to Ministry of Land, Water and Resource Stewardship staff Jamison Romano for providing field equipment and field training for the crews to initiate the project.

Much of the technical guidance, early planning and field design benefited from the wisdom of Ministry of Lands, Water and Resource Stewardship (MLWRS) staff Jaro Szczot (Aquatic Ecologist) and Ron Ptolemy (Rivers Biologist / Instream Flow Specialist). Finally, the assistance from the POLIS Project on Ecological Governance provided the necessary direction to get the project off the ground.

Countless thanks are owed to my advisors and / or reviewers who have helped to identify the strengths and weaknesses of this work and where it can be improved. Special thanks to Dr. Ian Jowett (ret. Instream Flow Specialist), Ron Ptolemy (Instream Flow Specialist), Mike Miles (Fluvial Geomorphologist), Dr. Dave Wilford (MLWRS, Research Hydrologist) and Dr. John Rex (MLWRS, Research Hydrologist) for their thoughtful and insightful guidance.

1 INTRODUCTION

1.1 Project Context

Over the past number of years water has been elevated to the centre of planning, resource management, and policy discussions. First Nations often refer to water as the *life-giving force,* as *sacred,* and as *essential for all life.* Similarly, western science has described water as the 'master variable' in both the distribution and abundance of fish and fish habitat (Poff et al., 1997; DFO 2013). Commensurate with each of these sentiments, water requires a prominent role in policy, regulation, planning, and management if we are to have a sustainable future where the needs of both people and nature are being met (Annear et al., 2004).

Land-use in the Xwulqw'selu Sta'lo (Koksilah River) Watershed has had significant and measurable impacts on the health and condition of the riverscape. The watershed struggles with both extreme flood and extreme drought events, making both people and nature vulnerable to the life-sustaining resources [water] they rely upon. The volume and timing of flows in the Koksilah watershed are altering river condition and adversely impacting both water users (e.g., agriculture, municipal) and water dependents (Quw'utsun Nation People, salmon, trout, wildlife). In recent history, neither people nor nature in the Koksilah Watershed are meeting their *environmental flows needs*, primarily due to insufficient *environmental water* at key times.

To address these issues, the Cowichan Watershed Board (CWB) retained Geomorphic Consulting to perform an environmental flow assessment of the lower Koksilah River, which is important rearing habitat for Coho and Steelhead fry along with critical spawning habitat for Chinook salmon.

1.2 Environmental Flow Overview

Environmental Water (EW) is the contemporary term used to describe *Environmental Flow Needs (EFN)*, which from the 1970s to early 1990s was referred to as *Instream Flow Needs (IFN)*. Parallel to the development of that nomenclature were *critical flows*, *sustenance flows,* and *ecological flows*, among others. The evolution of this nomenclature is not trivial in that it signifies the structural underpinning of the instream flow science being used or considered. Indigenous flow signifies one such structural underpinning.

There are over 200 recognized methods – including both field and desktop approaches - to assess available instream flow around the world (IFC 2002). The Instream Flow Council (IFC), who governs the methods and practices for Canada and the U.S., recognizes approximately 75 methods (Annear *et al*., 2004) and provides a description of the intent, strengths, and weaknesses of each technique they endorse in their textbook *Instream Flows for Riverine Resource Stewardship* (IFC, 2002).

In British Columbia, *Instream Flows* were first introduced through the BC Instream Flow Methodology (Lewis et al., 2004) in response to hydropower interest at the time (Independent Power Producers (IPPs)). More recently, the BC Water Sustainability Act (BCWSA), and the Environmental Flow Needs Policy (BC ENV 2016) were introduced into government mandates. However, this mandate for the integration of EFN resides explicitly within the regulatory framework for water authorizations unless a Water Sustainability Plan Process is initiated. This process allows for *Whole of Watershed* planning and management of water values.

In Canada, including BC, there are no regulations for EFN (WMO, 2019); instead, British Columbia deals with aquatic ecosystems through several *Acts* such as the: Forest and Range Practices Act, Environmental Assessment Act, Water Protection Act, Water Sustainability Act. etc. Until the BC WSA, and specifically the potential within the Watershed Sustainability Plan process, there has been no explicit connection between land-use and environmental flows / environmental water.

Looking more broadly, at the *10th International River Symposium and Environmental Flows Conference*, held in Brisbane, Australia in 2007, more than 800 scientist, economists, engineers, resource managers and policy makers from 57 nations penned what is now referred to as the *Brisbane Declaration* which states that:

> *"…Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems…"*

Since its inception in 2007, this [Brisbane Declaration] definition has become the global standard for instream flow policy, regulation, and science. The common thread between almost all instream flow science, in addition to the 10th and 20th International River Symposiums on Environmental Flows, the CWRA's hosting of Environmental Flows conference in BC in 2018, and the European Commissions' Ecological Flows Framework (EC, 2015), is the overwhelming agreement to prioritize EFN / EW for the protection and restoration of healthy watersheds.

1.3 Environmental Flow Application

Aquatic ecosystem health can only be protected by preserving the intrinsic ecosystem processes and functions necessary for the rivers' physical, chemical, and biological processes (Annear et al 2004). Aquatic ecosystem functions are, in turn, based on five main riverine components which include: hydrology, biology, water quality, geomorphology, and connectivity (Locke et al., 2008). As such, instream flow science tends to rely upon one or several of these riverine components to assess the EFN / IFN / EW to assess aquatic health.

Available EFN / IFN methods can be split into two distinct categories (e.g., Jowett 1997; Stalnaker et al., 1995; Summit 1998), which include:

(i) **Standard Setting methods** which are primarily **office-based** scoping exercises that rely upon historic hydrology data to predict the required streamflow to sustain aquatic life; and
(ii) **Incremental methods** which are primarily **field-driven**, intensive studies that rely upon collecting physical and biological data to predict the required streamflow to sustain aquatic life.

Both standard setting and incremental methods have a role in the management of aquatic ecosystems. Standard setting methods are often used over broad areas as a scoping exercise to identify potential seasonal issues; whereas incremental methods are site-specific tools used once an issue has been identified. Incremental methods, such as IFIM, show how river characteristics vary with flow (incrementally) and do not make any decision on flow requirements.

Tharme (2003) reviewed international trends in environmental flow management and divided assessment methods into two levels: (i) reconnaissance-level initiatives that rely on existing hydrology (such as standard setting); and (ii) a more comprehensive scale of assessment where the incremental approach is used. Both Tharme (2003) and Stalnaker (1995) have articulated a two-tier approach to understanding riverine health and instream flow science (Table 1-1).

Table 1-1. A categorical comparison of instream flow methods. (From Stalnaker et al., 1995)

Standard Setting	Incremental
Low controversy projects	High controversy project
Reconnaissance level planning	Project-specific
Few decision variables	Many decision variables
Inexpensive	Expensive
Fast	Lengthy
Rule-of-thumb	In-depth knowledge required
Identify restoration needs	Identify restoration objectives / design
Based on historical hydrology data	Based on fish or habitat data collection

The assessment of environmental flows / environmental water, however, requires one further division of scientific underpinning to understand the technique being employed. Within the science of instream flows there are three main approaches employed, which include: (i) historic, (ii) hydraulic, and (iii) habitat approaches (Figure 1-1; Jowett, 1997). The descriptions are as they sound, historic approaches use historic hydrology data to predict habitat suitability; hydraulic approaches use field surveying and hydraulic models to predict habitat suitability; habitat approaches use biological data to predict habitat suitability; and hybrid approaches combine the hydraulic and habitat approaches. Hybrid approaches are among the most common and most robust approaches available.

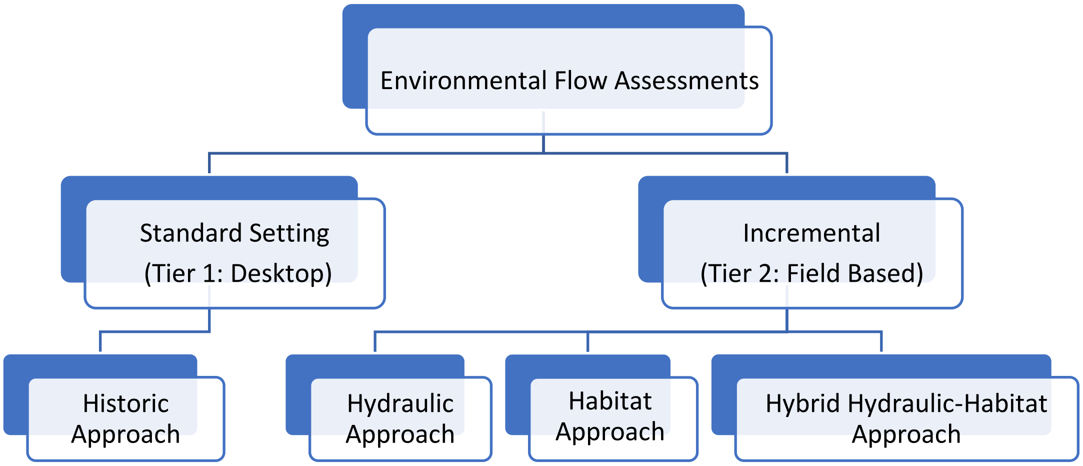


Figure 1-1. Two-tiered environmental flow assessment hierarchical framework.

According to an international review conducted by the UK Environment agency, incremental approaches are considered the most defensible methods in existence (Dunbar et al., 1998). Similarly, the Freshwater Research Institute of the University of Cape Town states: "…. *incremental methods are currently considered to be the most sophisticated, and scientifically and legally defensible, methodology available for quantitatively assessing the instream flow requirements of rivers…*" (Tharme, 1996).

Standard Setting methods are desirable because they can be used to understand the EFN / EW supply issues of the stream quickly with limited resources. Following Poff's (1997) assertion that streamflow (hydrology) is the 'master variable' in the distribution of fish and fish habitat, standard setting methods tend to rely solely on historic hydrology data (historic approach). Specifically, this approach prescribes percentages of mean annual discharge (MAD) as the EFN requirements.

Although Standard Setting methods rely upon existing hydrometric data, they are all based on extensive field data and empirical relationships between fish and flow. As early as 1985 the Department and Fisheries and Oceans (DFO) along with the Ministry of Environment (MoE) had recognized that prescribed percentages of MAD could be used to predict the suitability of streamflow for fish and fish habitat (Newcombe and Ptolemy, 1985). During the hydropower push in the early 2000s the BC Ministry of Sustainable Resource Management, and BC Ministry of Water, Land, and Air Protection produced guidelines for the use of standard setting methods in BC (Hatfield et al., 2003).

More comprehensive reviews of these methods can be found at:

- Instream Flow for Riverine Stewardship textbook (Annear et al., 2004),
- Review of Approaches and Methods to Assess Environmental Flows across Canada and Internationally (Linnansaari et al., 2013),
- Development of Instream Flow Thresholds as Guidelines for Reviewing Proposed Water Uses (Hatfield et al., 2003), and
- Appendices section of the *Alberta Desktop Method* (Locke and Paul, 2011).

1.4 Project Overview

The aim of the Xwulqw'selu Sta'lo (Koksilah River) Environmental Flow Assessment (EFA) is sustainable management of landscapes and riverscapes in the Cowichan Valley. Water is a central focus of this project as both people and nature are struggling to meet their *environmental flow / environmental water* needs. Water, in the greater Cowichan Valley, has become a story of extremes; whereby, both extreme flood and drought events are not only increasing in frequency and magnitude, but also occurring in the same year, back-to-back – where, in the Koksilah River, extreme floods are followed by extreme low-flow conditions.

The Twinned Watershed Project includes both the Koksilah and Chemainus rivers. This report is specifically about the Koksilah River. A companion document presents the results of the Chemainus Environmental Flow Assessment. The focus of this report is warm season low-flow conditions in the Koksilah River. To explore this issue, an Environmental Flows Assessment (EFA) has been performed. An EFA approach was chosen for three primary reasons, as follows:

(i) *Environmental Flows* and / or *Indigenous flows* support the foundational rights to water and a healthy ecosystem that enable the exercising of Aboriginal Section 35 Rights (CWRA 2018) and it appears that the EFN / IFN are not being met for the Quw'utsun Nation people;

(ii) EFA methods were developed to protect, conserve, and restore aquatic ecosystems to have sustainable futures where both human and ecological needs are being met; and

(iii) The *British Columbia Water Sustainability Act (2016)* makes specific provisions for *environmental flows, indigenous rights,* and watershed-scale planning, which are all essential for sustaining a healthy river to meet the needs of both people and nature.

1.5 Koksilah River Environmental Flow Assessment

The Koksilah River Environmental Flow Assessment has several complementary, yet independent, parts that follow the above Chapter 1: Introduction. These are as follows:

Chapter 2: Meso-Habitat Evaluation
Chapter 3: Environmental Water – Supply
Chapter 4: Environmental Water – Availability
Chapter 5: Report Synthesis

Chapter 2 (Meso-Habitat Evaluation) aims to characterize the riverscape that low-flows are occurring within. Chapter 3 (Environmental Water Supply) investigates historical water supply. While Chapter 4 (Environmental Water Availability) aims to quantify the instream habitat-flow relationships to better understand rearing conditions for Coho and Steelhead fry along with [potential low-flow] implications for migrating adult Chinook. Chapter 5 (Report Synthesis) will draw from the previous three sections to make larger inferences.

Two additional studies were commission to support the work outlined above. These include a: (i) low-flow analysis to support Chapter 3, and (ii) regional integration study to contextualize the watershed behaviour in comparison to nearby watersheds. These two studies are presented in the Appendices.

2 MESO-HABITAT EVALUATION

2.1 Study Area

The Koksilah River watershed is situated on southeastern Vancouver Island (Figure 2-1) within the traditional territory of the Quw'utsun Nation People. The Koksilah watershed is 311 km^2 and ranges in elevation from sea level to its highest point on Waterloo Mountain at 1070 metres above sea level (masl; Figure 2-2). Land-use in the watershed includes urban development mixed with agriculture in the lower watershed and forestry in the middle to upper watershed.

Land-use in the watershed has recently been investigated and has been described as over 97% impacted by anthropogenic development (Prichard et al., 2019). Watershed wide, this amounts to roughly 85% forestry, 14% agriculture, and 1% urban development (Prichard et al. 2019). The Koksilah River threads its way through the working lands of this riverscape, collecting numerous tributaries along the way, and eventually merging its with the Cowichan River near the tidal limit. The Koksilah River EFA occurred in the lower watershed, from approximately 2.5 to 7 km upstream of the Cowichan River (Figure 2-2).

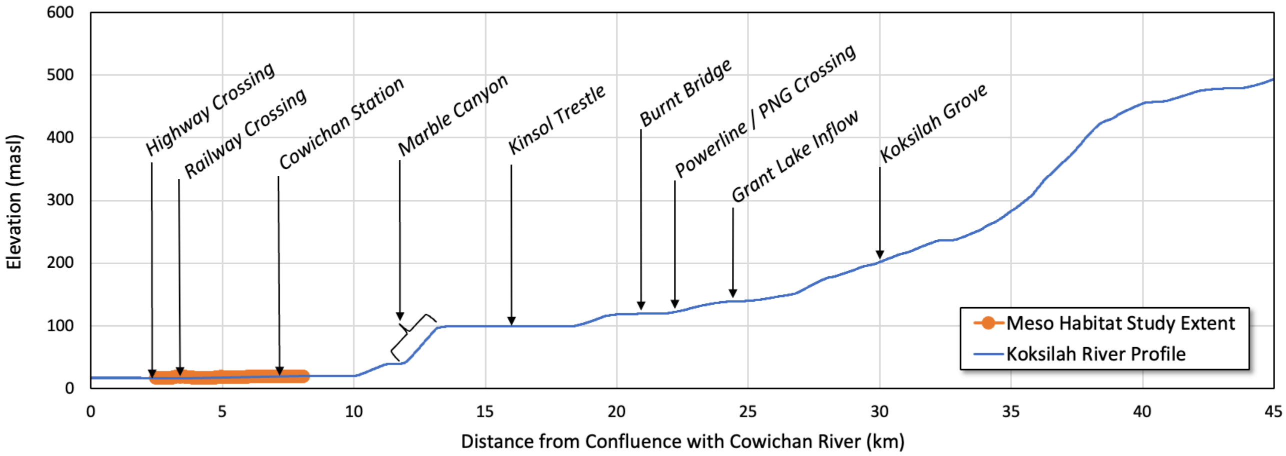


Figure 2-2. Longitudinal profile of the Koksilah River showing study area in lower watershed.

2.2 Meso-Habitat Background

The Meso-Habitat Evaluation (MHE) was inspired by the Watershed Restoration Program (BC Gov, FPC, 1995) and the suite of tools that were used to inventory fish-bearing streams. The MHE was developed to fill a void in management of fish and fish habitat, and that is: readily available data on fish habitat at a scale that is meaningful for fish, and for resource management.

The Meso-Habitat Evaluation, by design, is building on the Fish and Fish Habitat Assessment Procedures (FHAP; Johnson and Slaney 1996), Channel Assessment Procedure (CAP; FPC 1999), and Riparian Assessment Procedure (RAP; Koning 1999) as these were well laid out, comprehensive guidebooks. More specifically, each was designed prior to the digital integration of the present day; ironically, this appears to be what has held each of these procedures back from ubiquitous use over the past 20 years.

The updated context of the Meso-Habitat Evaluation is therefore about:

(i) building on past tools developed by the Ministry of Forests (FHAP, CAP, RAP),
(ii) adding new tools and new science (RGA and WPC), and
(iii) packaging the results in the context of stream evolution, geomorphic condition, and Process-Based Restoration (Beechie 2010).

The Koksilah River is located on Southeastern Vancouver Island (Figure 2-1) and the MHE was applied to a 5.7 km segment of the lower Koksilah River (Figure 2-2) as a mean of evaluating habitat condition.

2.3 Meso-Habitat Evaluation Methods

2.3.1 Methodological Overview

The integrated Meso-Habitat Evaluation is comprised of several components that include: (1) habitat condition, (2) riparian condition, (3) channel condition, (4) substrate composition, (5) stream evolution (SEM & REM), and (6) stream influence (SET). Most of these components have pre-existing protocols that make up the architecture of the Meso-Habitat Evaluation.

Pre-existing procedures that have been integrated into the Meso-Habitat Evaluation include: (i) Rapid Geomorphic Assessment (RGA), (ii) Wolman’s Pebble Count (WPC), (iii) Fish Habitat Assessment Procedure (FHAP), (iv) Channel Assessment Procedure (CAP), and (v) Riparian Assessment Procedure (RAP). In addition to the pre-existing protocols, three river evolution models have been included which are the: (1) Cluer and Thorne (2014) *Stream Evolution Model* (SEM; Figure 2-3), (2) Castro Thorne (2019*) Stream Evolution Triangle* (SET; Figure 2-4), and (3) Wheaton et al. (2019) Riverscapes Evolution Model (REM; Figure 2-5). Integrating the stream evolution models into the MHE provides a means of relating existing conditions to recovery potential.

There are inevitably aspects of the pre-existing protocols and procedure that are not included in the MHE methodology, largely because they are overly onerous to be included in rapid stream assessment protocol. It is suggested that any omissions or exclusion that were made does not alter the integrity of the MHE methodology. Moreover, the integrated and updated nature of the MHE methodology is its strength.

As each of the existing protocols is available elsewhere for review and detailed accounts of precision and accuracy for individual field measurements, it should simply be stated that the field protocols employed in the Meso-Habitat Evaluation meet or exceed the guidance provided by British Columbia Resource Industry Committee (RISC) guidelines / protocols (several). Those field protocols that are not addressed by specific RISC guidelines, such as the inclusion of RGA, WPC, SEM, and SET, are simply because they are new additions to stream / habitat surveys in British Columbia.

There were many aspects of the pre-existing procedures / protocols that were qualitatively obtained (e.g., visual estimates). As such, an aim of the MHE was to increase the level rigour and to provide scientifically defensible field measurements so that the MHE produces are repeatable, quantitative results representing riverine condition and recovery potential.

In summary, the MHE draws from numerous new and existing protocols and brings them together in a single framework. Results are presented in the context of stream evolution and geomorphic condition to frame the results in the larger context of recovery potential for the benefit of people and nature [healthy riverscapes].

2.3.2 Detailed Methodology

The Meso-Habitat Evaluation was based on a continuous stream survey from a downstream starting point to an upstream end point. This methodology is applied at the scale of stream reaches and consists of walking slowly upstream while collecting detailed and specific field measurements. The whole procedure is based on an iPad and simple hand-held instruments.

Field Practices

Distances were captured with Rangefinders, depths with metric metre sticks, gradients with Abney Levels, substrate composition with Gravelometers, coordinates with handheld GPSs, and all data entry was conducted in the field with an iPad using the FileMaker App. Field crews were trained to meet or exceed RISC guidelines as they pertained to field data collection.

Meso-Habitat Typing

Meso-habitat typing is the identification of geomorphic units such as pools, riffles, runs, and glides. The identification of meso-habitats is outlined very well in the *Fish-Stream Identification Guidebook* (FPC 1998), along with the *Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Reach Information Guide* (RISC 2000). All aspects of the MHE either meet or exceed the pertinent RISC standards.

During the Meso-Habitat field work, two different types of glides were observed. This included a natural glide that would typically be found downstream of a pool as flow starts to converge; and an unnatural glide that was not associated with pools at all, but resembled pools. The unnatural glides were formed because of large sediment slugs introduced into the river – which are deposits of sediment from landslides and / or debris flows that are slowly working their way downstream during peak flow events. Each time the slugs are reworked and redeposited they backwater streamflow upstream of them. As these are peak flow deposits, the crest (top) elevations are quite high, and this results in glides that are hundreds of meters long (100-400 m). Throughout this report natural glides are referred to as 'shallow glides' while unnatural glides are referred to as 'deep glides.'

Analysis

All field data collection was through the Meso-Habitat Evaluation App which is on the FileMaker platform. Field data collection using the Meso-Habitat App was conducted with FileMaker19 Go. Following field data collection, using FileMakerPro (FMP), data were summarized and analyzed using programmed calculations. In addition to the physical parameters collected in the field, derived parameters calculated in FMP included, but were not limited to:

(i) Width-depth ratio

(ii) Entrenchment and Incision ratios
(iii) Structure / km
(iv) Meso-habitat by % of reach
(v) Riffles and holding pools / km
(vi) SEM, SET by % of reach
(vii) Off-Channel and Secondary Habitat / km
(viii) Floodplain availability

Physical and derived parameters were exported with meso-habitat resolution. A summary analysis was also conducted / programmed in FMP, which organized parameters by reach and by meso-habitat units (pool, riffle, glide, etc.). By summarizing the meso-habitat data at the reach and meso-habitat scales, inferences can be made about reach-scale trends and management options. Finally, FMP was used to calculate various indicators of riverscape health which included:

(i) Structural Influence
(ii) Habitat Complexity
(iii) Meso-Habitat Condition
(iv) Floodplain Availability
(v) Channel Condition
(vi) Geomorphic Condition
(vii) Geomorphic Influence

Stream substrate composition, collected with the Wolman Pebble Count Methodology (Wolman 1954), was analyzed using resources published by the United States Forest Service (USFS), Rocky Mountain Research Station, Fort Collins, Colorado (Bunte and Steven, 2011). With these resources common substrate health metrics were derived which included:

(i) Histogram, Frequency Distribution, Cumulative Percent
(ii) D_{16}, D_{50}, D_{84}, D_{95}, D_g
(iii) % Fines (<2 mm & <8 mm)

Substrate data collection using the WPC Methodology was conducted throughout / during the field data collection and aimed to characterize the representative conditions of riffle and glide meso-habitat units. All pebble counts were based on the collection of 100 stones using the heal-toe method and ‘blind’ selection of each stone.

2.4 Meso-Habitat Evaluation Results

Meso-Habitat Evaluation results are presented in two sections that include: (i) the Lower Koksilah River, which presents the stream, channel, and substrate characteristics, and (ii) Riverscape Health Indicators, which presents the geomorphic condition, along with the condition of structure and habitat complexity. Each is described in the sections below.

2.4.1 Lower Koksilah River

Meso-habitat assemblages were mapped continuously from the Highway Bridge over the Koksilah River to a point 5,775 m upstream (Figure 2–9). The Meso-Habitat evaluation was focused on the lower six reaches of the Koksilah River (Koksilah Habitat Atlas, 2021). The analysis groups result by reach and by meso-habitat type (e.g., pool, riffle, glide) to look closely at riverscape indicators and characteristics.

Stream Characteristics

The meso-habitat types encountered in the reaches 2-6 of the Koksilah River were pools, riffles, glides, and runs (Table 2-1; Figure 2–6). Deep, classic pools were infrequent. Deep glides were very frequent and irregular in their form and function (Table 2-1). Overall, throughout Reaches 2-6, glides composed81% of the total habitat, runs 4%, riffles 12%, and pools 3% (Table 2-1; Figure 4-2).

The MHE was conducted at lower flows (1-5% MAD) which yielded *wetted depths* of 0.27 - 0.37 m in riffles, 0.4 0.5 m in shallow glides, and 2.0 m in pools (Table 2-1). Across all reaches and meso-habitats, *wetted width* ranged between 11-28 m, compared to bankful widths ranging between 21-43 m. Average length of deep glides was 295 m compared to 48 m for shallow glides. Similarly, wetted depth for pools in Reach 3 and Reach 4 were significantly deeper (18-25%) than the Reach 2 pools (Table 2-1).

Stream cover throughout the lower Koksilah ranged between 10-20% for Reaches 1-3 and increased to 20-30% in Reach 4 (Table 2-2). Reaches 1 and 2 also had almost entirely eroding banks, while primary disturbances in Reach 3 was bed scour, and in Reach 4, un-vegetated bars.

Channel Characteristics

Channel characteristics provide insight into the structure and complexity of the channel in reaches 2-6. Drawing from several metrics help paint a well-rounded picture of the structure and complexity in Reaches 2-6 of the Koksilah River (Table 2-2).

Stream substrates in the lower Koksilah tended to alternate between gravel-fine and fine-gravel with intermittent pockets of gravel-cobble (Figure 2-6). A visual estimate of spawning gravels indicated that much of the lower Koksilah River had low to fair spawning gravel quality with isolated locations where there were no spawning gravels (Figure 2-7).

The W-D ratio of glides ranged between 10 (Reach 6) and 50 (Reach 5); whereas the W-D ratio of riffles ranged between 34 (Reach 4) and 69 (Reach 3); and pools ranged between 8 (Reach 4) and 9 (Reach 5) (Table 2-1; Figure 2-13).

P*rimary Disturbance* differs between reaches in the lower Koksilah (Table 2-2; Figure 2-14). What appears to be clear in the channel characteristics is that the 'sediment slugs' that have been working their way downstream for decades are most prevalent in Reach 4 and Reach 6 as indicated by 'unvegetated and mid-channel bars; in contrast, *Eroding Banks* are prevalent in Reach 2 and Reach 3 (Table 2-2; Figure 2-13) where the sediment slugs are less prevalent.

Channel Entrenchment corroborates the *Primary Disturbance* observation in that, where there are un-vegetated bars (Reach 4 and 6), and the channel is aggrading (sediment slugs) the MHE shows lower *Channel Entrenchment* values (Table 2-2; Figure 2-15).

Stream Incision is a depth metric comparing the 'bankfull depth' to the 'wetted depth' and this indicates whether a stream is connected [or disconnected] from its' floodplain. Stream incision values $\leq$1 indicate a connected floodplain. The clearest result from *Stream Incision* is revealed in reaches 2, 4 and 6 where much of each reach was *incised*. In contrast, only portions of reaches 3 and 5 were incised (Table 2-2; Figure 2-16).

Off-Channel (OC) and *Secondary Habitat* (SH) are directly correlated with channel entrenchment and incision, as evidenced by the distribution of OC and SH in the lower Koksilah River. At the outset, there was very low quantity of woody debris within the channel contributing to in-channel complexity and SH (Table 2-2). Reach 3 had the highest OC (72 m or 5% of the reach length), followed by Reach 4 which had 30 m (2.8% of reach length) of OC habitat. In reaches 5 and 6 where were the only reaches with appreciable secondary habitat (Table 2-2).

Substrate Characteristics

Substrate characteristics were acquired using the Wolman Pebble Count (WPC) methodology (Wolman 1954). In total, 17 WPCs were collected to represent riffles and glides throughout reaches 2-6. Ten WPCs were collected in riffles, five in *Deep Glides* and two in *Shallow Glides*. All 17 WPC were based on 100 stones collected. In total 1700 stones were collected in the lower Koksilah River. Pools were not sampled as their depth prevented gathering the pebbles to count.

The *Frequency Distribution* of substrates of *Deep Glides*, *Shallow Glides* and *Riffles* was generally similar with three subtle differences. First, and not surprisingly, riffles had higher frequencies of large gravel and small cobbles than other meso-habitats (higher velocity environment); second, Shallow Glides had high frequencies of medium and large gravels that other meso-habitat; and lastly, Deep Glides had higher frequency of fine substrate (<2mm) than the other meso-habitats (Figure 2-6).

The *Cumulative Distribution* of substrates across Deep *Glides*, *Shallow Glides* and *Riffles* revealed expected differences in substrate characteristics (Figure 2-7). Immediately evident in the cumulative distribution is how different *Shallow Glides* are from *Deep Glides,* and how similar *Deep Glides* are to *Riffles* (Figure 2-5). *Deep Glides* consistently had larger substrates than *Shallow Glides* (Figure 2-6). *Deep Glides* had larger D_{16}, D_{50}, D_g, D_{84} and D_{95} than Shallow Glides (Table 2-3). However, in contrast to this, *Deep Glides* had 4.3% fines while *Shallow Glides* had only 0.5% fines (<2 mm); whereas, *Deep Glides, Shallow Glides* and *Riffles* all had similar percentages of larger fines (<8 mm) (Table 2-3).

2.4.2 Riverscape Health Indicators

Riverscape Health Indicators (RHIs) are collected at the meso-habitat scale but presented at the reach scale to roll-up the RHI to a management scale that is both meaning for the mechanism and for the fish and fish habitat (Wheaton et al. 2017). Seven RHIs are presented below, including: (i) structural influence, (ii) habitat complexity, (iii) meso-habitat condition, (iv) floodplain availability, (v) channel condition, (vi) geomorphic condition, (vii) geomorphic influence.

Structural influence included Functional Wood Debris, Wood Accumulations, Instream Structure and Beaver Dams as each can apply structural influence on river processes. Overall, there was very little structural complexity within the lower Koksilah River (barring the odd, but unusually large, log jam). One to eight pieces of Woody Debris were observed (per km); with even fewer Wood Accumulations and Instream Structure; there were no beaver dams observed (Table 2-4; Figure 2-17).

Habitat Complexity was represented by *Off-Channel* and *Secondary Habitats*. Off-Channel Habitat (OH) ranged between 0-7% of total reach length and Secondary Habitat (SH) ranged between 0-6% of total reach length (Table 2-4; Figure 2-18).

Meso-Habitat Condition included Holding Pools and Riffles (per km) along with composition of meso-habitat. Both pools (<1 /km) and riffles (<4 /km) were relatively infrequent in reaches 2-6 of the Koksilah River (Table 2-4). Section 2.4.1 presented the meso-habitat assemblages, reach by reach, which showed that 76% of the total stream length assessed (5,775 m) was Deep Glides, and that holding pools were very infrequent.

Channel Condition was assessed using floodplain connectivity, channel incision, channel entrenchment, and W-D ratio of riffles. Collectively, these were used to assess the expected condition (Table 2-5).

Geomorphic Condition is expressed as the Riverscape Evolution Model (Figure 2-3; Wheaton et al. 2019) which integrates the Cluer and Thorne (2014) Stream Evolution Model (Figure 2-1). Reaches 2-6, and the meso-habitats within them, fall within two stream REM stages that are (i) *Widening*, and (ii) *Aggrading / Widening* (Table 2-5), SEM stages 4-6 (Figure 2-3; Figure 2-19; Figure 2-20).

Geomorphic Influence was expressed as the Stream Evolution Triangle (Figure 2-4; Castro and Thorne, 2018) and categorizes reaches as influenced by either biology, hydrology, geology, or a mix of two. Unsurprisingly, the predominant influences in the Koksilah River are hydrology, with geology as a secondary influence along certain sections of the lower Koksilah River (Table 2-5; Figure 2-21).

Floodplain Availability was assessed in the field. A stream adjacent floodplain was considered available if it could plausibly flood within the contemporary flow regime. Although seemingly subjective, there was usually plenty of evidence to show when the stream was making it over the banks during flood events. Results suggest that there is very little available floodplain but that in Reach 1 there was 45 hectares of floodplain identified (Table 2-2; Figure 2-22). Understanding of course that these are private lands, this process is simply to understand is the river has the components it needs (riparian, floodplain) to be healthy.

In summary, field data for seven Riverscape Health Indicators (RHI) were collected and presented. Each RHI can / should be thought of with a school analogy in mind - whereby, seven different RHI grades contribute to an overall pass/fail for the *reach* of interest. A passing grade may require: (i) no failing grades in any of the RHI, and (ii) either all average grades or some good and some bad. A passing grade would suggest a healthy, climate resilient riverscape that can bolster the impacts of both floods and droughts while providing sufficient environmental flows / environmental water to meet the needs of both people and nature. A 'report card' of riverscape condition was developed to summarize the MHE.

Table 2-1. Koksilah River Meso-Habitat Evaluation. Stream Characteristics.

Reach	Meso-Habitat Type	Total Length (m)	Avg. Length (m)	Number of MH Units	% of Reach	Avg. Bankful		Avg. Wetted		Avg. Streambank		Avg. Width-Depth Ratio	Avg. Slope (%)
						Width (m)	Depth (m)	Width (m)	Depth (m)	Length (m)	Slope (°)		
2	Riffle	162	41	5	6%	31.8	1.90	16.3	0.28	10	37	58	0.9
	Run	39	39	1	1%	32.0	2.25	11.0	0.75	2	48	15	0.5
	Shallow Glide	43	43	1	2%	33.0	2.00	11.0	0.50	3	60	22	0.5
	Deep Glide	1135	227	5	40%	30.4	2.36	18.4	0.82	14	59	22	0.4
3	Riffle	232	46	5	8%	27.0	1.30	18.6	0.27	5	44	69	0.9
	Run	90	45	2	3%	21.5	1.55	15.5	0.45	5	24	34	0.8
	Shallow Glide	113	57	2	4%	26.0	1.30	18.5	0.40	2	45	46	0.6
	Deep Glide	1032	206	5	36%	22.0	1.70	18.8	1.02	2	56	18	0.3
4	Pool	75	75	1	3%	18.0	3.40	15.0	2.00	23	50	8	0.0
	Riffle	170	34	5	6%	30.4	1.33	12.6	0.37	12	38	34	1.0
	Run	125	125	1	4%	43.0	2.00	28.0	0.40	3	88	70	1.0
	Deep Glide	684	137	5	24%	27.0	2.13	18.8	1.15	9	53	16	0.2
5	Deep Glide	775	775	2	27%	31.0	1.50	25.0	0.50	7	15	50	0.3
6	Pool	78	39	3	3%	34.5	2.60	17.5	2.00	4	53	9	0.3
	Riffle	133	44	3	5%	25.0	1.12	13.0	0.27	18	44	48	1.3
	Shallow Glide	141	47	3	5%	24.0	1.47	17.7	0.47	21	47	38	0.6
	Deep Glide	748	125	6	26%	23.2	2.53	17.8	1.80	17	40	10	0.3

Table 2-2. Koksilah River Meso-Habitat Evaluation. Channel Characteristics.

Reach	Meso-Habitat Type	Number of MH Units	Primary Disturbance	Off-Channel Habitat (m)	Secondary Habitat (m)	LWD / 100 m	Riparian Cover	Channel Entrenchment		Stream Incision		Floodplain Availability	
								Ratio	% Entrenched	Ratio	% Incised	% Stream Length	Area (ha)
2	Riffle	5	Eroding Bank	20	5.7	4	11–20%	1.3:1	9%	3.8:1	9%	12%	3
	Run	1	Eroding Bank	0	0	5	31–40%	1.1:1	3%	1:1	0%	3%	1
	Shallow Glide	1	Bed Scour	0	0	2	1–10%	1.1:1	3%	1:1	0%	3%	1
	Deep Glide	5	Eroding Bank	0	0	1	21–30%	1.4:1	28%	5.3:1	54%	73%	16
3	Riffle	5	Eroding Bank	15	0	5	11–20%	1.2:1	11%	3.6:1	1%	16%	6
	Run	2	Wood Accumulation	0	0	2	11–20%	1.4:1	4%	1:1	0%	6%	1
	Shallow Glide	2	Eroding Bank	7	0	4	1–10%	1.1:1	8%	1.6:1	3%	8%	2
	Deep Glide	5	Eroding Bank	50	0	2	11–20%	1.1:1	70%	1.1:1	0%	70%	26
4	Pool	1	Unvegetated Bar	0	0	0	11–20%	2.1:1	0%	5.1:1	7%	7%	2
	Riffle	5	Eroding Bank	30	0	2	11–20%	1.7:1	7%	3.4:1	13%	14%	1
	Run	1	Log Jam	0	0	5	11–20%	1:1	12%	1.6:1	0%	12%	3
	Deep Glide	5	Eroding Bank	0	0	1	11–20%	1.3:1	53%	3.6:1	54%	34%	2
5	Deep Glide	2	Eroding Bank	0	77	0	21–30%	1.4:1	0%	1.1:1	0%	4%	0
6	Pool	3	Bed Scour	0	47	3	11–20%	1.1:1	7%	1:1	0%	4%	0
	Riffle	3	Bed Scour	25	0	1	21–30%	2.0:1	4%	11:1	12%	12%	1
	Shallow Glide	3	Mid-channel Bar	0	0	0	21–30%	2.0:1	0%	10:1	13%	13%	1
	Deep Glide	6	Unvegetated Bar	0	0	0	21–30%	2.0:1	0%	5.8:1	61%	34%	3

* Channel Entrenchment Values: 1.0-1.4 = Entrenched; 1.4-2.2 = Moderately Entrenched, 2.2 = Slightly Entrenched

* Channel Incision Values: Value of 1.0 indicates connected floodplain. The greater the number the more disconnected the floodplain.

Table 2-3. Koksilah River Substrate Ranges.

	D_{16} (mm)	D_{50} (mm)	D_g (mm)	D_{84} (mm)	D_{95} (mm)	% Fines (< 2 mm)	% Fines (< 8 mm)
Deep Glides	13	32	26	51	88	4.3	12
Shallow Glides	7	18	16	35	52	0.5	12
Riffles	10	29	24	59	89	1.3	10

Table 2-4. Koksilah River Meso-Habitat Indicators.

REACH	STRUCTURAL INFLUENCE				MESO-HABITAT CONDITION					HABITAT COMPLEXITY		FLOODPLAIN AVAILABLITY	
	Functional Woody	Wood Accumulations	Instream Structure	Beaver Dams	Holding Pools	Riffles	Pools	Riffles	Glides	Off-Channel Habitat	Secondary Habitat	River Left	River Right
	(F-LWD / km)	(Wood Accum. / km)	(>50% Span / km)	(Dams / km)	(Pools / km)	(Riffles / km)	(% of Reach Length)			(% of Reach Length)		(ha)	(ha)
2	0.00	0.03	0.01	0.00	<1	3	0	6	42	2	0.4	6	15
3	0.00	0.04	0.01	0.00	<1	3	0	8	40	5	6	22	13
4	0.00	0.06	0.04	0.00	<1	5	3	6	24	3	0	7	1
5	0.00	0.00	0.00	0.00	<1	0	0	0	27	0	10	0	0
6	0.00	0.02	0.00	0.00	<1	3	3	5	31	2	4	2	3

Table 2-5. Koksilah Riverscape Health Indicators

REACH	CHANNEL CONDITION				GEOMORPHIC CONDITION				GEOMORPHIC INFLUENCE			
	Floodplain Connectivity	Entranchment > Moderate	Incision > Moderate	Width-Depth Riffles	Anastamosing (SEM 8,0,1)	Incised /Incising (SEM 2-3)	Widening (SEM 4)	Agrading / Widening (SEM 5,6,7)	Biology	Hydrology	Geology	Mixed
	(% of Reach Length)			(Avg. W-D Ratio)	(% of Reach Length)				(% of Reach Length)			
2	37	100	63	15	0	0	100	0	0	100	0	0
3	96	100	4	19	0	0	20	80	0	100	0	0
4	25	88	75	18	0	0	63	37	0	66	34	0
5	100	100	0	21	0	0	0	100	0	100	0	0
6	14	69	86	15	0	0	39	61	0	83	17	0

2.5 Meso-Habitat Discussion

2.5.1 Context

The MHE is a rapid assessment. Field data collection is however rigorous, and the protocol generates a substantial quantity of continuous, riverscape (floodplain, riparian, stream) data. To properly digest this information, it is first necessary to mention that three very relevant advances have occurred in river science over the past two decades. These advances have included, but are certainly not limited to, (1) the contribution of *process-based restoration* (Beechie 2004), (2) development of much needed stream evolution models (Castro and Thorne 2018; Cluer and Thorne 2014; Wheaton et al. 2019), and (3) a literature review on the role of wood in streams, and its influence on fluvial processes (Roni et al. 2014).

These advances have brought about new tools, perspectives and approaches to river science, restoration and management of fish and fish habitat. The MHE is well aligned these advances including the: (1) River Styles approach (Brierley and Fryirs 2005), (2) process-based restoration (Beechie 2004); (3) packaging this information in the context of stream evolution (Castro and Thorne 2018; Cluer and Thorne 2014; Wheaton et al. 2019), and (4) thoroughly quantifying instream structure (Roni et al. 2014).

Structure forces complexity. Complexity results in diversity, heterogeneity, and resilience. Resilience in turn may result in ecological resistance whereby the stream can withstand extreme events and undergo adjustment without any ecological degradation. Stream evolution models help us to package current conditions in the context of geomorphic condition and recovery potential (Wheaton et al. 2019).

2.5.2 Lower Koksilah River Condition

The MHE of the lower Koksilah River covered an area from the Island Highway bridge upstream 5,775 m. Of the many observations captured within the data, there were two observations that were particularly informative towards understanding riverscape health, these were: (i) the formation of Deep Glides, and (ii) almost no structure and complexity in the lower Koksilah River.

During the Meso-Habitat Evaluation field work it was repeatedly observed that ‘irregular glides’ were very prevalent and ‘normal glides’ were infrequent. Within this report, ‘irregular glides’ will be referred to as ‘Deep Glides’ and ‘normal glides’ will be referred to as ‘Shallow Glides.

The *Deep Glides* were an observation made during the MHE and they are in response to an imbalance in the sediment budget. Specifically, as large sediment wedges (slugs) are reworked and re-deposited during high-magnitude flood events (e.g., November 2021), the deposits (sediment slugs) act as weirs and create a backwater effect upstream. The crest elevation of the deposits is proportional to the high-magnitude flood event and therefore leaves behind a crest elevation that is inappropriate at lower flows, creating a myriad of problems, including stranding and fish passage.

Deep Glide meso-habitats in the lower Koksilah River are hundreds of metres long. Natural {shallow} glides should be 1-2 channel widths in their form and function. As such, the length of *Deep Glides* (avg. length 224 m ranging from 180 m - 370 m) compared to *Shallow Glides* (25-50 m) in the lower Koksilah is basically an order of magnitude longer than they should be.

The MHE revealed that deep glides account for 71% of stream length (4,100 m or 5,575 m) and that the stream characteristics within these meso-habitats have very little structure and complexity (Figure 2-17 and Figure 2-18). This is alarming as there is a disproportionately positive relationship in fluvial environments between structure and complexity. It cannot be overstated how important structure is to stream health. Within river science it is commonly understood that structure forces complexity. As evidenced by Riverscape Principle 4: *Structure forces complexity and builds resilience* (Wheaton et al. 2019).

Across all reaches in the lower Koksilah River, the average structure, as represented by LWD, was 1.2 pieces / 100 m (Table 2-4; Figure 2-17). That translates to approximately 0.4 piece / channel width, which, under the *Watershed Restoration Program*, this amount of structure would have been considered 'poor' (Johnston and Slaney 1996). Equally as infrequent was *Off-Channel Habitat* and *Secondary Habitat*, which are both key attributes of habitat complexity (Figure 2-18).

It is suggested that the lack of *Off-Channel* and *Secondary Habitat* is due to high-magnitude flood events. As stream power overwhelms stream resistance (structure) the surviving channel is degraded into simpler planform (e.g., SEM 2-4). Under this condition off-channel habitat may become stranded, side channels can dry out, and the mainstem becomes confined, with higher return period events contained within the channel.

A stream that is neither entrenched nor incised inherently has higher structure and complexity (Pollock et al. 2014).

Typically, the processes of steam incision also result in a loss of channel structure and complexity (Rosgen 1996, Schumm et al. 1984, Shields et al. 1999), as stream power is concentrated within the channel for higher return periods. For example, bankful discharge in a healthy riverscape is around 1:5-to-2-year return period; whereas bankful discharge in an incised channel may support 1:5 or 1:10.

This concentration of stream power overwhelms structural capacity (resistance) of wood accumulations and instream or riparian vegetation. This is evidenced in the Koksilah River, post flood event, by mattresses of willow peeled from the bar it is growing on. To that end, a concentration of stream power appears to be sterilizing the lower Koksilah River of its structure and complexity. Without structure and complexity, a stream has little resilience.

Figure 2-23 shows (with the direction of arrows) how channel incision and channel widening advance in addition to how channel aggrading often occurs following channel widening. MHE results indicate and alternating pattern of stream incision in the lower Koksilah River, with four specific sections of stream incision (Figure 2-16). Each section is composed of six to eight individual meso-habitat units. Interestingly, the sections classified as Incised (Figure 2-16) correspond to SEM stage 5, which is *Degradation and Widening* (Figure 2-19).

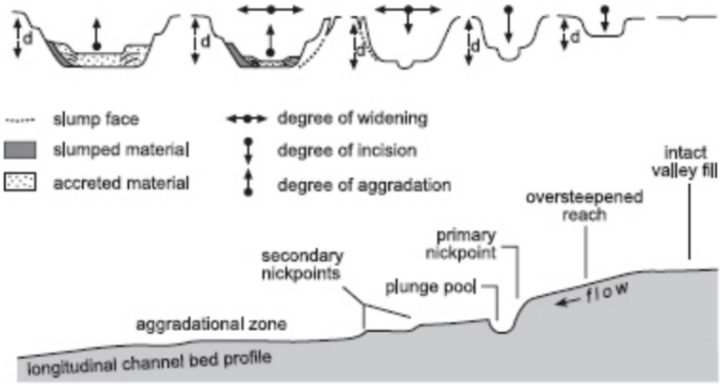


Figure 2-23. Stages of incised channel development. Source: Brierley and Fryirs (2005).

Where stream incision is a vertical context, channel entrenchment is a horizontal context (Rosgen 2006). Channel Entrenchment is a width metric comparing the 'flood prone width' to the 'bankful width' and indicates how confined the channel may be. Low entrenchment values indicate that flood water is concentrated within the channel and unable to access an adjacent floodplain during high flow (Figure 2-22). When floodplains are inaccessible floodwaters are not able to dissipate energy across the floodplain, and stream power is concentrated within the confined channel.

Confined channels that experience high magnitude peak flows such as the Koksilah River are subject to bank and bed erosion as channel shape adjusts to stream power. The MHE results indicate that reaches 2-6 all have high percentages of eroding banks or bed scour as the *Primary Disturbance*, and all three of these reaches are reported as *Entrenched* (Table 2-2). Whereas Reach 6 was shown to be aggrading and the least entrenched.

In summary, the primary observations made from the stream and channel characteristics were that: (i) Deep Glides account for 76% of the total habitat area; (ii) there are alternating sections of stream incision and aggradation; (iii) there is virtually no structure or complexity in the lower Koksilah River; (iv) deep pools are infrequent; and (v) riffles are wide and shallow and potentially an impediment to migrating adult Chinook during summer low-flows.

2.5.3 Riverscape Health Indicators

Wheaton et al. (2019) outlined four *Riverscape Principles* to guide the management and restoration of riverscapes, these are:

1. *Streams need space,*
2. *Structure forces complexity and builds resilience,*
3. *The importance of structure varies, and*
4. *Inefficient conveyance of water is healthy.*

In keeping with the above principles, the Riverscape Health Indicators are collectively intended to represent riverscape health. Following the assessment of the RHI, including: (i) structural influence, (ii) meso-habitat conditions, (iii) habitat complexity, (iv) floodplain availability, (v) channel condition, (vi) geomorphic condition, and (vii) geomorphic influence, there were three main observations made for the lower Koksilah River.

Geomorphic & Structural Influence

Structure and complexity in the Koksilah River were extremely low (Tables 2-2, 2-4, 2-5) and this is communicated most clearly through RHI *Geomorphic Influence* (Table 2-5). *Geomorphic Influence* is based on the Stream Evolution Triangle (SET) and is used to identify and communicate the influential forces responsible for channel form and function. This is presented very nicely in Figure 2-4 which shows the observed SEM stages [4-6] as occurring within the 'hydrology-geology' range of [SET] influence observed in the Koksilah River MHE results.

Of the nearly six kilometres of stream assessed, 89% was dominated by hydrology (Table 2-5). Given this, it is fair to suggest that the Koksilah River is 'stuck' in degrading [SEM] stages [potentially] due to the peak flow events and hydrological dominance. It is these peak flow events that are responsible for stripping the Koksilah River of its structure, complexity, and resilience. It is worth noting that RHI, *Geomorphic Influence*, both demonstrates that hydrology dominates river form and function in the Koksilah River.

Geomorphic Condition

Geomorphic influence (SET) goes hand in hand with *Geomorphic Condition* (SEM) as shown in Figure 2.2. The *Geomorphic Condition* of the lower Koksilah River was *Incising* and *Widening / Incising* (Figure 2-5; Figure 2-20). The significance of understanding Geomorphic Condition (SEM / REM) is knowing what habitat values to expect from these evolutionary stages (Figure 2.3; Figure 2-19) and therefore recovery potential.

Stream evolution in the lower Koksilah River (Reaches 2-6) were SEM stages 4-6. These are single thread degrading SEM stages and the significance of this is that Figure 2-1 shows SEM stages 4-6 to contain some of the lowest habitat values; this is evidenced through the MHE results indicating very little structure and complexity (Tables 2.2 - 2.5). This is further evidenced by the fact that the lower reaches have substantial stream incision and very little Off-Channel habitat connectivity. SEM stages 4-6 have very little lateral connectivity and very low habitat value.

Meso-Habitat Condition

Meso-Habitat condition in the assessed portions of the Koksilah River was low compared to its ecological potential (landscape position). For example, all four of the reaches assessed were dominated by glides which accounted for 71% of the 5,757 m of habitat surveyed (Table 2-4). Interestingly, when glides are un-aggregated into *Deep Glides* and *Shallow Glides*, what is revealed is that Shallow Glides, or natural glides, account for only 7% of the 4,464 m of glide habitat, while Deep Glides account for the remaining 4,167 m or 93% (Figure 2-9).

Deep Glides provide very little structure and complexity (Tables 2-2, 2-4, 2-5) and have acted to reduce the frequency of holding pools (<1 / km) and riffles (+/- 2 riffles / km) in the lower Koksilah River (Table 2-4). Riffle frequency is critical for food production and the formation of Deep Glides has reduced the riffle frequency to 2 / km.

Integrating the above considerations with results from the Wolman Pebble Counts, further reveals that *Shallow Glide* habitat has much higher suitability for Chinook spawning as compared to *Deep Glide* habitat (Figure 2.9). Collectively, this indicates that 6% of the available habitat in the lower Koksilah River has suitable substrate conditions for spawning Chinook.

Applying substrate criteria for spawning Chinook (Kondolf and Wolman 1993), indicates that only 21% of the *Shallow Glide* habitat was considered as suitable for Chinook spawning; however, by comparison, only 1% of *Deep Glide* habitat was considered suitable. These results underscore the extent of degradation to channel conditions in the lower Koksilah River and further highlight the impact of Deep Glides occupying 76% of the lower Koksilah River.

Riverscape Indicator ***Summary***

It is not surprising that as watershed integrity has declined over time [due to land-use] and stream sinuosity has been reduced [due to stream straightening] that the stream evolution stages remaining are lacking structure and complexity. If the goal for the Koksilah watershed is sustainable fish populations, then consideration of restoring stream evolution through process-based restoration would be warranted as the current riverscape condition appears to have low ecological value (Figure 2-3; Figure 2-19).

In summary, many of the Riverscape Health Indicators (RHI) appear to have been affected by high-energy peak flow events, leaving behind very little habitat structure (Figure 2-17), very little habitat complexity (Figure 2-18) and [some], incised sections of river (Figure 2-16). The Meso-Habitat Evaluation has packaged these results in the context of stream evolution, geomorphic condition, and Process-Based Restoration (Beechie 2010), to provide the information and context needed for restoration planning moving forward (Table 2-6).

Table 2-6. Riverscape Condition of the Lower Koksilah River.

Riverscape Indicators	Poor	Moderate	Good
Channel Condition	x		
Geomorphic Condition	x		
Geomorphic Influence	x		
Structural Influence	x		
Meso-Habitat Condition	x		
Habitat Complexity	x		
Floodplain Avialability		x	

2.5.4 Synthesis

The MHE results have demonstrated that in the lower Koksilah River:

(i) sediment slugs are responsible for formation of *Deep Glides*,
(ii) 76% of the lower Koksilah River are *Deep Glides,*
(iii) *Deep Glides* were shown to have 1% suitable spawning substrates compared to *Shallow Glides* which had 21% suitable spawning substrates,
(iv) sediment budget is out of balance with the flow regime, and
(v) the channel is structurally starved and absent of complexity.

The metrics generated through MHE exceed the RISC field data collection requirements. The strength of claim between this rapid protocol and any conclusions made, however, lies in the connection between concepts within the SEM (Cluer and Thorne 2014), SET (Castro and Thorne 2018), REM (Wheaton et al. 2019) and current conditions of the lower Koksilah River. Using these concepts, this Chapter has potentially outlined some of the symptoms and root causes related to declining riverscape health.

The Wild Salmon Policy established six indicators to represent threats to watershed integrity (DFO 2005). Following this, the Pacific Salmon Foundation used these indicators to provide watershed assessments for salmon sensitive watersheds by grading indicators either red, yellow, or green in selected watersheds. The WSP assessment of the Koksilah Watershed (PSF Salmon Explorer) shows the threats to watershed integrity in the Koksilah Watershed (Table 2-7). The MHE results further corroborate the WSP indicator results (Table 2-7) in that they demonstrate the symptoms of low watershed integrity and broken ecosystem functions and services.

Table 2-7. Wild Salmon Policy Indicators / Threats to Watershed Integrity.

	Road Density	Stream Crossings	Riparian Disturbance	Equivalent Clearcut Area	Linear Development	Total Land Cover Alteration
Lower Koksilah	🟥	🟨	🟥	🟩	🟥	🟥
Middle Koksilah	🟥	🟨	🟨	🟩	🟥	🟨
Upper Koksilah	🟥	🟨	🟩	🟨	🟥	🟨

- Green = Good Condition; Yellow = Moderate Condition; Red = Poor Condition

The MHE results highlight the findings of the Forest Practices Board who stated in 2018 that: "…*no monitoring has been done to establish whether the planning and assessment undertaken by licensees is achieving protection of fish habitat*" (FBP, 2018). For decades it has been understood that habitat and fish populations in the Koksilah are at risk (Prichard at al., 2019), yet commensurate effort to assess the status and condition of fish habitat in the Koksilah River is yet to be realized. As early as 1973 Environment Canada (Marshall et al. 1997) had commented that "*...new logging activity in the upper reaches is causing flash flooding and excessive silting…"*

Contributing to the struggling fish populations, it has recently been shown that forest roads (PSF Salmon Explorer, Prichard et al., 2019; Hatfield 2021), forest cover changes (Hatfield 2021; Prichard et al., 2019) and increased evapotranspiration (Hatfield 2021) are all contributing to decreased groundwater recharge and decreased summer baseflow for salmon in the lower watershed.

In addition to the above, the MHE demonstrated a lack of holding pools (<1 / km), riffles (+/- 2.5 / km), woody debris (<3 / km), and habitat complexity in the lower Koksilah River. For example, the lower Koksilah River has only 2.5% off-channel habitat and 3.5% secondary habitat. These are clear symptoms of degraded watershed integrity and ecosystem functions.

The MHE results indicate that ecosystem services, such as the: (i) *provision of habitat*, (ii) *regulation of streamflow*, (iii) *regulation of sediment supply*, and (iv) *hydrologic connectivity* are failing or imperilled. To that end, four of the six ecosystem functions required for a healthy watershed and aquatic health are also imperilled in the lower Koksilah Watershed.

In summary, by demonstrating a lack of: (i) deep pools, (ii) riffles, (iii) structure and complexity, (iv) sufficient riparian corridors, (v) anastomosing sections of river, (vi) off-channel, and (vi) secondary habitat, along with high level of (viii) stream incision, and (ix) the formation of Deep Glides, has sufficiently underscored the magnitude of decline to watershed integrity and ecosystem functions and services in the Koksilah Watershed. Above and beyond all else, the MHE results indicate an urgent need for watershed scale restoration of aquatic health.

2.6 Next Steps

The application of the Meso-Habitat Evaluation is to use a rapid protocol to unearth a series of direct questions that need to be asked and answered. It is expected that these questions may require ground truthing, follow-up investigations or further inquiry. It is anticipated that there is variation in the precision (specific measurements) of these results but that the overall accuracy (reach scale summary) is sound. As such, managing reach scale riverscape health indicators are a scale that is repeatable, measurable, and meaningful for fish.

The Koksilah River is struggling with extreme floods, extreme droughts and degraded riverscape impacting both people and nature. Restoration of the aquatic health in the Koksilah River should be considered though *Whole-of-Watershed* thinking, and watershed-scale planning (FPB, 2018).

Floodplain storage is critical to reducing the impacts of both floods and droughts, while providing concurrent benefits to society, such as protection from infrastructure damage or crops without drought stress. The SEM, SET and REM are the necessary context for process-based restoration and can be used to guide restoration of headwater tributary streams. Understanding of course, that peak flows and water supply requires thorough consideration before the lower mainstem can be restored; therefore, it may be necessary to apply the 'ideal to real' approach. Presented here are 'ideal' restoration goals for the lower Koksilah River (Table 2-8); acknowledging that the mechanisms must first be dealt with before any downstream restoration can happen.

A logical next step would be to conduct a historical aerial photo interpretation to consider the *risks* and *opportunities* for process-based restoration in the greater Koksilah Watershed. Outputs from an exercise like this would include 'ideal to real' scenarios of 'restoration potential' and the risks /opportunities associated with each treatment (Wheaton et al. 2019).

Restoration goals for the Koksilah River can be drawn directly from the four main observations made during the MHE (Table 2-7). Broadly speaking, these observations include:

(1) *Deep Glides*. Increasing the percentage of SEM stages 7,8 throughout the Koksilah would introduce more complex habitat and begin to restore the *Deep Glides*.
(2) *Structural Starvation.* Working to increase the biological influence (SET) through the introduction of structure and complexity (biological uplift) is required as structure forces complexity and resilience (Wheaton et al. 2019).
(3) *Geomorphic Condition.* Increasing the percentage of *anastomosing* (REM) and / or *quasi-equilibrium*, *laterally active* (SEM) will help to off-set the poor Geomorphic Conditions throughout much of the lower Koksilah River.

Given the above four observations, along with the Riverscape Health Indicator results (Table 2-5), potential restoration goals for the Koksilah River include slowing water down, spreading water out and increasing the structure and complexity within each reach (Table 2-8).

That said, the current geomorphic condition of the lower mainstem focuses stream power within the channel therefore restoration of tributaries and higher elevation stream reaches are first required to reduce the energy profile of the lower Koksilah River.

Table 2-8. Potential Restoration Goals for the Koksilah River.

Riverscape Indicator	Goal	2-5 Years	5-10 Years
Channel Condition	Reconnect Floodplains	⇣ % Incised	⇣⇣⇣ % Incised
Geomorphic Condition	Increase % Anastamosing	10%	15%
Geomorphic Influence	Increase % Biological Influence	⇡	⇡⇡⇡
Structural Influence	Increase Structure	>4 /100 m	>8 / 100 m
Meso-Habitat Condition	Increase Deep Pool and Riffle Frequency	⇡	⇡⇡⇡
Habitat Complexity	Increase Off-Channel and Secondary Habitat	>10%	>25%
Floodplain Avialability	Increase Inset Floodplain Frequency	>10%	>25%

3 TIER 1 ENVIRONMENTAL WATER: STANDARD SETTING HISTORIC

3.1 Tier 1 Koksilah Environmental Flow Assessment Overview

Five standard setting methods have been utilized for the Koksilah River Tier 1 EFA. The same data inputs were used for each method, which included existing Water Survey of Canada hydrology data along with fish periodicity information for the species and life stages of interest in the Koksilah River. For the purposes of this investigation, the life cycle needs of summer rearing Coho and Steelhead fry along with migrating adult Chinook were the focus. A brief review of each *standard setting, historic,* method applied (Table 3-1) is presented in Appendix 3A.

Table 3-1. Periodicity Table Showing Multi-Species Life History Needs.

Standard Setting Method	Description	Appendix	Page
Tennant Method	Ascribes %MAD to Quality of Flow	3A	i
BC Modified Tennant	Ascribes %MAD to Life Stages	3A	ii
BC Desktop	Natural Flow Regime	3A	iii
Rule of Thumb	Prescribes %MAD for Salmonid Life Stages	3A	iii
Ecological Flows	Includes Flushing Flows and Formative Flows	3A	iii

3.2 Tier 1 Koksilah Environmental Flow Assessment Method

3.2.1 Model Context

Section 1.2 an overview of the origin and evolution of the science of environmental water (EW) and environmental flow needs (EFN) by touching on the vast array of EW / EFN tools, approaches, and methods available. This section presented the *Brisbane Declaration* and global support for prioritizing the protection, conservation, and restoration of EW / EFN in policy, regulation, planning, and practice.

Section 1.3 presented the primary methods in instream flow science including *standard setting*, desktop methods and *incremental*, field-based methods. This section also presented the three most common approaches to EFN assessments including (i) *historical, (ii) hydraulic,* and (iii) *habitat* approaches before reviewing five common Tier 1, standard setting, historic EFN methods. Each of these five desktop methods was reviewed for its application for the Twinned Watershed EFN model architecture.

Historically, standard setting applications have commonly selected a single method to predict EW / EFN flow thresholds. There are many risks to using a single, *standard setting* (desktop) method outside of the exact stream (physiographic setting) it was developed for. For this reason, the model architecture for the Twinned Watershed Project integrates into the analysis the combined strength of five common *standard setting* methods (Section 1.3).

This ‘integrated architecture’ is meant to provide a more robust platform to idealize the EW [predications] required to sustain the needs of both people and nature in the Koksilah Watershed. Using a combination of methods in an integrated fashion like this allows for leveraging the commonality across models and ignoring individual weaknesses. For example, a lack of fit due to the physiographic differences between where the methods were developed, and where they are applied, such as the Koksilah River.

3.2.2 Model Architecture

The Koksilah River Tier 1 EFA model architecture relies on three key inputs including:

(i) Standard setting methods (presented in Section 3.1, detailed in Appendix 3A),
(ii) Periodicity table for species of interest, and
(iii) Water Survey of Canada Hydrometric data.

Standard Setting Methods

Each of the standard setting methods that that is part of the integrated Tier 1 EFN is reviewed in Appendix 3A (including Tables 3.1-3.2) relies upon hydrometric data and a periodicity table. Hydrometric data from the Water Survey of Canada (WSC) gauging station at Cowichan Station (08HA003) and periodicity table was used to run each model, and each model output prescribed a percent MAD, week by week, to *idealize the life history needs* of the species presented in the periodicity table (Coho, Steelhead, Chinook). Using the 'integrated architecture' approach, an 'average EFN model result' was able to be extracted to represent the best guess for the Koksilah River.

Using professional judgement and empirical hydrology (low-flow statistics), the strongest components of each of the five standard setting models were used to establish the *Idealized Koksilah Conservation Flow*, week by week. The mathematics is designed to balance life history needs for rearing Coho and Steelhead fry along with migrating adult Chinook. The shape of the conservation flow is, by enlarge, the average of the five methods, with minor adjustments beyond that. This synthetic, singular *idealized conservation flow* was then used to assess the EW deficits, week by week, throughout the year.

Periodicity Tables

Streamflow hydrographs often correspond to life histories of fish. Life histories are phases such as migration, spawning, and rearing and they have evolved over time to match the stream hydrograph of their natal (home) stream. A periodicity table is used to map out a species life history, week by week, throughout the year (Table 3-3). Showing exactly when each life history phase occurs and how long it lasts. The periodicity table used was based on an existing table for the Cowichan River (Ptolemy per. com.). Presently, this periodicity table is not customized to the Koksilah River however, with input from Cowichan Tribes, CWB, FLNRORD, and MoE it is possible to refine the results further.

Hydrometric Data

Long-term (1960-2021) WSC hydrology data from a gauging station on the Koksilah River at Cowichan Station (08HA003) was used for the Tier 1 EFN assessment. The WSC data set for the Koksilah River extends back to 1912; however, to perform hydrological analysis it is necessary to have continuously monitored hydrometric data. In 1954 the WSC began more rigorous seasonal monitoring of the Koksilah River and in 1960 they began continuously monitoring hydrology of the Koksilah River. The WSC continuous data set spanned from 1960 - 2021.

Using the WSC dataset for the Koksilah River (08HA003), hydrometric statistics were calculated to inform the analysis of summer low-flows. These hydrometric statistics included:

1. *Frequency duration curves*, which are useful for observing volumetric change over time;
2. *Monthly low-flows*, represented by the seven-day low-flow with 10-year return period, which are useful in outlining the 'steady state' of low flow stress;
3. *Low-flow changes over time,* which is useful for identifying departures from the long-term average; and
4. *Climate Normal Windows* (CWN), to frame current flow conditions in the context of climate envelopes.

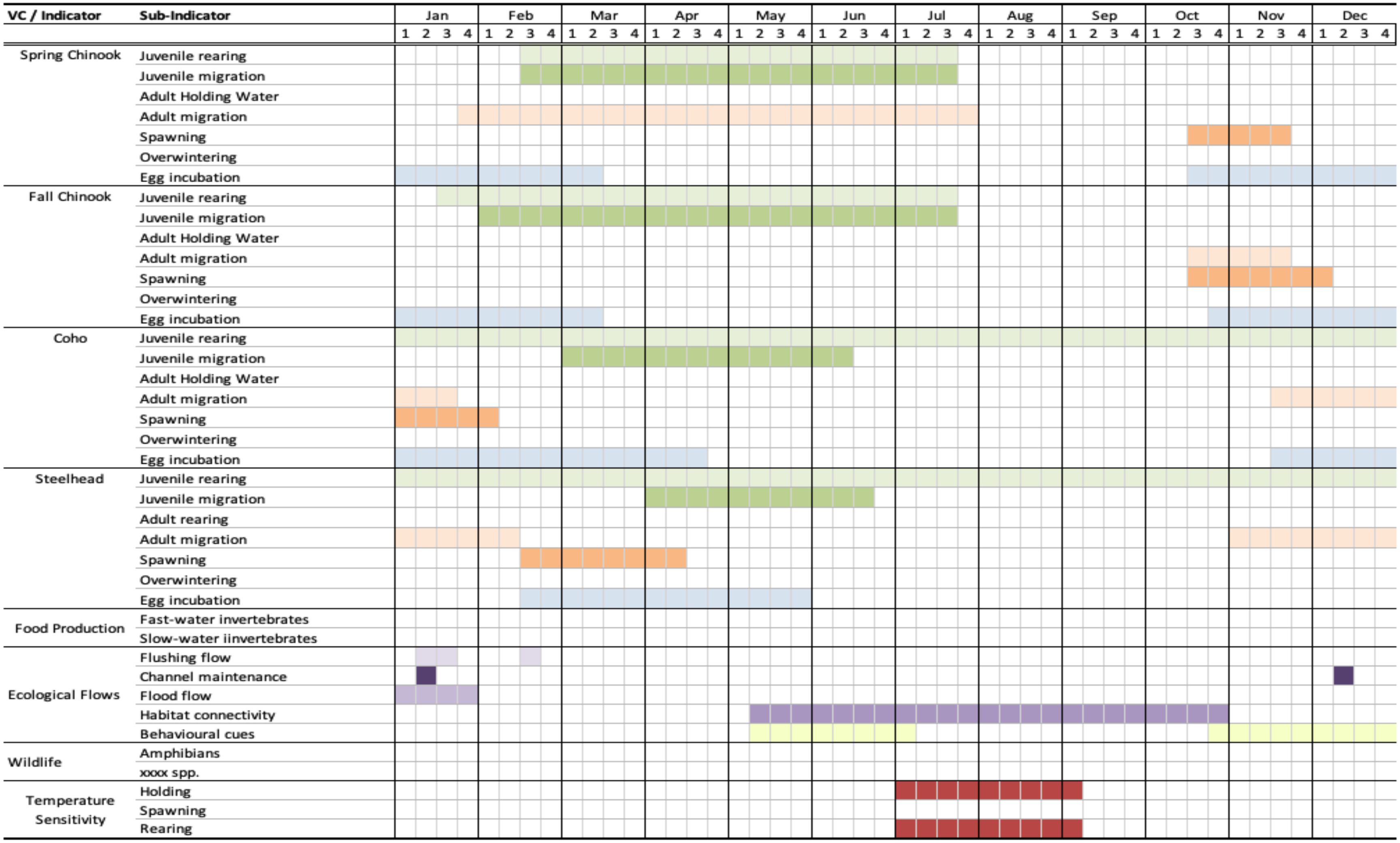
Low-Flow Study

To contextualize the present summer low-flows in the Koksilah River, a historic low-flow study was completed (Appendix 3B). The low-flow study focused on two main factors including: (i) monthly low-flows referred to as the 7-day low-flow ($7Q_{10}$), and (ii) analyzing the data for each Climate Normal Window (CNW) from 1960 to 2020 (e.g., 1960-1980, 1970-1990, etc.). By including these two aspects, the Tier 1 EFA was able to investigate historic water supply in the context of both climate change and changes over time. This study is presented in Appendix 3B.

Regional Integration Study

To contextualize the water supply (precipitation trends) to the Koksilah River a modest regional analysis was completed (Appendix 3C). The Regional Integration Study considered ten watersheds on Vancouver Island to identify a suitable watershed for a regional comparison of summer low-flow frequency and magnitude relationships. The Koksilah River, Chemainus River, Bings Creek and the Zeballos River were included in the study. The integration study looked at summer low-flow (7Q10) relationships and general land-use intensity (forestry, agriculture, urbanization) to identify if any regional trends were present in the long-term water supply. This study is presented in Appendix 3C.

Table 3-4. Periodicity Table Showing Multi-Species Life History Needs.



VC / Indicator	Sub-Indicator	Jan				Feb				Mar				Apr				May				Jun				Jul				Aug				Sep				Oct				Nov				Dec			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Spring Chinook	Juvenile rearing							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																					
	Juvenile migration							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																					
	Adult Holding Water																																																
	Adult migration				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																			
	Spawning																																							■	■	■	■	■					
	Overwintering																																																
	Egg incubation	■	■	■	■	■	■	■	■	■	■																													■	■	■	■	■	■	■	■	■	■
Fall Chinook	Juvenile rearing			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																					
	Juvenile migration					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																					
	Adult Holding Water																																																
	Adult migration																																							■	■	■	■	■					
	Spawning																																							■	■	■	■	■	■	■			
	Overwintering																																																
	Egg incubation	■	■	■	■	■	■	■	■	■	■																														■	■	■	■	■	■	■	■	■
Coho	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Juvenile migration									■	■	■	■	■	■	■	■	■	■	■	■	■	■																										
	Adult Holding Water																																																
	Adult migration	■	■	■																																								■	■	■	■	■	■
	Spawning	■	■	■	■	■																																											
	Overwintering																																																
	Egg incubation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																												■	■	■	■	■	■
Steelhead	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Juvenile migration													■	■	■	■	■	■	■	■	■	■	■																									
	Adult rearing																																																
	Adult migration	■	■	■	■	■	■																																			■	■	■	■	■	■	■	■
	Spawning							■	■	■	■	■	■	■	■																																		
	Overwintering																																																
	Egg incubation							■	■	■	■	■	■	■	■	■	■	■	■	■	■																												
Food Production	Fast-water invertebrates																																																
	Slow-water iinvertebrates																																																
Ecological Flows	Flushing flow		■	■					■																																								
	Channel maintenance		■																																												■		
	Flood flow	■	■	■	■																																												
	Habitat connectivity																		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
	Behavioural cues																		■	■	■	■	■	■	■	■																■	■	■	■	■	■	■	■	■
Wildlife	Amphibians																																																
	xxxx spp.																																																
Temperature Sensitivity	Holding																									■	■	■	■	■	■	■	■	■															
	Spawning																																																
	Rearing																									■	■	■	■	■	■	■	■	■															

* Based on Cowichan River (Source: Ptolemy 2021)

3.3 Tier 1 Koksilah Environmental Flow Assessment Results

3.3.1 Koksilah River Hydrology

WSC Data

Mean daily flow data for the Koksilah River were obtained from WSC gauging station 08HA003. Long-term (1960 -2020) mean daily flow was used to establish the mean annual discharge (MAD) which was 9.732 m^3/s (Figure 3-1). Immediately evident with the long-term mean daily flow hydrograph (Figure 3-1) is the pronounced low flow period from July through September - the summer low-flow period.

Monthly Streamflow

Long-term mean daily flow data were used to calculate average monthly flows. Average monthly flow data were used to establish the long-term average monthly flow and overall temporal trend. Looking at hydrology data like this allows for an understanding of change in monthly flow data over time (Figure 3.2). Immediately evident in Figure 3.2 are three trends. First, almost all months are trending down. Second, the rate of decline in July and August monthly flows is very pronounced. Third, the rate of increase in November monthly flows is also very pronounced.

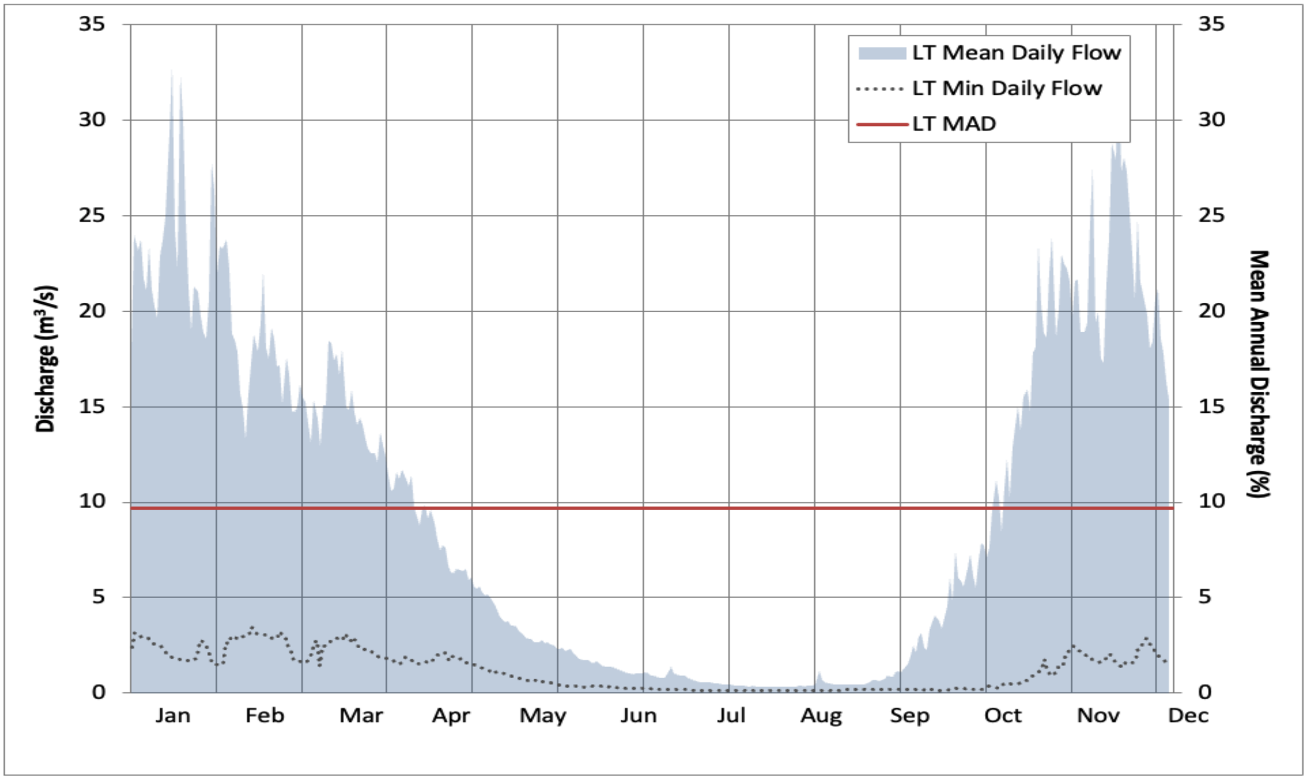


Figure 3-1. Long-term mean daily flow hydrograph for the Koksilah River based on data from Water Survey of Canada gauging station 08HA003.

3.3.2 Regional Trends in Low-Flow

Koksilah 7-Day Low flow (7Q10)

To further investigate trends in monthly flows, the monthly 7-day low flow, with a 10-year recurrence interval ($7Q_{10}$), was calculated. The rationale for the use of the $7Q_{10}$ is that this is what the river naturally experiences, every 10 years. As such, it is reasonable to purport that fish populations have adapted to this natural variation in low and high flow conditions within their natal streams (Table 3-5). The 7Q10 is, therefore, often used to understand baseflow (low-flow) conditions. One consideration is whether the instrument record (WSC gauging record) represents the baseline conditions that the Koksilah fish have adapted to, or whether the instrument record represents hydrologically impacted conditions.

To investigate whether climate change / variability has influenced low flows in the Koksilah River, CNW (Climate Normal Windows) were used as temporal boundaries for the calculation of monthly $7Q_{10}$ low-flows. Four CNW were used, including: 1960-1981, 1970-1991, 1980-2001, 1990-2020. 7Q10 values for each CNW were then plotted by the month to observe temporal trends between CNW (Table 3-5; Figure 3-3).

Table 3-5. Koksilah River Monthly 7Q10 Flows

Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961-1990	2.88	3.11	3.03	2.40	1.13	0.48	0.21	0.17	0.19	0.30	0.68	2.60
1971-2000	3.02	3.16	3.13	1.88	0.86	0.42	0.20	0.17	0.18	0.28	0.54	2.55
1981-2010	3.54	3.31	3.24	1.94	0.81	0.39	0.19	0.16	0.16	0.24	0.73	2.49
1991-2020	3.97	3.38	2.98	1.82	0.69	0.34	0.19	0.14	0.16	0.23	1.10	2.44

* Units are m^3/s

Similar trends to the LT monthly flow were observed in the monthly $7Q_{10}$ data. Specifically, winter months (Nov-Mar) had a strong upward trend in the $7Q_{10}$ while summer months (Apr-Oct) had a strong downward trend in the $7Q_{10}$ (Table 3-5; Figure 3-3). When considering the 1990-2020 CNW, nine months of the year (summer) have steadily declining $7Q_{10}$ low flows, while three months of the year (winter) have steadily increased $7Q_{10}$ low flows. Interestingly, this trend was observed in three of the four watersheds investigated (Table 3-6).

Table 3-6. Regional 7Q10 Flows

Season	7Q10 Trend Compared to 1990 Climate Normal (% Change in 2020 Climate Normal)			
	Chemainus River	Koksilah River	Bings Creek	Zeballos River
Winter (Nov – Jan)	Increasing (+49%)	Increasing (+32%)	Increasing (+43%)	Decreasing (-7%)
Summer (Apr – Sep)	Decreasing (-25%)	Decreasing (-23%)	Decreasing (-8%)	Decreasing (-26%)
Shoulder Months	Varies	Varies	Varies	Decreasing (-18%)

Both the Koksilah River and the regional watershed results can be viewed in greater detail in Appendices (3B & 3C).

3.3.3 Tier 1 Environmental Flow Assessments Using the Five Standard Setting Methods

The Tennant method was applied using the ‘Optimum Range’ throughout the year (Figure 3-4). Optimum flow for the Tennant method ranged between 60% to 100% MAD. The BC Modified Tennant (BCMT) method was adjusted monthly to account for life history needs of spring and fall run Chinook, as well as rearing Coho, and

Steelhead fry. BCMT results suggest EW deficits during June through October (Figure 3-5). The BC Desktop method applies the percentiles approach, so it maintains the natural range of variability quite well (Figure 3-6). This method determined the summer low-flows for juvenile rearing to be 20% MAD in both low and high flow scenarios. The Rule of Thumb also shows substantial EW deficits in June and July. Although in August and September, the flow requirement decreases from the 50th percentile to the 20th percentile, the Koksilah remains in EW deficit (Figure 3-7) according to the Rule of Thumb method. The Ecological Flow method is largely related to channel maintenance and wetland inundation during the freshet (Figure 3-8) and suffice to say, high energy is not in short supply in the Koksilah River.

3.3.4 Tier 1 Combined Results Using an Integrated Model Approach

Drawing from the results of all five methods, a minimum, mean (average), and maximum environmental flow values were calculated for each week of the year. These are presented as monthly in values in Table 3-7 for visualization purposes but calculated as weekly values, based on daily data. Results from the Low-Flow Study (Appendix 3B) and the EFN model (minimum, mean and maximum EFN) were used as guidance to fit a line through each week of the year.

$$\frac{Hydrometric\ Statistics + EFN\ Statistics}{Professional\ Judgement} = \textit{Koksilah Conservation Flow}$$

Fitting a line relies on professional judgement to set the absolute value for each week of the year. To accomplish this, all parameters are plotted in timeseries. This includes plotting: (1) known information that includes hydrometric statistics such as monthly 7Q10, dry period recurrence intervals such as the 1:2, 1:10, 1:50, 1:100 daily low flow, along with (2) modelled information that includes the min, mean, and max weekly values calculated for all five EFN methods. Drawing from these resources, professional judgement is then used to set the absolute value for each week of the year. This fitted line is the first draft of the *Koksilah Conservation Flow* (Table 3-7).

To determine *Available Environmental Water f*or the Koksilah River, the weekly *Koksilah River Conservation Flow* was subtracted from the long-term median weekly flow, as shown below:

$$\frac{LT\ Median\ Daily\ Flow}{Koksilah\ Conservation\ Flow} = \textit{Available Environmental Water}$$

Available Environmental Water in Table 3-7 is expressed as the percent of monthly flow available to meet the EFN of the Koksilah River. When the EFN was greater than the long-term median daily flow the EFN was determined to be in deficit. Colour coding in Table 3-7 is mean to indicate a surplus (green) or deficit (red). These results suggest the Koksilah River is in a significant water deficit from June through till September (Table 3-7; Figure 3.10).

In summary, the *Tier 1 EFA* highlights the fact that water supply in the summer months is a significant issue (Table 3-7; Figure 3.10); which further implies that the Koksilah River is not meeting the life history needs / EFN of Chinook, Coho, and Steelhead during the summer low-flow period of the year (Table 3-7; Figure 3.10).

Table 3-7. Koksilah River Tier 1 EFA Results Summarized by Month.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LT Median Daily Flow	(m^3/s)	16.3	13.7	11.4	6.8	2.8	1.1	0.5	0.3	0.4	1.5	11.1	16.2
Min EFN	(m^3/s)	3.4	2.7	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Mean EFN	(m^3/s)	9.9	7.4	6.9	4.9	4.1	4.1	4.0	2.7	2.7	3.6	7.0	8.4
Max EFN	(m^3/s)	15.5	9.7	9.7	7.9	6.0	6.0	6.0	5.8	5.8	6.0	11.6	14.9
Koksilah Conservation Flow	(m^3/s)	13.1	10.1	8.5	5.5	4.4	4.4	4.0	2.9	2.9	3.6	7.9	12.2
Available Environmental Water		124%	136%	134%	124%	-154%	**-415%**	**-860%**	**-950%**	**-769%**	-251%	140%	133%

*Monthly data represents median daily data aggragated to weekly data for the EFN analysis. The weekly results have been averaged to monthly results for demonstration.

3.3.5 Strengths and Weaknesses of Tier 1 Model Architecture

All models are subject to assumptions and data limitations. At times, scientists can meet all model assumptions and generate meaningful results. In these circumstances model results can be very robust. Below we look at the strengths and weaknesses of the Tier 1 EFA integrated modelling.

Model Strengths

There are several clear strengths to the Koksilah Tier 1 EFA. First, the data set used was from the Water Survey of Canada which is recognized as high-quality data. Second, the Low Flow Study was based upon these data generated industry standard hydrometric statistics to guide EFN development. Using this data is a clear strength to the Tier 1 EFN, as the whole approach relies upon long-term, quality data. Third, an additional strength to the Koksilah Tier 1 EFA was analysis using five commonly accepted Tier 1 EFN methods and the integration of these models into a single *Koksilah Conservation Flow*. By taking this integrated approach it removed the criticism due to physiographic differences between the development stream and the application stream. Fourth, change over time is an important factor in the management of aquatic health. Presenting the LT $7Q_{10}$ results by Climate Normal Window provided a glimpse into climate impacts as a possible separate mechanism of impact affecting summer low-flows.

Model Weaknesses

The history of heavy industrial activity in the Cowichan Valley goes back to the establishment of the E&N Railway. The hydrological impacts associated with the clearing of land for the railway that took place between 1891 and 1930 (roughly) presumably altered channel form and channel health. Following the building of the railway, cat logging from the 1920-1950's was further noted as having substantial hydrological impacts in the lower Koksilah valley. As such, a potential weakness of the Koksilah Tier 1 EFA is that the WSC dataset that the Tier 1 EFA is based on begins 50-70 years after substantial hydrological impacts in the lower watershed.

Additional weakness of the Koksilah Tier 1 EFN include physiography of the stream where these methods were generated and how those compare to the Koksilah River physiography. There is valid criticism to be had with this line of thinking; however, this is neither new nor unexpected for this type of analysis and this is what gave way to the use of (i) several methods concurrently, and (ii) the inclusion of professional judgement. Recently, Wheaton et al. (2017) demonstrated how professional judgment was able to enhance Fuzzy Inference System (FIS) of salmonid pollution-level life cycle modelling.

3.4 Tier 1 Koksilah Environmental Flow Assessment Discussion

The model results tell a commonly understood story – there is currently not enough streamflow in the Koksilah River to support the needs of both people and nature. In this case, the needs of people are water abstractions across a range of private / commercial uses; and the needs of nature are healthy streams to provide habitat for steelhead and salmon.

3.4.1 Koksilah River Water Supply and Demand

To fully understand water supply impacts on the riverscape of the Koksilah Valley, it would be necessary to have ample data prior to any hydrological impact. Substantial development occurred on Southeastern Vancouver Island between 1890-1930 with the building of the E&N Rail, subsequent clearing of floodplains, and straightening of the river for agriculture.

The WSC hydrology data for the Koksilah River (08HA003) reliably goes back to 1960. In the context of hydrological impacts, the WSC record began up to 70 years after significant floodplain alteration and development. Considering these points, the WSC record is not truly a 'historic' baseline, but it is good quality data.

Both Hatfield (2021) and Prichard et al. (2019) investigate different aspects of groundwater supply. Hatfield (2021) identified that forest cover changes and climate account for roughly 8% of the groundwater depletion in the Koksilah, which is equivalent to about one month of summer baseflow. Prichard et al. (2019) investigated aquifer recharge and suggested that the surface aquifers can be more water stressed during dry hot summers when irrigation is steady.

It goes without saying that present day summer streamflow <u>is not</u> meeting the EFN / EW for people and nature in the Koksilah River. This study corroborates this, and further indicates that EW deficits for the Koksilah River are in the order of 400-900%. These deficits are occurring during peak agricultural demand and during critical salmon sensitive periods (Table 3-7).

The Tier 1 EFA, and calculation of the *Koksilah Conservation Flow*, was not intended to identify minimum flow requirements, rather <u>to identify what flows are required for optimal habitat</u> (Figure 3-9). In the absence of baseline data, the Tier 1 EFA is an objective and robust approach to understanding the EFN / EW deficits that both people and nature are experiencing.

One of the values of developing the Tier 1 EFA with the approach applied herein, is that its' development is based on percentages of mean annual discharge (MAD) in relation to life history needs. The significance of this is that the 'need' is independent of the 'supply' in this type of analysis. This independence allows for the inclusion of additional values and when related to available water supply it becomes evident whether the river is in an EW surplus or deficit.

Potential extension work from this Tier 1 would be to understand what other community flow values [requirements] exist such as:

(i) Indigenous flow needs,
(ii) Agriculture flow needs, and
(iii) Domestic and municipal flow needs.

By planning for all flow users / needs / requirements the stage will be set for understanding the restoration required to meet that condition. When the whole community benefits from the restoration, it is welcomed and celebrated.

3.4.2 Indigenous Flows

Quw'utsun People have a long history with the Koksilah River and there is evidence of historic salmon harvesting weirs and permanent villages along its length. The Indigenous descriptions provided in Traditional Knowledge interviews (Luschiim, Sylvester, Kulchyski 2021) of the landscape and riverscape of the lower Koksilah Watershed describe historic conditions that resemble a shallower, more braided river. These are riverscapes with greater structure, complexity, ecology, and resilience (Chapter 2, Figure 2-1).

So then, what were the historic flows that supported Quw'utsun culture (Indigenous Flows) and sustained people, salmon and nature? Many of stories are direct accounts of the geomorphic conditions (e.g., stream evolution) provided by an intact watershed with high watershed integrity (pre-contact), which provided ecosystem functions and services that sustained complex fluvial systems and healthy populations of salmon.

Stream evolution links both traditional knowledge and western science in a shared understanding that both environmental flows and indigenous flows rely on complex fluvial systems with engaged, functioning floodplains (e.g., SEM Stages 6,7,8,0). Traditional Knowledge of the ecosystem that once provided sustainable salmon populations can help build an understanding of the geomorphic potential of Koksilah River (Rideout et al. 2021).

3.4.3 Whole-of-Watershed

If we can agree on the Natural Flow Regime (Poff et al. 1997), and that historically salmon were plentiful in the Koksilah River, then it is fair to suggest that the cumulative effects of land-use and climate change have been the loss of EFN / EW necessary to meet the needs of both people and nature.

This is a common story and one that is described in Allan's 2004 paper "*Landscapes and Riverscapes: The Influence of Land-Use on Stream Ecosystems.*" Allan's theory of river health, simply put, purports that as the anthropogenic gradient increases, the biological conditions of a river ecosystem decrease (Allan 2004; Figure 1-1). In no uncertain terms this is what the FPB report (2018) was concluding by stating that no monitoring of aquatic values [of biological condition] was happening and that more consideration should be given to watershed scale planning [anthropogenic gradient] to meet sustainability targets.

Water is managed at the watershed scale (Ulibarri and Garcia 2020).

3.5 Tier 1 Summary

The Koksilah Tier 1 EFA applied provincially and internationally accepted standard setting, historic methods to assess water supply and to then make inferences around the adequacy of current conditions for the health of the Koksilah River and the fish and fish habitat within it. The analysis has identified that: (i) winter streamflow (7Q10) is increasing (appendix A or B?) while summer streamflow (7Q10) is decreasing (Figures 3-2 and 3-3); and (ii) warm season low flows are in deficit by hundreds of percent (150-950%) during critical fish sensitive periods (Table 3-7).

Understanding Indigenous practices, places and stories may help to further characterize the historic Indigenous Flow Needs required for sustaining salmon populations in the Koksilah River. A natural next step to a Tier 1 EFA is to further identify additional human values that rely upon the Koksilah River for their culture, sustenance, and livelihoods. These may include Indigenous flow needs, agricultural flow needs, and / or community flow needs. Taking such a step towards understanding the broader flow needs may provide an opportunity to manage at a scale that considers both people and nature. Taking a 'whole of watershed' approach to understanding Environmental Flow / Environmental Water values of the community is a necessary first step to allow for a 'whole of watershed' approach to managing those values at a watershed scale.

3.5.1 Koksilah Watershed Restoration Goals

At the most basic level, the issue at hand for the Koksilah River is either too much water (extreme flood) or too little water (extreme low-flow). Both are due to limited structure and complexity at the landscape and riverscape scales. Water in the tributaries and headwaters needs to be slowed down, spread out and roughed up (so to speak).

The ecological benefits and increased biodiversity associated with slower, more complex fluvial environments is exponential (Wheaton et al. 2019; Pollock et al. 2011; Cluer and Thorne 2014). However, given the peak flow events that occur in the lower Koksilah River, it will be necessary to first deal with the peak flow mechanisms before restoring mainstem, lower Koksilah River habitat.

In any event, the focus of this Chapter was water supply and low-flow conditions in the lower Koksilah River. Drawing from this, the appropriate restoration goals (Table 3-8; Figure 3-11) are two-fold:

1. In the near-term, increase summer baseflow to 5% MAD
2. In the long-term, increase summer baseflow to 10% MAD

Table 3-8. Lower Koksilah River Restoration Goals.

	Existing Condition	2-5 Years	5-10 Years
Summer 7Q10 (% MAD)	$\leq$1% MAD	$\geq$ 5% MAD	$\geq$10% MAD
Summer 7Q10 (m^3/s)	$\leq$0.1	$\geq$0.5	$\geq$1.0

* Restoration goals refer to monthly 7Q10 from June to October.

Restoration actions such as restoring baseflow (7Q10) to the lower Koksilah River will require both Whole-of-Watershed thinking and Whole-of-Government support.

4 TIER 2 - ENVIRONMENTAL WATER: INCREMENTAL HYDRAULIC-HABITAT

4.1 Tier 2 Koksilah Environmental Flow Assessment Overview

In recent years, the extreme low flows experienced in the Koksilah River have gained attention in the public eye. Streamflow as low as 0.1 m^3/s or 1% Mean Annual Discharge (MAD) have been observed in the Koksilah River between July and September, when streamflow is naturally low (Chapter 3, Figure 3-1). These extreme low flows have resulted in Provincial Section 88 orders applying restrictions on consumptive water users as the Koksilah River has been unable to meet its *Environmental Flow Needs* (EFN) / *Environmental Water* (EW) of both people and nature.

Chapter 3 – Environmental Water Supply – presented the historical hydrology for the Koksilah River which revealed that: (i) mean monthly flow has decreased from April to October since 1960; (ii) the 7-day low flow with a 10-year return period (7Q10) has decreased from April to October since 1960; (iii) the 7Q10 has increased in November, January, February and the first three weeks of March; and (iv) that the instrument record begins in 1960 (reliably) which was as much as 30-70 years after substantial hydrological impacts (e.g., E & N rail, floodplain clearing, channel straightening; logging in much of the upper watershed) in the Koksilah Watershed (Chapter 3, Figure 3-2 & 3-3).

This Chapter – Environmental Water Availability - the hybrid hydraulic-habitat approach, presents eco-hydraulic methods used to explore the in-situ conditions (micro-habitat) or available habitat (EFN / EW) for the Koksilah River during low flow events. This is based on detailed field work over the low flow period of 2021 and desktop modelling.

4.2 Koksilah Environmental Flow Condition

The extreme low flow conditions experienced in the Koksilah River may potentially imperil many aquatic species due to a host of factors including their physical environment, physiological condition, or detection / predation. However, the specific focus of this Chapter is rearing conditions for Coho and Steelhead fry, along with passage conditions for adult Chinook through riffles.

To develop a precise understanding of the available EW, Cowichan Watershed Board (CWB) employed a field-based, incremental, instream flow study (EFA). Field practices employed in the assessment were intended to meet or exceed those requirements of the BC Instream Flow Methodology (Lewis et al. 2004), in addition to other relevant standards and practices (Annear et al. 2004; Beecher and Caldwell 2013; Bovee 1982).

The System for Environmental Flow Analysis (SEFA), a physical habitat modelling software package, was used to support the EFN assessment. SEFA is an impact assessment framework that implements the substance of the *Instream Flow Incremental Methodology* (IFIM; Payne et al., 2012). SEFA is a software model composed of several moving parts within the package. 1)The hydraulic model is a one-dimensional (1D) model that uses surveyed transect data (depth and velocity) and stage-discharge relationships to predict hydraulic conditions (microhabitat) over an incremental range of flows. 2) The habitat model compares hydraulic conditions (depth, velocity and substrate suitability), at points along each transect, to known habitat suitability criteria (HSC), for the species and life stage of interest. 3) The habitat model then calculates the total usable habitat, referred to as Area Weighted Suitability (AWS) Curves, for each life stage across a range of predicted flows.

4.3 Tier 2 Assessment Methods

The assessment applied is an IFIM using the SEFA platform to model hydraulic-habitat conditions. Seventeen transects stretched over six kilometers of habitat were used to characterize habitat conditions for Coho and Steelhead fry rearing in the Koksilah mainstem. In general terms, the EFN assessment contains three parts including the (i) hydraulic model, the (ii) habitat suitability criteria, and the (iii) habitat-flow relationship.

This section presents the methods employed for the Koksilah River IFIM, including the: (i) selection and installation of transects, (ii) hydraulic model calibration, (iii) hydraulic model validation, (iv) habitat suitability criteria.

4.3.1 Transect Selection and Installation

Seventeen stream transects were used to represent three different meso-habitat types in the Koksilah River including: *pools, riffles and glides* (Photo 4-1). Three transects were installed in *pools*; eight transects were used to characterize *glides; and s*ix to characterize *riffles* (Table 4 -1).

Table 4-1. Koksilah River Environmental Flow Assessment Transect Locations

				UTM Location[1]		
Watershed	**Reach**	**Site Name**	**Meso Habitat**	**Zone**	**Easting**	**Northing**
Koksilah	1	1	Riffle	10 U	449994	5400429
Koksilah	1	2	Deep Glide	10 U	449947	5400433
Koksilah	1	3	Pool	10 U	449773	5400478
Koksilah	2	4	Pool	10 U	449713	5399293
Koksilah	2	5	Shallow Glide	10 U	449709	5399257
Koksilah	3	6	Riffle	10 U	449781	5398505
Koksilah	3	7	Deep Glide	10 U	449819	5398514
Koksilah	3	8	Riffle	10 U	450396	5397975
Koksilah	4	9	Shallow Glide	10 U	450644	5397520
Koksilah	5	10	Riffle	10 U	450842	5397249
Koksilah	5	11	Shallow Glide	10 U	450901	5397131
Koksilah	5	12	Riffle	10 U	450894	5397092
Koksilah	5	13	Pool	10 U	451409	5396600
Koksilah	5	14	Shallow Glide	10 U	451432	5396552
Koksilah	5	15	Riffle	10 U	451445	5396512
Koksilah	5	16	Deep Glide	10 U	451723	5396107
Koksilah	5	17	Deep Glide	10 U	451695	5396031

The selection of stream transects involved several experts and agencies including CWB, FLNRORD and Cowichan Tribes. The team investigated the lower three reaches of the Koksilah River, discussing meso-habitat types, preferences, and selection criteria at each site. During this field visit numerous transects were agreed upon by the team; while the remaining transects were selected by the field crew, based upon these criteria.

Installation of stream transects aimed to provide semi-permanent benchmarks while maintaining a low visual appearance. Where possible, benchmarks were tucked out of site, but flagged for future identification. In addition to the transect survey, each transect had a staff gauge installed for follow-up *calibration flow* measurements.

Each transect was surveyed with an engineer's rod and level (Lecia NA328) in accordance with the British Columbia Hydrometric Standards (RISC 2018). All benchmarks, staff gauges and water surface elevations were surveyed during initial *survey flow* (Figure 4-1). All transects were surveyed to a local datum and survey error for all measurements was $\leq$2 mm (RISC 2018).

Stage-discharge (S-D) measurements were conducted with a Flow Tracker II provided by Cowichan Tribes. During each S-D, the original *survey flow* field form was used so that each S-D panel could be related to the cross-section survey. Additionally, as each staff gauge was surveyed, during each calibration trip, a staff gauge reading was captured. Finally, on all *survey flow* and *calibration flow* S-D measurements, all depth and velocity data were recorded to assist with calibration and validation of the hydraulic model.

Finally, selection of the Tier 2 transects was intended to meet the objectives of investigating rearing conditions for Coho and Steelhead fry. However, during the meso-habitat evaluation there was a realization that the Koksilah River has two rather different expressions of glides. The first is as fisheries biologist, hydrologist or fluvial geomorphologist would imagine them to be and these are referred to as 'shallow glides' within this report.

The second expression of glides was substantially impacted by sediment dynamics and presented like a pool with deep water and little to no velocity below the surface. However, the formation of these glides was not due to the normal formative mechanism but rather the deposition of large volumes of sediment. The sediment would in turn create a pool crest and back water up. These glides tend to be greater than 100 m in length. In the natural environment, outside of bedrock canyons or influence, neither glides nor pools span, on average, five to ten channel widths. Within this report these are referred to as 'deep glides.

Given the dramatically different meso-habitat conditions between shallow and deep glides, Tier 2 transects were split to characterize each. Of the eight transects allocated to glides, four were established in shallow glides and four were established in deep glides.

Photo 4-1. Koksilah River EFA survey flow measurements.

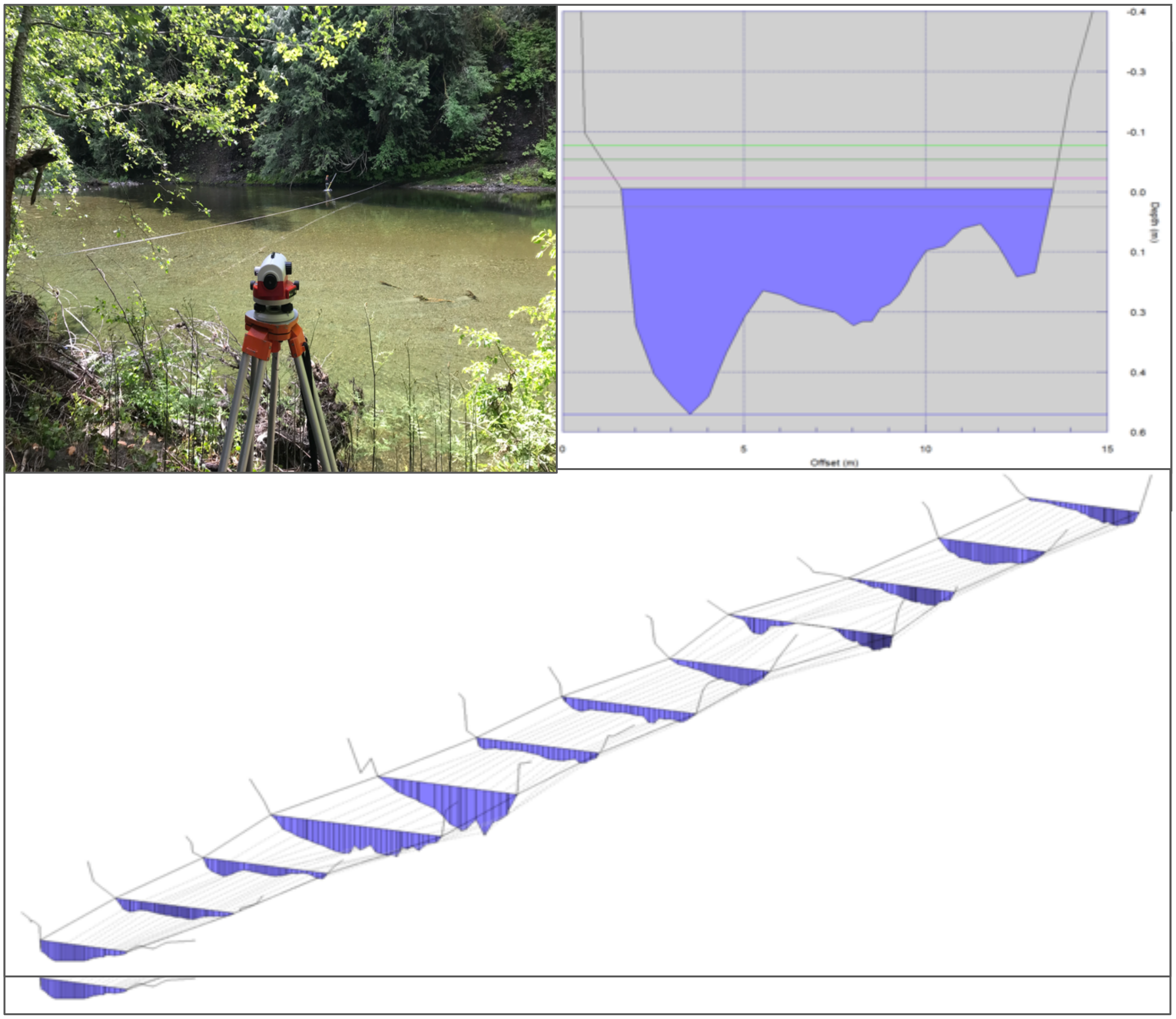


Figure 4-0. Left: Koksilah River EFA stream transects field surveying.

4.3.2 Hydraulic Model Calibration

The primary limitation to any modelling exercise is the quality of [input] data and, therefore, the integrity (accuracy and precision) of the model [output]. During the development of the Koksilah River EFA, several steps were taken to ensure quality [input] data would lead to good model integrity [reliable output]; these steps included: (1) installing sufficient transects to characterize the conditions of interest; (2) collecting sufficient field measurements at each transect to allow for a robust calibration of the model; and (3) validating the model across a range of flows (low to medium). Collectively, these steps result in a good quality model with demonstrated reliable output.

The norm for EFA is to collect one detailed flow measurement per transect, where both depth and velocity are recorded at every panel across the stream. This is referred to as the *survey flow* and is usually the first measurement during the transect installation. Then, depending on the budget and capacity available, between two and three follow up discharge measurements are performed. These are referred to as *calibration flows*. Calibration flows will often use one discharge measurement to represent several transects within the general vicinity, as discharge will be the same both up and downstream for some distance.

The BC Hydrometric Standards (2018) require 5-8 stage-discharge measurements to develop a draft rating curve. A rating curve represents the shape of the channel and how it fills with water as discharge (volume) increases. All hydraulic modelling is based on rating curves, so it is important that each transect has sufficient stage-discharge measurements (rating points) to accurately characterize the relationship between stream shape (geometry) and stream discharge (volume). This relationship is the *rating curve*. On average, the seventeen transects that are part of the Koksilah River EFA, each received between five and eight *calibration measurements* to ensure a robust rating curve as the backbone of the hydraulic model.

In summary, the Koksilah River EFA calibration - of all seventeen transects - was based on a *survey flow* conducted at approximately 20-25% MAD, followed by five to eight *calibration measurements*, successively descending the hydrograph, targeting rating points at 15%, 10%, 5% and 1% MAD. In total, 109 *calibration stages and flow*s were measured across the seventeen transects. As a result, every transects meets the standard criteria for draft rating curve development. This is a high level of rigor for hydraulic modelling and the benefits are clear in the model validation results.

4.3.3 Hydraulic Model Validation

The primary limitation to understanding any model output is understanding the integrity of model input, in addition to the various decisions made during model development. To that end, model calibration refers to using field measurements of discharge, depth and velocity to fit the hydraulic model to the data. The more calibration data collected, the better functioning a model can be.

Model validation, however, refers to comparing modelled output (post calibration) to measured conditions in the field. Specifically, validation is a process of comparing modelled versus measured depth and velocity across a range of target conditions, for specific transects (all seventeen).

Model validation is used to demonstrate how well a calibrated model behaves around the targeted range of flows. For the Koksilah River EFA, the target range of flows was 15%, 10%, 5%, and 1% MAD. The easiest way to collect validation data is to record the depth and velocity measurements during the *survey measurements,* for all transects, and all *calibration flow* measurements. Although this is much more work, and requires budget and capacity, this specifically enables validating the model and demonstrating its behaviour across the target flow range.

In summary, the Koksilah River EFA validation – of all seventeen transects – was based on depth and velocity measurements collected during all 109 *calibration measurements*. Validation was performed for all target flows, and all transects. In total, 109 validation runs were performed as part of the Koksilah River EFA model build.

4.3.4 Habitat Suitability Criteria

Habitat suitability criteria (HSC) refer to the physical preferences of individual species and their life stages, which include depth, velocity, and substrate preferences. They can range widely within a species or life stage due to regional differences in physiography and can also range widely between life stages as each life stage has modified behaviour to suit different meso-habitats.

Within the practice of EFA it is widely recognized that the HSC has the single biggest impact on model results. They can be the Achilles heals if not taken seriously, or if not done well.

Through a conversation with B.C. Ministry of Environment staff, it was suggested that the Koksilah River EFA begin with regional HSC's and modify later as needed (R. Ptolemy 2021, pers. comm.). Numerous regional HSC are available and three specific HSCs were used for the Koksilah EFA that include: Coho fry summer rearing, Steelhead fry summer rearing, and Insect preferences for riffle food production. In addition to these HSC, the general criteria for Adult Chinook (depth ~0.24 m and velocity <2.54 m/s) were for conditions for successful riffle passage.

4.4 Tier 2 EFA Model Results

The EFA was designed to meet several objectives, including investigating: (1) Coho fry rearing; (2) Steelhead fry rearing; and (3) adult Chinook passage through riffles. This section outlines the (1) calibration and validation results for the Koksilah EFA model build; along with the (2) model results and habitat-flow relationships.

4.4.1 SEFA Model Calibration and Validation

Model Calibration

Prior to calibration, each rating curve for each transect was plotted and reviewed for any points that appeared erroneous. Rating curve development and adjustment resulted in all curves having an R^2 value of greater than 0.9 (an R^2 of 1.0 would be a perfect relationship). Once rating curve development was finalized for each transect the curves were loaded into SEFA for calibration. Figures 4-1 to 4-9 present the rating curves for all Koksilah River transects. By plotting the ratings together, and referencing them to height above zero flow, the ratings can be compared, and reviewed (Figure 4-10). One riffle transect had quite different behaviour than the other transects but that is not unexpected for a riffle: especially, given the sediment dynamics in the Koksilah River.

During calibration of the Koksilah SEFA model, velocity distribution factors (VDFs) are calculated for each depth and velocity measurement along each transect. This process matches model results to field-measured results from the *survey flow*. These factors are used to predict the velocity distribution at for any flow.

SEFA produces what is referred to as a *velocity adjustment factor* (VDF) which is a measure of how much the modelled velocity differs from the measured velocity during the survey flow (initial field data collection). The average velocity adjustment factor for the SEFA model, across all transects, was 1.014, suggesting that for any model run, velocity may be adjusted 1.4% from the measured field data. Across sixteen of seventeen transects, and all *calibration flows*, the VDF’s were all within 5% of the measured values (Figure 4-11).

In summary, given the relatively shallow nature of the Koksilah River during summer low flows, which is a notably difficult condition for hydraulic modelling, these are excellent results. The strength of these results was realized during model validation.

Model Validation

Model validation was performed to demonstrate the integrity (accuracy and precision) of the SEFA hydraulic model. Validation of the model was performed on all transects, and all calibration flows, which ranged between five and eight flow measurements (calibration flows) per transect (Figures 4-12 to 4-28). Figures 4-12 to 4-28 present the individual validation results for each transect. The further away from the survey flow, the more likely the VDFs will change to balance stage with depth.

Summarized measured and predicted/modelled depths and velocities were compared for each target flow and the percent difference between measured and modelled was considered as a surrogate for model error (Table 4-2). Validation results for the Koksilah SEFA model indicate that, on average, modelled depths were less than 5% or 0.025 m different from measured depths; and, modelled velocities were, on average, ± 5% or 0.018 m/s different from measured velocities (Table 4-2).

Table 4-2 Koksilah River SEFA Model: Validation Results for Low Flow*

	Average Depth Measured vs. Predicted (% difference)	Average Depth Measured vs. Predicted (m)	Average Velocity Measured vs. Predicted (% difference)	Average Velocity Measured vs. Predicted (m/s)
Average Validation	±3.84	±0.025	±5.72	±0.018

* Represents all transects, and all calibration flows, ranging between 1-20% MAD.

Overall, the Koksilah SEFA model was built with thorough and robust field data that were well calibrated and validated across a range of flows; and subsequently, [the model] demonstrates good functionality and integrity across range of target flows (15%, 10%, 5%, and 1% MAD).

Model Limitations

Normally the target flow condition would be where the model performance is expected to be best; however, hydraulic modelling of stream conditions below 5% MAD brings a host of difficulties. With respect to hydraulic modelling of low-flows, as discharge decreases (below 5% MAD), the width-depth ratio can increase by an order of magnitude and, in turn, flow vectors become increasingly complex, roughness and frictional forces increase dramatically, the overall the basic assumptions of one-dimensional (1D) hydraulic modelling may be violated, and the model error can increase (Table 4-2).

As the ultimate interest of the Koksilah EFA is summer low-flows that are 0-3% MAD, it must be recognized that it can be difficult to predict depths and velocities using 1D hydraulic modelling and velocity distributions measured at flows of 20-30% MAD. However, many of the transects performed very well in this range, while others had larger deviations from measured results. Four of the seventeen transects have modelled velocities varying between 30% to 80% from measured velocities. This is because it is the VDF that are adjusted to maintain stage and depth for a given discharge. For this reason, modeled depths are consistently and accurately predicted.

If greater accuracy were required for low flow predictions, there is sufficient data to develop a low flow model based on a survey flow in the ranges of 4-7% MAD or 9-17% MAD, depending on the flow range of interest. However, this is not considered necessary at this stage.

It is necessary to take into consideration the HSC and their sensitivity to the range of error expressed in Table 4-2. Habitat Suitability Criteria for Coho fry (Figure 4-29), Steelhead fry (Figure 4-30) and insects (Figure 4-31) indicate that the sensitivity to velocity is at the first decimal place (0.1). Sensitivity of the model is at the second decimal (0.01) place for velocity, an order of magnitude lower. This suggests that although the model behaviour is diverging from field validation data, the actual range of error (second decimal place) may not be influential on model results.

While model error can tell a clear story of the *accuracy* of a hydraulic model (Table 4-2), graphing validation results can tell a clear story about *behavior* of the hydraulic model, which is arguably considerably more important in interpreting model results. Figures 4-12 to 4-28 present the validation data for each transect so the reader can understand both the strengths and weaknesses of the Koksilah River EFA, after all…

> *All models are wrong, as they are all an over- simplification of reality, but some offer value with careful planning and good input.*

For example, Transect KO 1.2, Calibration 6 @ 3% MAD (Figure 4-13) shows a difference of 79% between measured and modelled velocities. By any standard this is an exceptionally large error. However, at 3% MAD the depths and velocities are so small that very small differences result in very large percentages. Figure 4-13 reveals that although the model error was 79%, the actual difference between measured velocities and modelled velocities was 0.009 m/s.

The Koksilah River EFA is therefore neither right or wrong: it is a model with 17 transects, 109 calibration points and 109 validation runs. The validation results for most transects and most *calibration flows* are a compelling representation of reality. The reported errors are convincingly low and, therefore, the model can offer quality information if the reader understands which areas of the model results are subject to higher variability (ex. Transect KO 1.2, 3% MAD results can be up to 0.01 different than reported results).

Collectively, the validation results demonstrate that the Koksilah River hydraulic model is very robust across the target range of flows. Indicating that predicted depths and velocities between 1% to 15% MAD are sufficiently accurate (<5% error) to produce a meaningful habitat-flow relationship. The integrity of the habitat-flow relationship, in turn, is dependent on two things including: (i) the hydraulic model, and (ii) the habitat suitability criteria. Like the hydraulic model, a well-developed and well validated habitat suitability model offers tremendous analytical strength.

4.4.2 Habitat-Flow Relationships

It is important to recognize that the habitat-flow relationship represents the incremental range, not the actual current condition in the field. As such, all habitat-flow relationships require interpretation. Interpretation of these relationships, in turn, requires knowledge of the strengths and limitations of physical habitat modelling (Bovee 1983), and the validation process controlling behavior of the actual hydraulic model.

Habitat-flow relationships are the common currency of all incremental EFA looking to predict habitat. To do that, the platform used for the Koksilah River EFA, SEFA, produces two metrics that require explanation to properly interpret model outputs. These metrics are the Area Weighted Suitability (AWS; previously termed Weighted Usable Area (WUA)), and the Combined Suitability Index (CSI).

AWS is the **quantity** of available habitat, while CSI is the **quality** of available habitat. AWS is expressed as the area (m^2 / m) of suitable habitat for every linear metre of stream length. CSI is dimensionless scale from 0-1 and can be thought of as a report card grade, where 1 is perfect (excellent habitat) and 0 is poor (no habitat). Considering both quantity and quality of habitat availability provides insight into the management of streamflow / riverine habitat.

During analysis of the Tier 2 EFA, shallow (natural) and deep (impacted) glides were separated into different groups for modelling. Shallow glides are natural, normally functioning glides; whereas deep glides are impacted with large sediment deposits at the downstream end, which operate as a pool crest / weir, backing water up large distances [upstream].

The Tier 2 EFA has looked at five areas of the habitat-flow relationships important to low-flows including: (i) width-depth relationships, (ii) Coho and Steelhead fry rearing, (iii) riffle production for insects, (iv) adult Chinook passage through riffles, and (v) sediment deposition in deep and shallow glides.

Width-Depth Relationship

Stream width-depth ratio is a common metric to understand aquatic habitat availability and there are many ways to investigate the relationship between flow and the amount of aquatic habitat available. Wetted perimeter and depth are two metrics that highlight appreciable differences between the deep and shallow glides throughout the Koksilah River.

The wetted perimeter for shallow glides begins at about 9 m (wide) as flow initiates at 0.01 m^3/s and increases rapidly to 14 m (wide) by 0.1 m^3/s (Figure 4-32). As flow transitions from 1% MAD (0.1 m^3/s) to 10% MAD (1.0 m^3/s) the wetted perimeter increases from 14 m to 17 m. The flow-depth relationship for shallow glides transitions from 0.05 m at zero flow to 0.26 m (depth) at 10% MAD (1.0 m^3/s).

The wetted perimeter for deep glides begins at about 10 m (wide) as flow initiates at 0.01 m^3/s and increases rapidly to 12 m by 0.1 m^3/s (Figure 4-33). As flow transitions from 1% MAD (0.1 m^3/s) to 10% MAD (1.0 m^3/s) the wetted perimeter increases from 12 to 13 m. The flow-depth relationship for deep glides transitions from 0.25 m (depth) at zero flow to 0.51 m (depth) at 10% MAD (1.0 m^3/s).

In summary, shallow glides are four metres wider than deep glides at 10% MAD; while deep glides are 0.25 m deeper than shallow glides at 1% MAD (0.1 m^3/s).

Coho & Steelhead Fry Rearing

Coho and Steelhead fry habitats were each modelled with resolution of 0.01 m^3/s to ensure that no inflection points were overlooked by simplifying the analysis. Shallow and deep glides were each assessed separately to highlight any habitat-flow differences that may exist.

The maximum AWS for Coho fry ranged between 4 – 13 m^2/m across all glides (Figure 4-34). Maximum AWS occurred between 0.25 and 0.75 m^3/s (2.5 – 7% MAD) and corresponded to CSI values of 0.5 – 0.7 in this flow range (Figure 4-34). The maximum AWS for Steelhead fry ranged between 1 – 11 m^2/s across all glides (Figure 4-.35). Maximum AWS occurred between 0.25 – 0.75 m^3/s (2.5 -7% MAD) and corresponded to CSI values of 0.1 – 0.5 (Figure 4-35).

Differences between Coho and Steelhead AWS and CSI, and between shallow and deep glides are viewed best through aggregate curves. By combining all shallow glides and all deep glides into separate groups the relative contribution of meso-habitat characteristics is highlighted (Figures 4-36 to 4-39).

Maximum AWS for Coho fry are the same in both shallow and deep glides at 9 m^2/m; while maximum AWS for Steelhead fry ranges between 7 m^2/s in shallow glides to 3 m^2/m in deep glides (Figures 4-36 to 4-37). Maximum CSI for Coho fry ranges from 0.6 in shallow glides to 0.65 in deep glides; while maximum CSI for Steelhead fry ranges between 0.45 in shallow glides to 0.2 in deep glides (Figure 4-38 to 4-39).

In summary, model results for Coho fry appear to be more plastic with the quantity (AWS) and quality (CSI) of habitat in shallow and deep glides, while Steelhead fry results appear negatively impacted by the low velocity environment in deep glides. Further, the shape of the AWS and CSI curves for shallow glides is as would be expected across a range of streams, species, and physiography; however, the shape of the AWS and CSI curves for deep glides are very flat and broad in comparison to expected results for natural, healthy streams.

Riffles and Insect Production

As part of the Koksilah River EFA, riffle production for insects was considered for all six riffles transects in the analysis. Like other habitat metrics, the AWS for insect production increased rapidly from 0 to 1% MAD (Figure 4-40). Maximum AWS for insect production occurs across a higher and broader range than the rearing steelhead fry HSCs (Figure 4-40).

There are notable differences in the shape of the curves for the quality (CSI) of riffle production habitat as compared to the quantity (AWS). In the case of insect production, the quality increases faster than the quantity across most transects (Figure 4-41). The overall quality of insect production peaks between 1% - 12% MAD or 1 to 12 m^3/s with maximum values ranging between 0.4 – 0.9 (Figure 4-41).

Aggregating the riffle transects into a single curve allows for broader investigation of the flow-habitat relationship between flow and the quality of insect production. Revealed through the aggregate curve is that, during low-flows, as defined as those below 5% MAD, each flow increase of 1% MAD results in a 10% increase in the quality of insect production (Figure 4-42).

Riffles and Adult Chinook Passage

The extreme low-flows experienced in the Koksilah River over the past decade are certainly cause for concern, as numerous issues arise as flow dwindles, and increases in temperature. Adult Chinook passage through riffles is one such issue of concern. Six transects were used to characterize riffle conditions in the lower Koksilah River. As passage depth requirements can change with body size both specific and general passage assessments both were applied.

Using 0.24 m as the specific passage depth criteria, and 2.44 m/s (Reiser and Bjornn 1979) as the maximum velocity criteria, the passage assessment for adult Chinook indicates that passage initiates at 10% MAD (Figure 4-44). Passage width increases rapidly from 0 - 8 m, between 10% and 40% MAD or between 1.0 m^3/s and 4 m^3/s (Figure 4-44). It is important to realize that fish are well adapted to pulses in hydrology and even though passage depth may be too shallow, it is the rainfall events that often provide temporary passage. But in 2021, those rainfall events did not materialize for nearly 100 days straight.

To look more generally at static passage criteria in riffles throughout the lower Koksilah River, six scenarios were modelled where passage depth criteria ranged from 0.14 – 0.24 m in increments of 0.02 m. Velocity criteria was equal across all scenarios at 2.54 m/s. Superimposed on these results, rather arbitrarily for discussion, are a passage width criterion of 1.0 m (Figure 4-45) and a continuous passage channel criterion of 5% channel width (Figure 4-46). It is not that these have scientific backing, but on first principle, a width of 1 m and depths of 0.14 – 0.24 m are not much for adult Chinook to work with. And less than 5% of the stream channel in the Koksilah for passage really is not much at all.

Again, these [arbitrary criterion] are superimposed on top of the model results for discussion and rationalization of the model results themselves. Interestingly, this [general] approach indicates that the passage flows required, to support depth criteria between 0.14-0.24 m, would range between 6% to 20% MAD or 0.6 m^3/s to 2.0 m$^{3/}$s (Figure 4-25 to 4-26).

Sediment Deposition in Glides
The impacts of sediment deposition on insect habitat and salmon redds is well documented and this report makes no effort to elaborate on or expand that knowledge, rather to use this knowledge to compare substrate deposition in shallow and deep glides as a by-product of extreme low-flows in the Koksilah River.

The deep glides, as described in Chapter 2 (Meso-Habitat), have unusually high riffle crest elevations that results in water being backed up for hundreds of metres in some cases, like pools, but these are glides in their width-depth profile and formative mechanisms. The high crest elevations of the deep glides result in lower velocities near the bed, and therefore, increase sediment deposition.

Focusing on silt deposition as the surrogate for comparison, model results indicate that shallow glides experience deposition of silt across 50% of the streambed area at 0.1 m^3/s (1% MAD), 20% of the streambed area at 0.3 m^3/s (3% MAD), and 10% of the streambed area at 0.9 m^3/s (9% MAD) (Figure 4-47). Conversely, in deep glides, model results indicate that deposition of silt occurs across 100% of the streambed area at 0.1 m^3/s (1% MAD), 70% of the streambed area at 0.3 m^3/s (3% MAD), and 28% of the streambed area at 1.0 m^3/s (10% MAD) (Figure 4-48).

Both streams and aquatic species are generally well adapted to the environment they are surrounded by; however, the formation of deep glides is ‘unnatural’, and the habitat suitability is markedly different when compared to natural glides. For example, during summer low-flow period Koksilah River streamflow can range between 1-5% MAD for weeks to months. This would indicate that between 50 to 100% of the streambed would be covered in silt deposition. This assertion is evidenced by the MHE results which show the Deep Glides to have high silt contents.

When the sediment flushing, or flushing flows, are considered for these same meso-habitats (shallow and deep glides), model results indicate that shallow flushing (<10 cm into the bed) in deep glides initiates at 30% MAD (3 m^3/s) and is fully developed and moving 50% of the streambed at 150% MAD (15 m^3/s) (Figure 4-49). As streamflow exceeds 150% MAD numerous times per year. Realistically speaking, given the height of the riffle crests, Deep Glides may not be adequately flushing, as velocity may not reach the bed during high flow events.

4.5 Discussion

The EFN assessment was designed to meet several objectives that were Coho fry rearing, Steelhead fry rearing, and adult Chinook passage through riffles in the Lower Koksilah River. The following section presents discussion on the: (i) habitat flow relationships, (ii) deep and shallow glides, (iii) riffle passage, and (iv) a multi-value EW / EFN perspective.

4.5.1 Habitat-Flow Relationships

Payne describes SEFA as new software that implements the substance of the IFIM (Payne et al. 2012). To achieve this outcome requires both a robust hydraulic model, and robust HSC for the species and life stages of interest. This does not come without criticism. Rosenfeld and Ptolemy (2012) demonstrated that prediction of suitability (PHABSIM) consistently overestimated productivity at low flows for rearing Coho. This highlights the importance of understanding the strengths and limitations to modelling EFN with one-dimensional hydraulic-habitat models such as SEFA and PHABSIM.

The CWB has developed a hydraulic model for the Koksilah River that functions very well across the target range of flow (0.01 to 2.0 m^3/s), while also functioning moderately well over a broader range of flows (0.1 to 6 m^3/s). However robust the hydraulic model, a limitation to all EFA is the robustness of the HSCs used. To that end, the Koksilah EFA is hydraulically robust and, quite likely, biologically (HSC) accurate in representing rearing conditions in mainstem habitat for Coho and Steelhead fry. That said, field validating and adjusting the HSCs for the Koksilah River would inevitably increase the validity of habitat-flow relationships.

4.5.2 Deep and Shallow Glides

One of the more interesting aspects to the Koksilah River EFA is the classification of *deep glides*. Deep [unnatural] glides account for a substantial portion of stream length (71%) in the lower Koksilah River and have very different micro-habitat when compared to natural, *shallow glides*.

With respect to meso-habitat and flow interactions, the habitat-flow relationships between shallow and deep glides were quite different shapes (Figures 4-36 to 4-39), indicating a natural (shallow) and impacted (deep) meso-habitat expressions. Interestingly, model results suggest that Coho respond the least to the hydro-ecological differences between the two meso-habitat expressions; while other model results indicate that Steelhead respond abruptly to these differences (Table 4-3). Importantly, these responses are based solely on HSC with no consideration for temperature or food (Weber et al. 2014).

Coho fry have a glide depth preference of basically 0-4 m suggesting they are comfortable pool dwellers. Whereas Steelhead fry depth preference is a narrow range spanning 0.1 to 0.4 m before suitability drops dramatically. These differences expose the weaknesses of one-dimensional IFIM models based on transects. The difficulty is that different species use habitat differently, but transect-driven studies tend to rely on singular transects to predict multiple conditions, as is the case in the study.

Table 4-3. Koksilah River Habitat-Flow Relationships for Shallow and Deep Glides.

Species	Meso-Habitat	Max AWS (Quantity) (m^2/m)	MAX CSI (Quality) (0-1)	Flow Range (m^3/s)	Flow Range % MAD
Coho	Shallow Glides	9.0	0.60	0.2 – 0.4	2 - 4%
	Deep Glides	8.8	0.65	0.3 – 0.8	3 - 8%
Steelhead	Shallow Glides	7.4	0.49	0.2 – 0.4	2 - 4%
	Deep Glides	2.7	0.20	0.2 – 1.0	2 – 10%

4.5.3 Riffles

Two aspects of riffles were considered that were entirely independent of one another yet model results for each suggest similar flow ranges for idealized habitat conditions. These include insect production in riffles, as a food source to downstream pools; as well as adult Chinook passage through riffles during extreme low-flows. Insect production in riffles was considered as a complement to the rearing component of the EFA. Riffles account for 14% (822 m) of the study area and are important features for nourishing fry.

The habitat-flow relationship for insect production in most of the [six] riffles had similar shapes to the rearing habitat-flow curves presented in *Section 4.3.2*. Noteworthy from this analysis was the level of agreement between the insect model results for the Koksilah and Cowichan rivers (LGL 2015). Both the Koksilah and Cowichan rivers had maximum AWS values of 17 (Table 4-4). Also noteworthy is that overall quality (CSI) of the model results (0.9) between flows of 10% – 60% MAD (Table 4-4).

Table 4-4. Koksilah River Habitat-Flow Relationships

	Max AWS (Quantity) (m^2/m)	MAX CSI (Quality) (0-1)	Flow Range (m^3/s)	Flow Range (% MAD)
Insects	17	0.9	1 - 6	10 - 60
Adult Passage	-	-	>1.5	15 - 40

Modelling low-flow passage of riffles can present a host of difficulties common to hydraulic modelling. So, rather than rely upon the specificity of an exact number (flow or depth) or prescription for adult Chinook passage through riffles, a general approach of looking at a range of flow depth criteria across a range of flows was applied.

This general approach was based on two considerations. First, flows in the Koksilah are only partially controlled through water allocation and regulatory response during extreme low-flows and so an exact number [above existing flow levels] is not actually usable. Second, the model results for passage depth are well above extreme low-flows which are also difficult to manage. As such, these results really speak towards restoration goals for the Koksilah rather than prescriptive management thresholds; although adult passage may become a factor if spring chinook are trying to migrate up the Koksilah River when irrigation begins, and flows are very low.

4.5.4 Multi-Value Flow Range

The lower Koksilah River habitat-flow relationships each provide meaningful insights toward rearing conditions across the low-flow period (July to Oct.). When considering the habitat-flow relationships (Figure 4-32 to 4-49) and the range of parameters investigated (Figure 4-50), it is important to consider there are many variables [in the natural environment] and that each exert a different level of influence on rearing conditions, such as food availability and stream temperature (Webber et al. (2014). These are simply model limitations to be aware of.

The Koksilah River Tier 2 EFA modelled five primary instream values and / or conditions which included: (i) insect production in riffles, (ii) Steelhead fry rearing, (iii) Coho fry rearing, (iv) siltation of glides at low-flow, (v) Chinook passage through riffles. Drawing from collective overlap, model results suggest that flows between 0.25 – 1.6 m^3/s optimize all but insect production (Figure 4-50).

Model results from the Koksilah River EFA suggest that 'optimum' flows for Coho and Steelhead fry rearing in the Koksilah River occur across a range of flows, rather than a specific flow. For example, the habitat-flow relationship for Coho and Steelhead rearing suggests moderate-to-optimum conditions between flows of 0.25–0.75 m^3/s; whereas the insect-flow relationship suggests optimum conditions between flows of 1 – 6 m^3/s, which is well past the peak of the rearing curves; similarly, flows that are too low (<0.4 m^3/s) may result in increased deposition of fines in slow water (Pools, Deep Glides), as presented in Table 4-5.

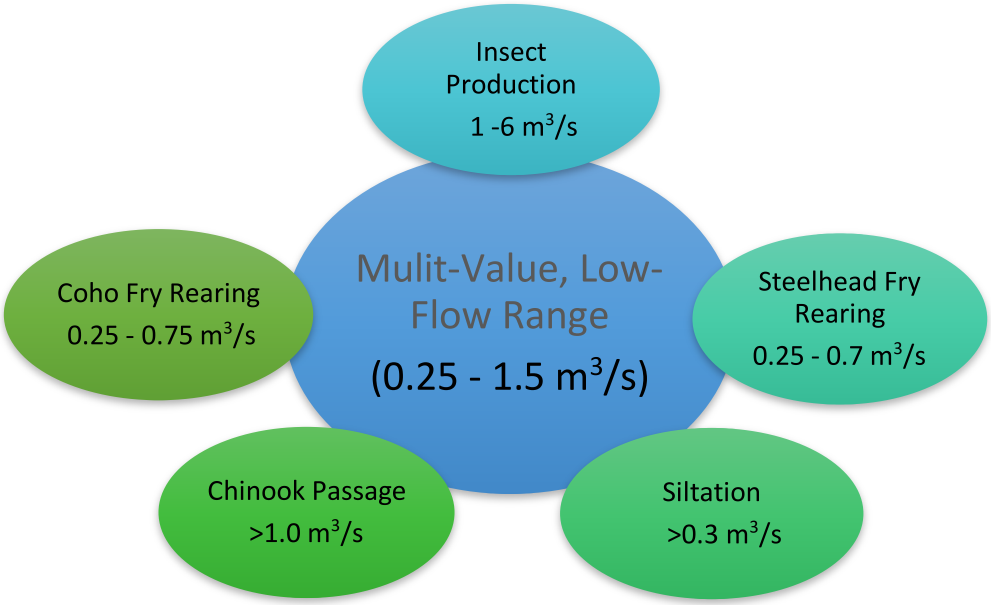
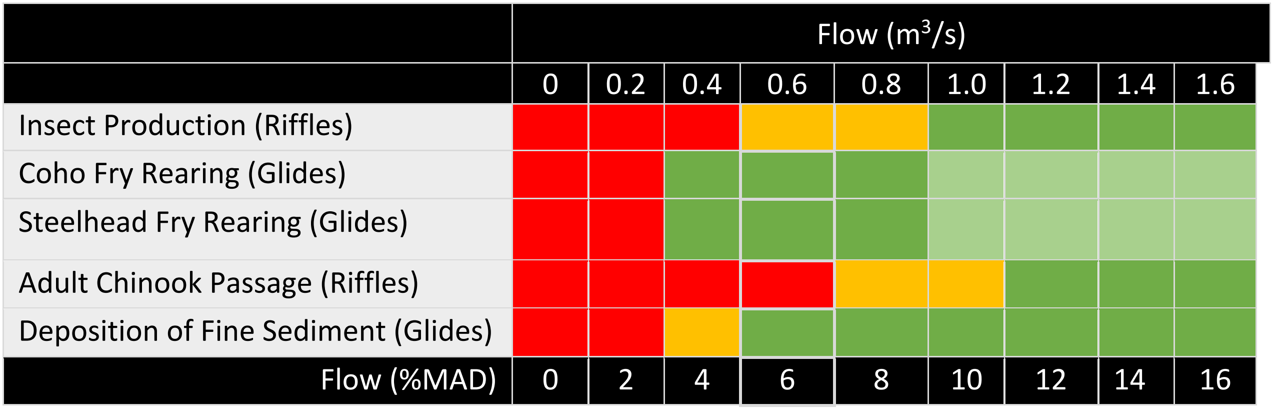


Figure 4-50. Koksilah River EFA Optimum Flow Range(s).

Table 4-5. Koksilah River EFA Optimum Flow Range(s).



	Flow (m^3/s)								
	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6
Insect Production (Riffles)	🟥	🟥	🟥	🟧	🟧	🟩	🟩	🟩	🟩
Coho Fry Rearing (Glides)	🟥	🟥	🟩	🟩	🟩	▨	▨	▨	▨
Steelhead Fry Rearing (Glides)	🟥	🟥	🟩	🟩	🟩	▨	▨	▨	▨
Adult Chinook Passage (Riffles)	🟥	🟥	🟥	🟥	🟧	🟧	🟩	🟩	🟩
Deposition of Fine Sediment (Glides)	🟥	🟥	🟧	🟩	🟩	🟩	🟩	🟩	🟩
Flow (%MAD)	0	2	4	6	8	10	12	14	16

- Red indicates outside of the optimum zone.
- Orange indicates sub-optimum
- Yellow indicates within the optimum zone
- Dark Green indicates squarely within optimum zone
- Light Green is outside of the modelled optimum but still good

However well a model appears to function - all models are an over-simplification of reality (Rosenfeld and Naman 2021). Therefore, the validation of a model is not necessarily to demonstrate it is ‘true’, but that it is able to generate testable hypotheses with relevance to the study objectives. The validation results (Figures 4-12 to 4-28) demonstrate repeatability of the hydraulic model. Assuming the HSI is accurate it would be fair to suggest model results are close to reality.

In a recent investigation into systematic biases in eco-hydraulic modelling with HSC’s, Rosenfeld and Naman (2021) argue that territorial aspects of fishes and diel predatory-prey relationships have created systematic biases in EFN work as they do not account for food. Weber et al. (2014) also criticize IFIM for not included both food and temperature and went on to demonstrate that both food and temperature control behaviour. These criticisms are well founded and speak directly towards the need to consider a broad range of results when applying IFIM (Figure 4-50, Table 4-5) and to be cautious about prescribing exact, or minimum flows.

In summary, the EFA explored several eco-hydraulic parameters that are each well correlated with salmonid life cycle needs. The traditional IFIM approach based on HSC yielded flow-depth, flow-velocity, and hydraulic-habitat curves; using the hydraulic model yielded flow-width and habitat-flow curves. Although it is clear that these parameters influence the mechanics of the microhabitat conditions, it is also clear that there is a range of conditions thought to be ‘optimum’ (Figure 4-50; Table 4-5). These are expected outcomes in eco-hydraulic modelling on small streams, and further highlights the need to validate the HSC, as HSC are the single most limiting factor in any EFA – the Achilles Heel.

4.5.5 Restoration Goals

The origin of EFA in the U.S. is based on evaluating [EFN] trade-offs between people and nature and the next step of setting restoration goals is no different as restoration is also about evaluating trade-offs between people and nature.

Presently, agricultural, residential, and municipal infrastructure is at risk to extreme floods and droughts. A simple trade-off with exponential benefits would be investing in a protected riparian corridor where the river has space to move, helping to balance hydrology, geomorphology, biology and ecology with natural fluvial processes. Such actions could benefit both people and nature for generations to come.

The Tier 2 EFA investigated five parameters surrounding rearing and passage conditions in the Lower Koksilah River. Although each has its' own 'sweet spot', what is abundantly clear across all five parameters is that streamflow below 2-4% MAD (0.2-0.4 m^3/s) is assumed to presents irreparable harm to fish (Table 4-5).

A starting point for restoration would be to plan a future where irreparable harm to fish would not occur. From this Tier 2 EFA, model results indicate that summer low flows (7Q10) of 5% MAD would reduce the current risk [of extreme low flows] to aquatic life. That said, model results further indicate the minimum streamflow for all five parameters is 10% MAD and with that, the commensurate restoration goal would be:

Table 4-6. Lower Koksilah River Tier 2 EFA Restoration Goal.

	Existing Condition	2-5 Years	5-10 Years
Increase Summer Baseflow	$\leq$ 1% MAD	$\geq$ 5% MAD	$\geq$10% MAD

* Restoration goal referring to monthly 7Q10 from June to October.

It is noteworthy that these restoration goals mirror the Tier 1 restoration goals (Chapter 3, Table 3-8).

4.6 Next Steps

Habitat Use - To build on this detailed model of habitat availability, a natural next step would be to capture measurements of feeding fish (depth, velocity, fish size) to develop an understanding of habitat use and suitability. SEFA has tools to build this into the existing model.

Modelling Bioenergetics - Traditional EFA have always received criticism over shortcomings related to HSCs, such that the habitat preferences may not match the fitness consequence of habitat use (Naman et al. 2019). In recent years Bioenergetic modelling has bridged this gap by linking hydraulic conditions to energy balance (Jowett et al. 2021). Bioenergetic modelling would be a natural extension from the Tier 2 EFA and could be performed with the same software package (SEFA) used to perform the Tier 2 EFA.

5 REPORT SYNTHESIS

5.1 Report Synthesis

Environmental flows in the Koksilah River are unable to meet the needs of both people and nature during the warm season low-flow period of the year (June to Sept.). In response to competing water needs between people and nature as well as the extreme low flows, the Koksilah River Environmental Flow Assessment began with objectives of: (i) evaluating channel condition, (ii) evaluating historical water supply, and (iii) evaluating instream habitat-flow relationships for rearing Coho and Steelhead fry along with adult Chinook passage.

The following sections provide reflections on these three objectives, followed by a short discussion on the relationship between environmental flows and process-based restoration along with a few general recommendations for the Twinned Watershed Project to continue evaluating habitat condition and working towards restoration

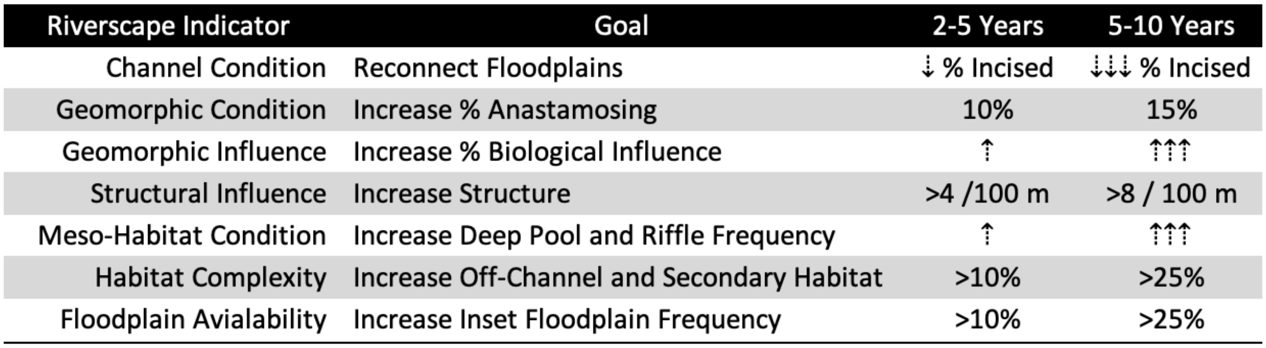
5.1.1 Meso-Habitat Evaluation

The Meso-Habitat Evaluation characterized 5,775 m of the lower Koksilah River, capturing detailed measurement for every meso-habitat within this stream segment. The most notable outcomes were not the fine details, rather the larger channel evolution trends observed, such as the formation of Deep Glides.

The channel evolution of the lower Koksilah River is predominantly *'degraded'* and heavily influenced by *'hydrology'*. Ecological degradation in the Koksilah River appears to be a product of both channelization and peak flow events.. As structure has been eroded away over the years, the remaining condition is a much simpler river planform with limited complexity, ecological value or resilience.

From the Meso-Habitat Evaluation the single largest take home is the evolutionary stages the Koksilah is in (76% Deep Glides) , contrasted by its history of thriving salmon returns. In order to increase the ecological value of the Koksilah River it will be necessary to identify locations where process-based restoration can be applied to increase the overall structure, complexity and biodiversity of the lower Koksilah River.

Restoration Goals



Riverscape Indicator	Goal	2-5 Years	5-10 Years
Channel Condition	Reconnect Floodplains	⇣ % Incised	⇣⇣⇣ % Incised
Geomorphic Condition	Increase % Anastamosing	10%	15%
Geomorphic Influence	Increase % Biological Influence	⇡	⇡⇡⇡
Structural Influence	Increase Structure	>4 /100 m	>8 / 100 m
Meso-Habitat Condition	Increase Deep Pool and Riffle Frequency	⇡	⇡⇡⇡
Habitat Complexity	Increase Off-Channel and Secondary Habitat	>10%	>25%
Floodplain Avialability	Increase Inset Floodplain Frequency	>10%	>25%

5.1.2 Tier 1 EFA – Water Supply

The Koksilah Tier 1 Environmental Flow Assessment of water supply used historical hydrology, Canadian Climate Normal Windows, fish periodicity (Coho and Steelhead fry), and a suite of *Standard Setting* methods to estimate 'optimum' streamflow for life history needs, for each week of the year. Optimum conditions were used to develop the *draft Koksilah Conservation Flow*.

It is commonly understood that *Standard Setting* methods perform best in their natal stream. That said, using the *average* EFN values across the five methods, coupled with professional judgement, make a compelling case for the application of this approach on the Koksilah River. Therefore, what this Tier 1 EFA has revealed is that the current baseflow conditions (7Q10, 1960-2021) are not adequate to sustain critical life histories during the summer low-flow period (July-Sept.). It is therefore hypothesized that currently observed baseflow conditions (instrument record) are not true baseline conditions for the Koksilah River.

Often *Standard Setting* methods are used to identify a particular flow (e.g., 20% MAD) and when this is the focus of the project, accuracy of the prediction is essential. However, the Koksilah Tier 1 EFN intended to explore 'optimal flow conditions' for rearing Coho and Steelhead fry. A natural next step to build on this would be to integrate the human dimension and include Indigenous flows, agricultural flows and community flows.

The most notable outcome of the Tier 1 EFA was the assertion that 7Q10 is not adequate and that restoration of the 7Q10 is required. Chapter 3 recommended setting both near and long-term restoration goals; with a goal of restoring the 7Q10 to 0.5 m_3/s or 5% MAD in the near-term and 1.0 m^3/s or 10 % MAD in the longer-term.

Restoration Goals

	Existing Condition	2-5 Years	5-10 Years
Increase Summer Baseflow	≤ 1% MAD	≥ 5% MAD	≥10% MAD

5.1.3 Tier 2 EFA – Water Availability

The EFN assessment was designed to meet several objectives, including Coho and Steelhead fry rearing and adult Chinook passage through riffles. In total 17 transects were used to characterize *deep glides*, *shallow glides* and *riffles*. Model calibration and validation went very well with average model error reporting ± 0.025 m depth and ±0.018 m/s velocity.

A multi-value environmental water / environmental flow range was developed using five of the six parameters (flushing was excluded) investigated (Chapter 4, Figure 4-50). When considering several parameters at once (Chapter 4, Table 4-5) the overall trend is quite clear - more water is required in the Koksilah River during the low-flow period of the year (July-Sept.).

What is immediately clear in Table 4-5 (Chapter 4) is that the minimum flow threshold for insect production in riffles is 10% MAD, which is much more water than is historically available since the 1960's. Yet, to maintain river health - for Coho and Steelhead fry - it is necessary to maintain the conditions of healthy habitat which include food and thermal refugia. Model results suggest that food resources are diminished during the summer low flow period.

When we talk of the health of the river it is important to remember we are talking about the whole watershed (Chapter 1, Figure 1.1) as a river is the 'sum of its parts'. Many hydrologists consider a watershed to be the 'engine' while the streamflow is the 'exhaust'; with that, an imbalance in watershed integrity will inevitably manifest in the aquatic environment (Chapter 1, Figure 1.1).

To reverse the declining ecological trends within the Koksilah River, it will be necessary to increase summer baseflow conditions (7Q10). Similar to Chapter 2 and Chapter 3, the Tier 2 EFA had both near term and long-term restoration goals that include increasing summer baseflow to 5% MAD (near-term) and then 10% MAD (long-term).

Restoration Goals

	Existing Condition	2-5 Years	5-10 Years
Increase Summer Baseflow	≤ 1% MAD	≥ 5% MAD	≥10% MAD

5.2 Environmental Flows and Process-Based Restoration

Land-use, climate change, and water supply demands have put unprecedented pressure on the Koksilah River. The clearing of floodplains, logging of old growth, straightening of the channel and removal of riparian areas, are but a few activities that have tipped the scales with respect to landscape alteration (Allan 2004). In 2005 the Department of Fisheries and Oceans published the Wild Salmon Policy (DFO, 2005) which outlined thresholds for landscape alteration. Collectively anthropogenic impacts, along with exacerbations from climate change, have led to the loss of environmental flows for both people and nature in the Koksilah River.

An alteration in the [environmental] flow regime (Chapter 3, Figure 3.2 and Figure 3.3) of a river modifies essential fluvial processes that often results in ecological adjustment to a new, altered physical habitat (e.g., *Deep Glides]*. Restoration of the flow regime, flood storage and natural fluvial processes is essential for the on-going health of the Koksilah River if the goal is to have adequate environmental water to meet needs of both people and nature into the future.

To plan a future where the environmental flow needs are being met in the Koksilah will require a 'Whole-of-Watershed' approach with 'Whole-of-Government' support. And specifically, ecological restoration / process-based restoration to accelerate fluvial processes and encourage the rebuilding ecosystem health and resilience.

When we talk about environmental flows we are referring to some condition that is inherently healthy for one or several species across a range of flows. For flows to be truly 'sustaining' for a given species there needs to be structure, complexity, biodiversity, heterogeneity, and resilience. Process-based restoration / ecological restoration inherently reintroduces these into fluvial systems.

Process-based restoration is, then, the practice of implementing environmental flows.

5.3 Recommendations

The Xwulqw'selu Sta'lo (Koksilah River) Environmental Flow Assessment was designed to investigate several objectives, including: (1) Coho fry rearing; (2) Steelhead fry rearing; and (3) adult Chinook passage. Next steps that can be taken to address each of the restoration goals presented in Section 5.1 may include:

1. **Meso-habitat mapping** – Mapping in key tributaries can advance restoration planning and deepen the understanding of geomorphic condition and recovery potential in those tributaries.
2. **Peak-flow analysis** – Performing a peak flow analysis to understand the mechanisms behind these flow events will be critical piece of the picture towards restoring ecosystem functions and riverscape health.
3. **Precipitation analysis** – Performing a regional analysis would provide an opportunity to compare how different watersheds are responding to precipitation events as compared to the Koksilah. Such an analysis may confirm whether the increase 1:2 return periods are dur to climate variability or due to land-use changes.
4. **Historical aerial photo analysis** – Reviewing historical aerial photographs can assist with restoration planning by identifying risks and opportunities for restoration design and implementation.
5. **Expanding the Tier 1 EFA -** Adding Indigenous, agricultural and community flow needs would enhance a 'whole of watershed' approach and provide a platform to understand water needs.
6. **Expanding the Tier 2 EFA –** Both validating HSI's and adding bioenergetics suite of tools would each strengthen the scientific understanding of limiting factors in the Koksilah River.
9. **Watershed Restoration Plan** – The vast extend of habitat degradation revealed in the lower Koksilah River speaks clearly towards the need for watershed-scale restoration and management. As a watershed restoration plan is formed it is suggested that plan be based on: (i) a credible framework that can (ii) integrate process-based restoration.
7. **Process-Based Restoration Team** – It is self-evident that the Koksilah River and its tributaries will require on-going, process-based restoration / ecological restoration. Process-based restoration embraces a 'whole of watershed' approach and lends itself to being implemented through local capacity - such as Guardians, Technicians, youth, or community / stream keeper volunteers. Taking initial steps to put several summer jobs in place and supply training for a 'stream team' would reap rewards at many levels.

5.4 References

Allan DJ. 2004. Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. Annu. Rev. Ecol. Evol. Syst. 2004, 35: 257-284.

Annear, T., I. Chisholm, H. Beecher, A. Locke, and 12 other co-authors. 2004. Instream flows for riverine resource stewardship, revised edition. Published by the Instream Flow Council, Cheyenne, WY.

Arthington, Angela H. and Bhaduri, Anik and Bunn, Stuart E. and Jackson, Sue E. and Tharme, Rebecca E. and Tickner, Dave and Young, Bill and Acreman, Mike and Baker, Natalie and Capon, Samantha and Horne, Avril C. and Kendy, Eloise and McClain, Michael E. and Poff, N. LeRoy and Richter, Brian D. and Ward, Selina. 2018. The Brisbane Declaration and Global Action Agenda on Environmental Flows. Policy and Practice Reviews. Frontiers of Environmental Science: 6 (45).

BC MFLNRO and ENV. 2016. Environmental Flow Needs Policy. Accessed December 10, 2021. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/water-rights/efn_policy_mar-2016_signed.pdf

Beechie, T.J., David A. Sear, Julian D. Olden, George R. Pess, John M. Buffington, Hamish Moir, Philip Roni, Michael M. Pollock, Process-based Principles for Restoring River Ecosystems, *BioScience*, Volume 60, Issue 3, March 2010, Pages 209–222, https://doi.org/10.1525/bio.2010.60.3.7

Beechie TJ, Pollock MM and Baker S. 2007. Channel Incision, evolution and potential recovery in the Walla Walla and Tucannon River basins, northwestern USA.

Beecher, H., and B. Caldwell. 2013. *Instream flow study guidelines: Technical and habitat suitability issues including fish preference curves, Updated April 1, 2013*. Washington Department of Fish and Wildlife & Washington State Department of Ecology.

Bovee, K. D., and R. T. Milhous. 1978. Hydraulic simulation in instream flow studies: Theory OBS-78/33).

Bovee, K. D. 1996. Perspectives on two-dimensional river habitat models. The PHABSIM experience. PagesB149-162. In M. Leclerc, H. Capra, S. Valentine, A. Boudreault, and Y. Cote, editors. Ecohydraulics 2000. Proceedings of the Second International Symposium on Habitat Hydraulics. Quebec: INRS-Eau, Co-published with FQSA, IAHR / AIRH.

Bovee, K.D. 1982. *A guide to stream habitat analysis using the instream flow incremental methodology.* Instream Flow Information Paper 12. U.S. Fish and Wildlife Service FWS/OBS-82/26.

Bovee, K.D. 1986. *Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology*. Washington, DC: USDI Fish and Wildlife Service Instream Flow Information Paper #21 FWS/OBS-86/7.

Brierley, G.J., and K.A. Fryirs. 2005. Geomorphology and River Management: Application of the Riverstyles Framework. Blackwell Publishing. 398 p.

Brisbane Declaration. 2007. *10th International Riversymposium and International Environmental Flows Conference*, held in Brisbane, Australia, on 3-6 September 2007.

Brisbane Declaration. 2018. Arthington AH, Bhaduri A, Bunn SE, Jackson SE, Tharme RE, Tickner D, Young B, Acreman M, Baker N, Capon S, Horne AC, Kendy E, McClain ME, Poff LN, Richter BD and S Ward. 2018. The Brisbane Declaration and Global Action Agenda on Environmental Flows. *Front. Environ. Sci., 02 July 2018.*

Bunch MJ, Morrison KE, Parkes MW, Venema HD. 2011. Promoting health and well-being by managing for social-ecological resilience: the potential of integrating ecohealth and water resources management approaches. *Ecology and Society 2011* **16**: 6. [accessed online].

Bunte, K., Steven R. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. Gen. Tech. Rep. RMRS-GTR-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 p.

Canadian Water Resources Association. 2018. Siwtkʷ (Water) For All – Our Responsibility. Conference proceedings: *Environmental Flow Needs Conference 2018:* Science, Policy & Practice held in Kelowna, British Columbia, Canada, on Oct 17-18, 2018. Syilx Okanagan Nation Territory.

Castro, J. M. (2021). Personal communication.

Castro, J. M., and Thorne, C. R., 2018. The stream evolution triangle: Integrating geology, hydrology and biology. *Rivers Research and Applications*, 35(4): 315-326

Cluer, B. and Thorne, C., 2014. A stream evolution model integrating habitat and ecosystem benefits. *Rivers Research and Applications*, 30(2): 135-154.

Department of Fisheries and Oceans Canada. 2005. Canada's Policy for Conservation of Wild Pacific Salmon. ISBN 0-662-40538-2.

DFO. 2013. Framework for Assessing the Ecological Flow Requirements to Support Fisheries in Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/017.

European Union. 2000. Directive 2000/60/EC of the European Parliament and of the Council: Establishing a Framework for Community Action in the Field of Water Policy.

Flotemersch JE, Leibowitz SG, Hill RA, Stoddard JL, Thoms MC, and RE Tharme. 2015. A watershed integrity definition and assessment approach to support strategic management of watersheds. *River Res. Applic.,* 2015.

European Commission. 2015. Ecological flows in the implementation of the Water Framework Directive. Technical Report – 2015 – 086. Guidance Document No. 31

European Union. 2000. Water Framework Directive – Integrated River Basin Management for Europe. Directive 2000/60/EC. (OJ L 327). December 2000.

Flotemersch JE, Leibowitz SG, Hill RA, Stoddard JL, Thoms MC, and RE Tharme. 2015. A watershed integrity definition and assessment approach to support strategic management of watersheds. *River Res. Applic.,* 2015.

Forest Practices Board. 2018. Special Report: Conserving Fish Habitat under the Forest and Range Practices Act. Part 1: A Review of the BC Government Approach. FPB/SR/56.

Forest Practices Code of British Columbia. 1996. Queens Printer. RSBC 1996. Chapter 159.

Forest and Range Practices Amendment Act, 2003. Bill 69-2003. c.55. B.C. Reg. 7/2004 and 525/2004.

Forest Practices Board. 2018. Special Report: Conserving Fish Habitat under the Forest and Range Practices Act. Part 1: A Review of the BC Government Approach. FPB/SR/56.

Forest Practices Code of British Columbia. 1996. Channel Assessment Procedure Field Guidebook. ISBN 0-7726-3072-0.

Hatfield, T., Lewis, A., Ohlson, D., and M. Bradford. 2003. Development of instream flow thresholds as guidelines for reviewing proposed water uses. British Columbia Ministry of Sustainable Resource Management, and British Columbia Ministry of Water, Land, and Air Protection. Victoria, BC.

Irvine, J.R., I.G. Jowett, and D. Scott. 1987. A test of the Instream Flow Incremental Methodology for under yearling rainbow trout (Salmo gairdneril) in experimental New Zealand streams. New Zealand Journal of Marine and Freshwater Research, Vol. 21, pp. 35 - 40.

Johnston, N.T., and P.A. Slaney. 1996. Fish Habitat Assessment Procedures. Watershed Restoration Technical Circular No. 8. Revised April 1996.

Jowett, I., Hayes, J.W., & Neuswanger, J.R. (2021). Salmonid bioenergetic drift-foraging: swimming costs and capture success. *Journal of Ecohydraulics, 6*, 186 - 197.

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

Koksilah Habitat Atlas. URL: will be published soon. M.C. Wright and Associates LTD. 2021.

Kondolf, G.M. and Wolman, M. (1993). The Sizes of Salmonid Spawning Gravels. *Water Resour Res*. 29. 2275-2286. 10.1029/93WR00402.

Koning, C.W. 1999. Riparian Assessment and Prescription Procedures. Watershed Restoration Technical Circular No. 6. Revised April 1996.

Kuhn A, Leibowitz SG, Johnson ZC, Lin J, Massie JA, Hollister JW, Ebersole JL, Kake JL, Serbst JR, James J, Bennett MG, Brooks JR, Nietch CT, Smucker NJ, Flotemersch JE, Alexander LC, and JE Compton. 2018. Performance of national maps of watershed integrity at watershed scales. *Water* 2018, **10:** 604.

Kuhn A, Leibowitz SG, Johnson ZC, Lin J, Massie JA , Hollister JW, Ebersole JL, Kake JL, Serbst JR, James J, Bennett MG, Brooks JR, Nietch CT, Smucker NJ, Flotemersch JE, Alexander LC, and JE Compton. 2018. Performance of national maps of watershed integrity at watershed scales. Water 2018, 10: 604.

Lamouroux, N.; Jowett, I.G. 2005. Generalized instream habitat models. Canadian Journal of Fisheries and Aquatic Sciences 62: 7-14.

Lewis, A. T. Hatfield, B. Chillbeck, 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. Consultant's report prepared for the British Columbia Ministry of Sustainable Resource Management and the British Columbia Ministry of Water, Land and Air Protection.

Linnansaari, T., Monk, W.A., Baird, D.J. and Curry, R.A. 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.

Locke, A., and A. Paul. 2011. A desk-top method for establishing environmental flows in Alberta rivers and streams, Government of Alberta. Iv + 94 p.

Locke, A., C. Stalnaker, S. Zellmer, K. Williams, H. Beecher, T. Richards, C. Robertson, A. Wald, A. Paul, and T. Annear. 2008. Integrated Approaches to Riverine Resource Management: Case Studies, Science, Law, People, and Policy. Instream Flow Council, Cheyenne, WY. 430 p.

McManamay, R., Orth, D., Kauffman, J., M.M., Davis. (2013). A Database and Meta-Analysis of Ecological Responses to Stream Flow in the South Atlantic Region. Southeastern Naturalist. 12. 10.1656/058.012.m501.

Newcombe, C.P. and RA. Ptolemy. 1985. The use of prescribed percentages of mean annual discharge to recommend instream flows for fish in British Columbia (the Montana Method Revisited). In Instream Flow Methods. Department of Fisheries and Oceans Workshop on Instream Flow Methods. Vancouver and Nanaimo B.C.

Naman, S.M., Rosenfeld, J.S., Neuswanger, J.R., Enders, E.C., & Eaton, B. 2019. Comparing correlative and bioenergetics-based habitat suitability models for drift-feeding fishes. *Freshwater Biology*.

Payne, T.R., and Jowett IG (2012). SEFA - Computer software system for environmental flow analysis based on the instream flow incremental methodology. In: Proceedings of the 9th International Symposium on Ecohydraulics (ISE 2012) (eds. Mader H & Kraml J). University of Natural Resources and Life Sciences (BOKU) Vienna, Austria, ID 16589, p. 8.

Pike, R.G., T.E. Redding, R.D. Moore, R.D. Winker and K.D. Bladon (editors). 2010. Compendium of forest hydrology and geomorphology in British Columbia. B.C. Min. For. Range, For. Sci. Prog., Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Manag. Handb. 66. www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh66.htm

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, and others. 1997. The Natural Flow Regime: A paradigm for river conservation and restoration. Bioscience 47 (11): 769-784

Poff, N. L., J, K.H. Zimmerman. 2010. Ecological responses to altered flow regimes: A literature review to inform the science and management of environmental flows. *Freshwater Biology 2010, 55-1: 194-205.*

Pritchard, H., E, Doyle-Yamaguchi, and M. Carver. 2019. Ecosystem-Based Assessment of the Koksilah River Watershed. Phase 1 Report: Watershed Character and Condition. Cowichan Station

Polluck, M.M., T. J. Beechie, J.M. Wheaton, C.E. Jordan, N. Bowes, N. Webber, C. Volk. 2014. Using Beaver Dams to Restore Incised Stream Ecosystems. Bioscience 64(4): 279-290.

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. General Technical Report PNW-96. October 1979.

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

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. D., J. V. Baumgartner, R. Wigington, and D. P. Braun. 1997. How much water does a river need? Freshwater Biology 37:231-249.

Richter, B. D., J. V. Baumgartner, J. Powell, and D. P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10: 1163-1174.

Rideout, Natalie K. et al. Rewilding watersheds: using nature's algorithms to fix our broken rivers. *Marine and Freshwater Research* (2021): n. pag.

Rosenfeld, J. and S, Naman. (2021). Identifying and mitigating systematic biases in fish habitat simulation modeling: Implications for estimating minimum instream flows. River Research and Applications. 37. 10.1002/rra.3803.

Rosgen, D. 2006. Watershed Assessment of River Stability and Sediment Supply. Wildland Hydrology. For Collins, Colorado. 2nd. Ed.

Roni, P. Tim Beechie, George Pess, and Karrie Hanson. 2014. Wood placement in river restoration: fact, fiction, and future direction. *Canadian Journal of Fisheries and Aquatic Sciences*. **72**(3): 466-478. https://doi.org/10.1139/cjfas-2014-0344.

Schumm S, Harvey M and Watson C. 1984. Incised Channels: Morphology, Dynamics and Control. Water Resources Publications: Littleton, CO.

Schwartz, J.S. Use of Ecohydraulic-Based Mesohabitat Classification and Fish Species Traits for Stream Restoration Design. *Water* **2016**, *8*, 520. https://doi.org/10.3390/w8110520

Shields FD, Jr., Brookes A and Haltiner J. 1999. Geomorphological approaches to incised stream channel restoration in the United States and Europe. Darby SE and Simon A (Eds), Incised River channels; processes, forms, engineering and management. John Wiley & Sons: Chichester, pp. 371 - 394.

Slaney, P. A., A. D., Martin. 1997. The Watershed Restoration Program of British Columbia: Accelerating Natural Recovery Processes. Water Quality Research Journal (1997). 32(2): 325-346. https://doi.org/10.2166/wqrj.1997.022

Smith, 10M. and M.J. Sale. 1993. Standardizing instream flow requirements at hydropower projects in the Cascade Mountains, Washington. In: Proceedings of the international conference on hydropower. (Ed: Hall,WD) American Society of Civil Engineers, New York, 286-295.

Smokorowski K.E. and T.C.Pratt. 2007. Effect of a change in physical structure and cover on fish and fish habitat in freshwater ecosystems – a review and meta-analysis. *Environmental Reviews*. 15(NA): 15-41. https://doi.org/10.1139/a06-007

Stalnaker, C., B.L. Lamb, J. Henriksen, K. Bovee, and J. Bartholow. 1995. The instream flow incremental methodology: A primer for IFIM. Biological Report 29, U.S. Department of the Interior, National Biological Service, Washington, D.C. 45pp

Stanford, J. A., J. V. Ward, W. J. Liss, C. A Frissell, R. N. Williams, J. A. Lichatowich and C. C. Coutant. 1996. A general protocol for restoration or regulated rivers. Regulated Rivers: Research and Management, 12: 391-413.

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

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

Tharme RE. 1996. Review of International Methodologies for the Quantification of the Instream Flow Requirements of Rivers. Water Law Review Report for Policy Development, Freshwater Research Unit, Zoology Department, University of Cape Town, South Africa.

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 pplications 19: 397-441.

Thorp, J.H., Flotemersch, J.E., Delong, M.D., Casper, A.F. Thoms, M.C., Ballantyne, F., Williams, B.S., O'Nie;, B.J., Haase, S. 2010. Linking ecosystem services, rehabilitation, and river hydrogeomorphology. BoScience 60: 67-74. DOI: 10.1525/bio.2010.60.1.11

Ulibarri, N. and Escobedo Garcia, N., 2020. Comparing Complexity in Watershed Governance: The Case of California. *Water*, *12*(3), p.766.

U.S. Environmental Protection Agency. 2011. Healthy Watersheds Initiative: National Framework and Action Plan. EPS 841-R-11-005

Walker B, Salt D. 2012. Resilience Practice: Building capacity to absorb disturbance and maintain function. *Island Press 2012:* Washington, DC.

Weber, N., Bouwes, N. and Jordan, C.E., 2014. Estimation of salmonid habitat growth potential through measurements of invertebrate food abundance and temperature. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(8), pp.1158-1170.

Wheaton, J.M., Bennett, S.N., Bouwes, N., Camp, R., Maestas, J.D., and Shaverdian, S.M., 2019. Chapter 2 – Principles of Low-Tech Process-Based Restoration. In: J.M. Wheaton, S.N. Bennett, N. Bouwes, J.D. Meastas and S.M. Shaverdian (Editors), Low-Tech Process-Based Restoration of Riverscapes: Design Manual. Utah State University Restoration Consortium, Logan, Utah. 30 pp.

Wheaton, Joseph & Bouwes, Nick & Mchugh, Peter & Saunders, W. & Bangen, Sara & Bailey, Phillip & Nahorniak, Matt & Wall, Eric & Jordan, Chris. 2017. Upscaling Site-Scale Ecohydraulic Models to Inform Salmonid Population-Level Life Cycle Modelling and Restoration Actions - Lessons from the Columbia River Basin: Upscaling Ecohydraulic Models. Earth Surface Processes and Landforms. 43. 10.1002/esp.4137.

Wolman, G.M. 1954. A method of sampling coarse river-bed material. Transactions, American Geophysical Union (35) 6:951-95

World Meteorological Organization. 2019. Guidance on Environmental Flows: Integrating E-Flow Science with Fluvial Geomorphology to Maintain Ecosystem Services. WMO-No. 1235.

WWF. 2016. Living Planet Report 2016. Risk and resilience in a new era. WWF International, Gland, Switzer.

THIS PAGE IS LEFT BLANK

Appendices

Chapter 1 Appendices

Appendix 1A: Healthy Watersheds

Healthy Watersheds

Healthy watersheds perform a number of '*jobs'* or *ecosystem functions / services* (EFS) that benefit humanity. EFS include things such as the provision of clean water, regulation of water quantity and quality, and the creation and maintenance of habitat (Flotemersch et al. 2015; Allan 2004; Kuhn et al. 2018). A watersheds' ability to provide *EFS* however is contingent on *its' watershed integrity* (Bunch et al., 2011; Walker and Salt, 2012).

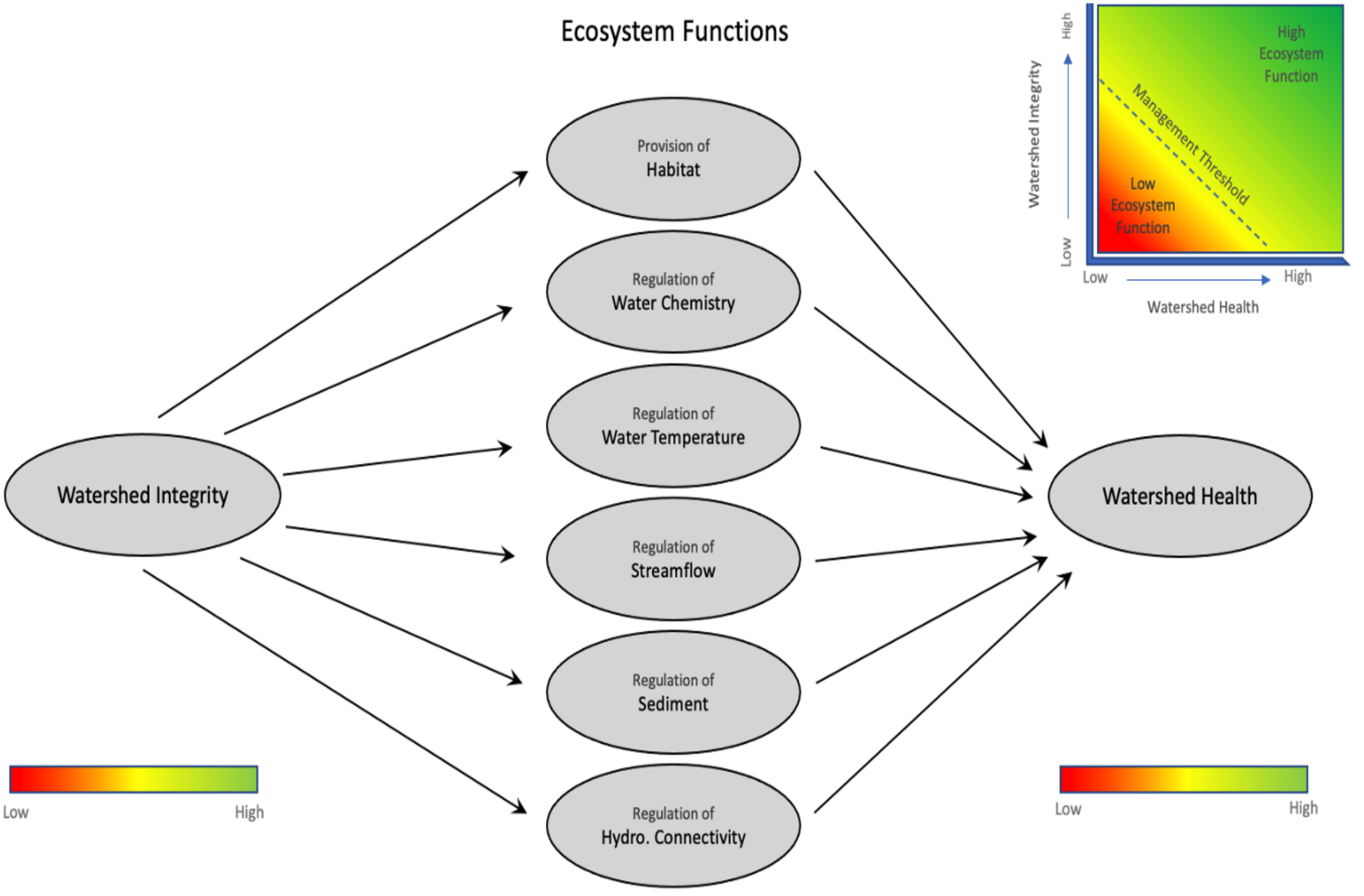
Watersheds require a high level of *watershed integrity* to regulate water supply, provide hydrologic connectivity and the provision of habitat (Allan 2004; EU Water Framework 2000; US EPA 2012). As such, *watershed integrity* is described as:

> "*…the capacity of ecosystem services and functions essential to the sustainability of biodiversity and of the watershed resources and services provided to* society"
>
> (Flotemersch et al., 2015; Kuhn et al., 2018).

The resources and services that society has come to know, and rely upon, has specifically been provided as a function of [historically] having high *watershed integrity*. When *watershed integrity* is high, and *ecosystem service* are well-functioning, there are six commonly accepted *EFS* provided by watersheds (Kuhn et al. 2018; Flotemersch et al. 2015); additionally, there is one unique ecosystem component that is intrinsically connected with watershed integrity – and that is Indigenous cultural, and ceremonial uses. Therefore, the *EFS* provided by intact watersheds, with high *watershed integrity* include:

- Indigenous Cultural and Ceremonial use
- Provision of Habitat
- Hydrologic Connectivity
- Hydrologic Regulation
- Regulation of Water Chemistry
- Regulation of Sediment
- Temperature Regulation

In summary, intact watersheds provide the necessary structure and complexity (*watershed integrity)*, for *ecosystem functions and services* to benefit both people and nature (Figure 1.1). Healthy watersheds, in turn, create climate change resilience by providing sufficient land cover, soil storage, floodplain storage and riparian buffering to offset the impacts of climate episodes (e.g., heat dome or extreme rainfall event), and climate impacts (e.g., infrastructure damage, loss of land). Therefore, investing in *watershed integrity*, is investing in *watershed health*. And maintenance of healthy watersheds requires consideration of the interconnectedness between landscapes, riverscapes, and environmental flows.



Adapted from: Allan, D.J. (2004). Influence of land use and landscape setting on the ecological status of rivers. *Limnetica* 23(3-4): 187-198.

Figure 1-2. Relationship between Watershed Integrity, Ecosystem Functions and Watershed Health.

Chapter 2 Appendices

Appendix 2A: Project Location

MAP 2-1: Koksilah River Watershed Overview

Base Map:
ESRI World Imagery

SCALE: 1:250,000

M. C. Wright and Associates Ltd.
Biological Consultants

NCompas
Software Development

Appendix 2B: Meso-Habitat Context

Meso-Habitat Context

Watershed health, represented as the quality of instream [fish] habitat, depends on physical, chemical and biological processes at the watershed scale (Pike at el. 2010). To sustain well-functioning physical, chemical, and biological processes, a watershed must have intact *watershed integrity*.

Within the fisheries and water resources fields there are several common assessments or techniques that can be employed to understand the hydro-ecological condition of fish habitat. Specifically, such assessments include methods focused on characterizing habitat at four different scales including the: (i) watershed scale, (ii) macro-habitat, or reach scale, (iii) meso-habitat, or site scale, and (iv) micro-habitat, or sub-metre (water column) scale.

Macro-habitat includes the sequencing of pools, riffles and runs along a segment of stream. It includes the assemblage of meso-habitats and generally looks at the proportion of meso-habitats within a reach (e.g., 10% pools and 90% runs) to understand habitat availability.

Meso-habitat assessments look at individual physical features such as measuring individual pools, riffles, runs or glides. Meso-habitats can be individually characterized using various assessment methods, or they can be mapped over large areas (100s of metres to kilometres).

Micro-habitat refers to the hydraulics of any given meso-habitat (pool, riffle, run, tailout) and includes parameters such as the depth, velocity, and substrate composition. Micro-habitat is commonly used in ecohydraulics to characterize habitat suitability for Environmental Flow Assessment (EFA) (Chapter 4). Micro-habitat aims to understand in-situ conditions for [e.g.,] spawning or rearing fish.

This section contains: (i) background information on geomorphic condition, structure and complexity and floodplain connectivity; along with the (ii) methods used in this study for the integrated meso-habitat Inventory and evaluation; (iii) results from the evaluation; and (iv) restoration goals inferred from the Meso-Habitat Evaluation.

Stream Evolution

Many hydro-ecological attributes critical to fish habitat have been studied for decades and are largely understood (Thorp et al 2010). Similarly, the impacts that human activities have on the hydro-ecological processes affecting watershed health and function have also been well-studied (Flotemersch et al. 2015; Kuhn et al. 2018; McManamay et al. 2013). We know that when ecosystem function is compromised that stream evolution and geomorphic condition decrease, followed closely by declining stream health and aquatic biodiversity (Cluer and Thorne 2014).

The stages of decline have emerged in the past decade as a stream evolution model (Cluer and Thorne 2014) that specifically connects the quality and quantity of ecosystem function with the ecological value of each evolutionary stage (Figure 2-1).

The Cluer and Thorne (2013) *Stream Evolution Model* (SEM) has provided aquatic science the necessary tools to contextualize landscape impacts (Figure 2-1 - top) and restoration targets (Figure 2-1 - bottom). It has long been understood that converting floodplains and forests to other forms of land-use (e.g., clear cuts, agricultural land, impervious surfaces) has direct impacts on the hydrologic cycle and eco-geomorphology of river systems. And that through intensive land-use, and / or cumulative impacts, ecosystem function and river health will become impacted.

The Stream Evolution Model (Cluer and Thorne 2013) provides a bridge between: (1) an emerging practice within the river restoration body of science, which is process-based restoration; and (2) a large gap in the river restoration body of practice whereby traditional restoration engineering practices have assumed streams were stationary, non-dynamic entities. Understanding the appropriate evolutionary stage of the river is essential to maximize biodiversity and ecosystem resilience, thus, providing restoration targets. To that end, the role of the Meso-Habitat Evaluation, among other things, is to identify the current evolutionary state of the Koksilah and the habitat value associated with that (Figure 2-1).

The Cluer and Thorne (2014) model has therefore provided a level of resolution and intention to habitat evaluations that has previously not been available to river science. Since most habitat evaluations, at some level, are interested in both characterizing impacts, and in articulating restoration goals, the Stream Evolution Model is an essential tool for restoration practitioners. For these reasons, the meso-habitat characterization integrated the *Stream Evolution Model* (Cluer and Thorne 2013) into the architecture of the assessment, such that those data that were collected and the restoration recommendations that were made, stand to maximize biodiversity and ecosystem resilience through riverscape restoration.

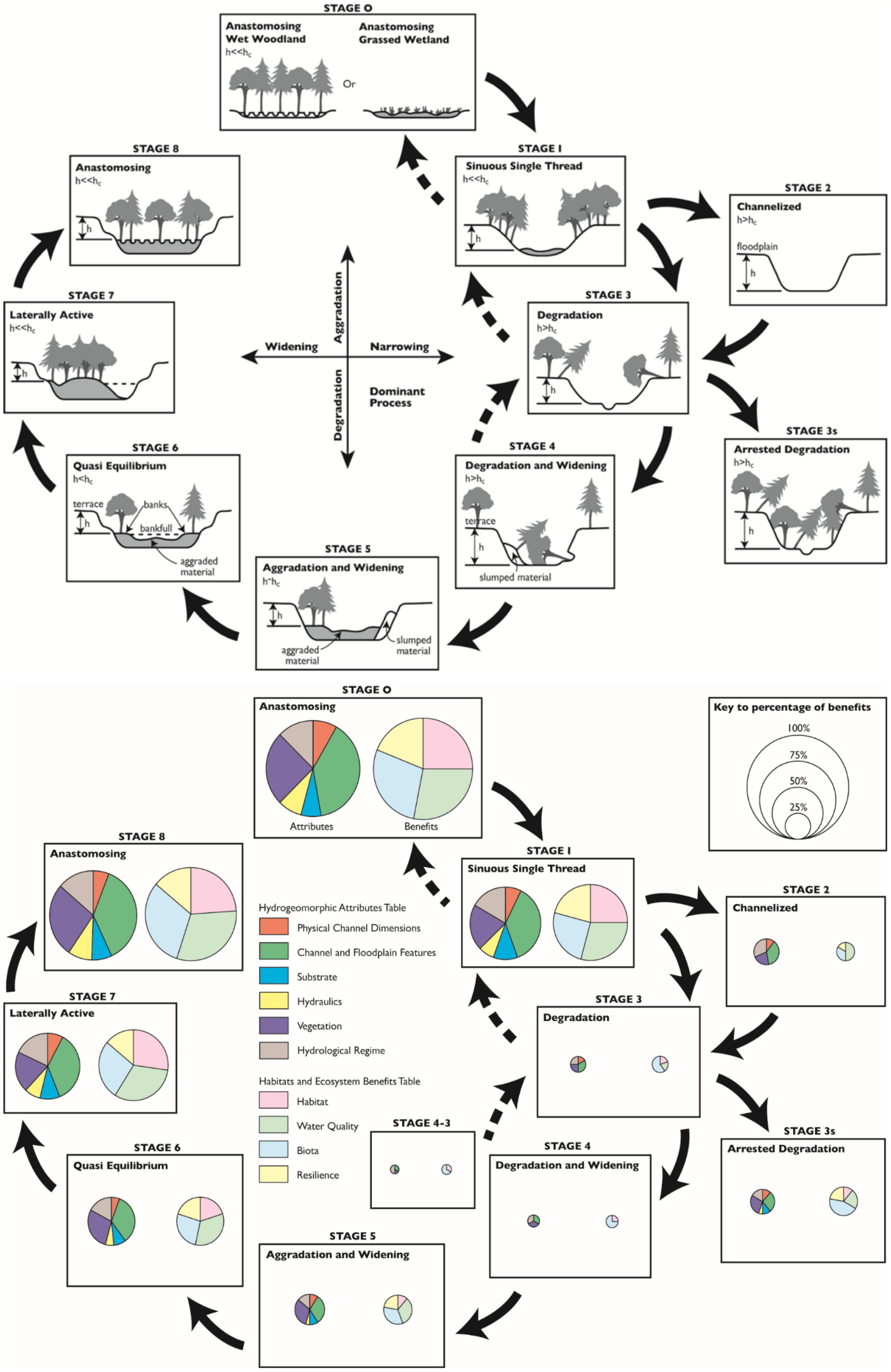


Figure 2-3. Stream Evolution Model (SEM).

This figure presents the Cluer and Thorne (2014) Stream Evolution Model (SEM). The top figure shows the evolution of stream processes. The bottom figure shows the ecological value associated with each SEM stage. Both the size of the icon and the number of attributes indicated increased quantity and complexity. This figure shows that SEM Stages 7, 8, 0 and 1 have tremendously more ecological value than SEM Stages 2-5.

Geomorphic Condition

The geomorphic condition of landscapes and riverscapes determines the quality and composition of macro-, meso-, and microhabitats in riverine ecosystems. Within that, the hydro-geomorphology of these habitats have been studied for many decades (McManamay et al. 2013). From the plethora of publications on riverine science, what has risen to the top has been the importance of structure and complexity in riverine environments (Rideout et al. 2021; Smokorowski and Pratt 2007). To address this, we need new tools and indicators to guide restoration of high-value riverine habitats as streams in British Columbia, like the Koksilah River, are becoming more and more degraded.

Swartz (2016) suggests that meso-habitats are the necessary scale to understand streams and their restoration needs. Similarly, Wheaton et al. (2019) suggests that stream evolution (reference appendix) can be used as a surrogate for the geomorphic condition of the channel, as channel configuration controls the quality and composition of meso-, and microhabitats. Collectively, there is a need for indicators characterizing meso-habitat health and composition, that can be used to look at reach-scale trends and determine restoration goals, in British Columbia as more and more streams are becoming *severely degraded*.

Structure and Complexity

Structure and complexity of riverscapes includes both riparian and channel condition which are becoming much more salient indicators of riverine / aquatic health

In riverine ecosystems, structure forces complexity and complexity provide both increased biodiversity and increased resilience. Thus, losing structure and complexity is synonymous with losing resilience. With increased structure and complexity in riverine environments, riparian and channel conditions increase in quantity and quality. This leads to intact floodplain connectivity

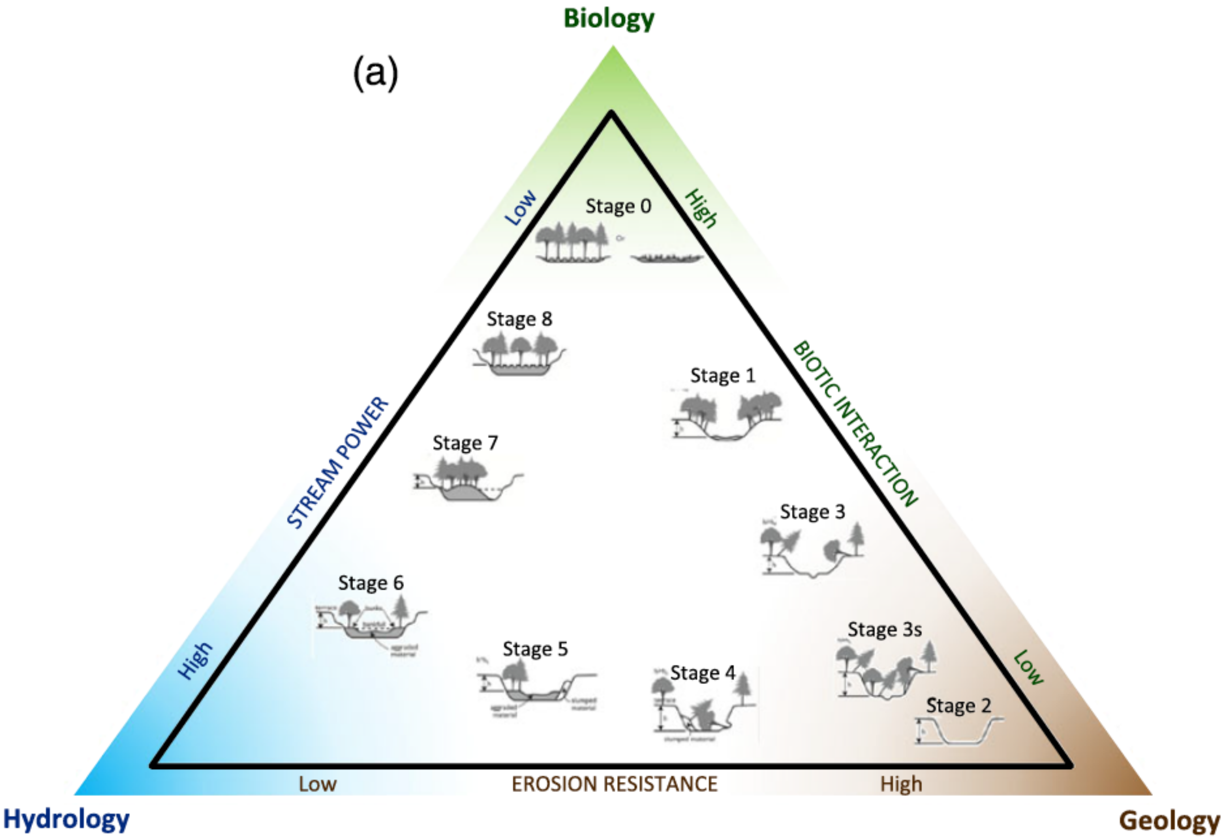


Figure 2-4. Stream Evolution Triangle (SET).

This figure presents the Stream Evolution Triangle (Castro and Thorne, 2019) with the Stream Evolution Model (Cluer and Thorne, 2014) inside the triangle to show what river types are produced with any of the three influences (biology, hydrology, geology).

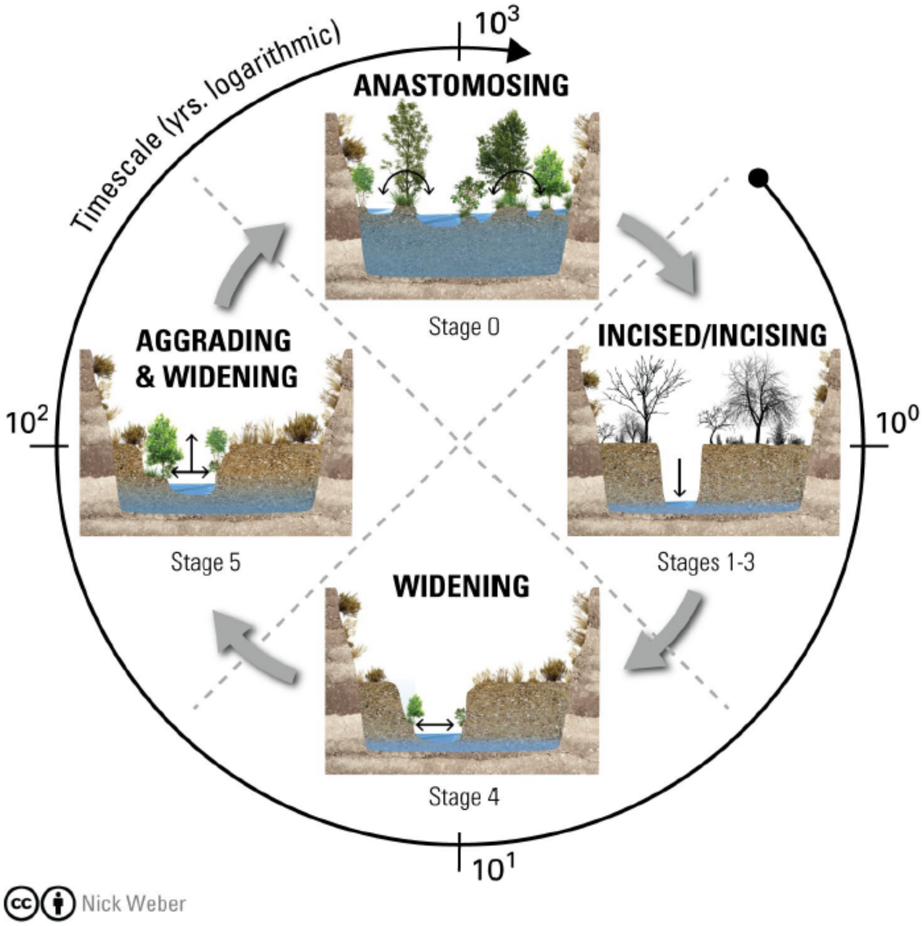


Figure 2-4. Riverscape Evolution Model (REM).

This figure presents the simplified riverscapes evolution model (REM) (Wheaton et al., 2019) based on Cluer and Thorne's (2013) Stream Evolution Model (ESM). The REM intentionally simplifies the SEM to break down the stream into basic restoration needs. This figure demonstrates the floodplain / riparian relationship with each of the four REM stages.

Appendix 2C: Meso-Habitat Figures

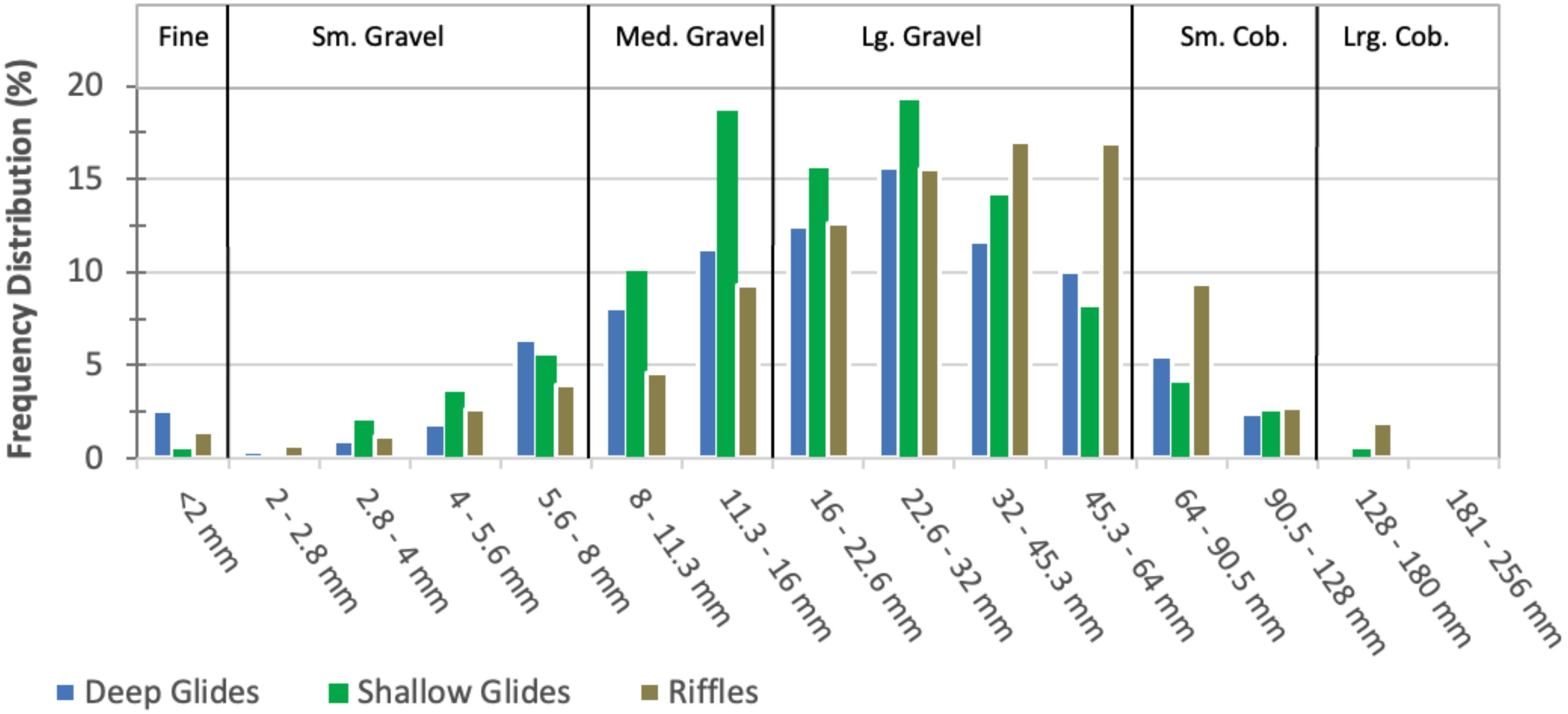


Figure 2-6. Substrate Frequency Distribution for Lower Koksilah River.

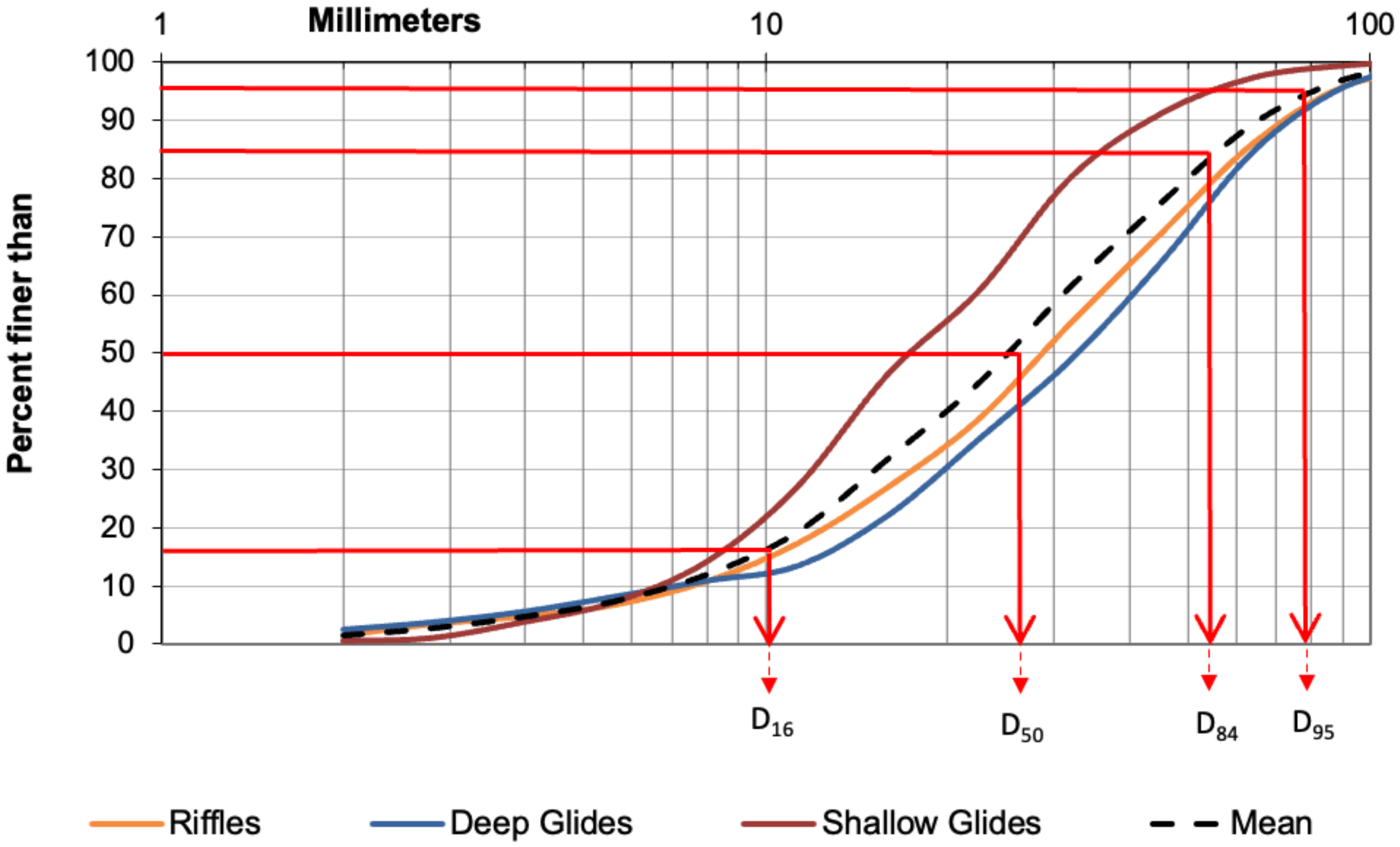


Figure 2-7. Cumulative Substrate Distribution for Lower Koksilah River.

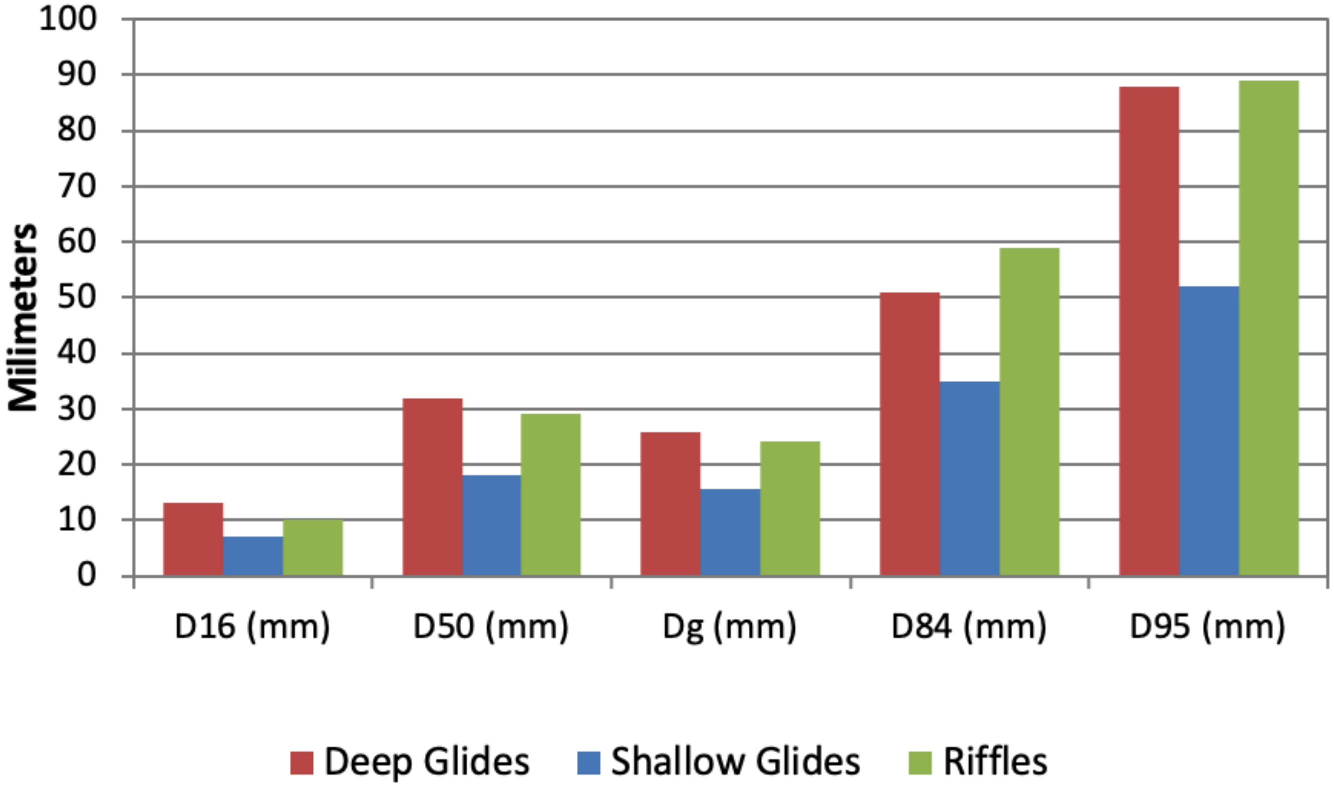


Figure 2-8. Substrate Characteristics for Lower Koksilah River.

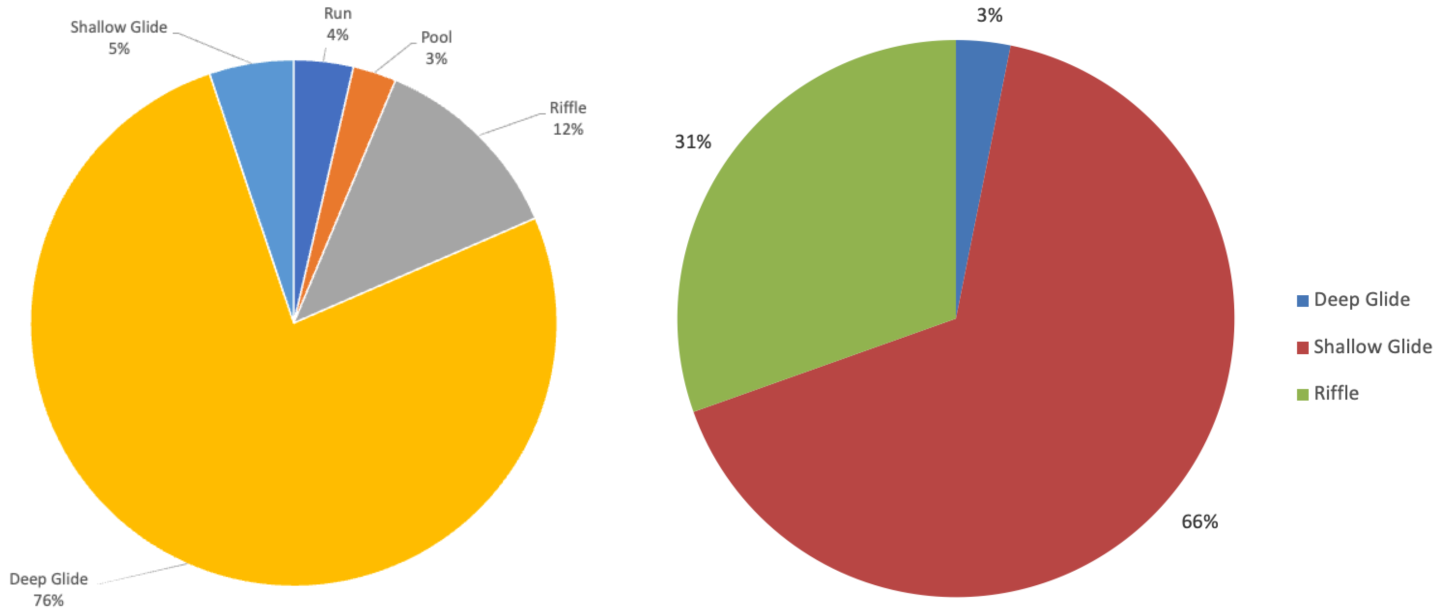


Figure 2-8. Left - Meso-Habitat composition for the lower Koksilah River. Right - Percent Suitability of Chinook Spawning Substrates in the Lower Koksilah River, as Defined by Kondolf's (1993) D50 range (34-90 mm) for Spawning Substrate Tolerances.

Appendix 2D: Meso-Habitat Mapping

Legend

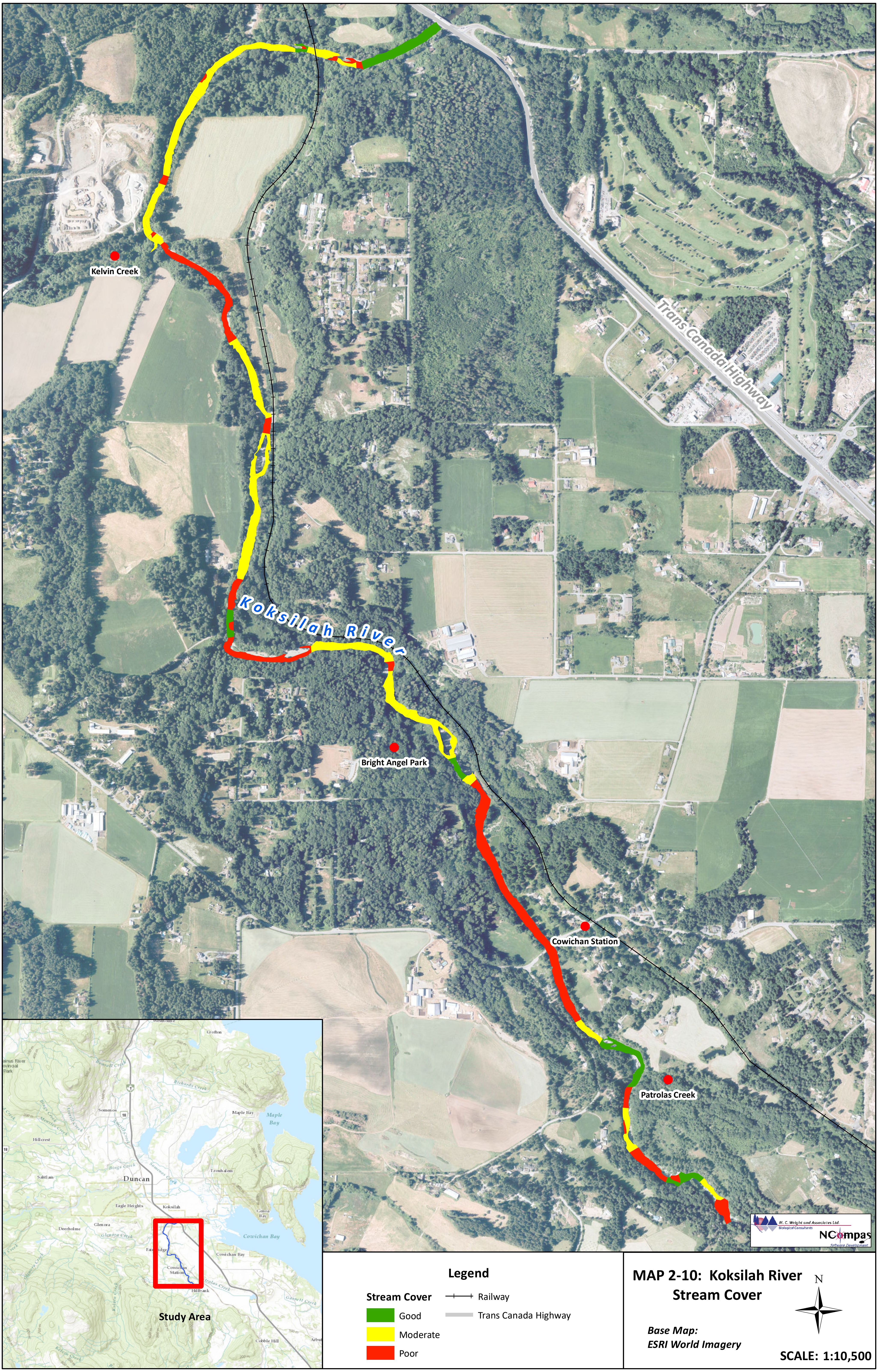
🟦 Pool	🟦 Run	+–+ Railway
🟦 Deep Glide	🟩 Riffle	▬ Trans Canada Highway
🟦 Shallow Glide	🟨 Tailout	

MAP 2-9: Koksilah River Meso-Habitat Units

N

Base Map:
ESRI World Imagery

SCALE: 1:10,500



MAP 2-10: Koksilah River Stream Cover

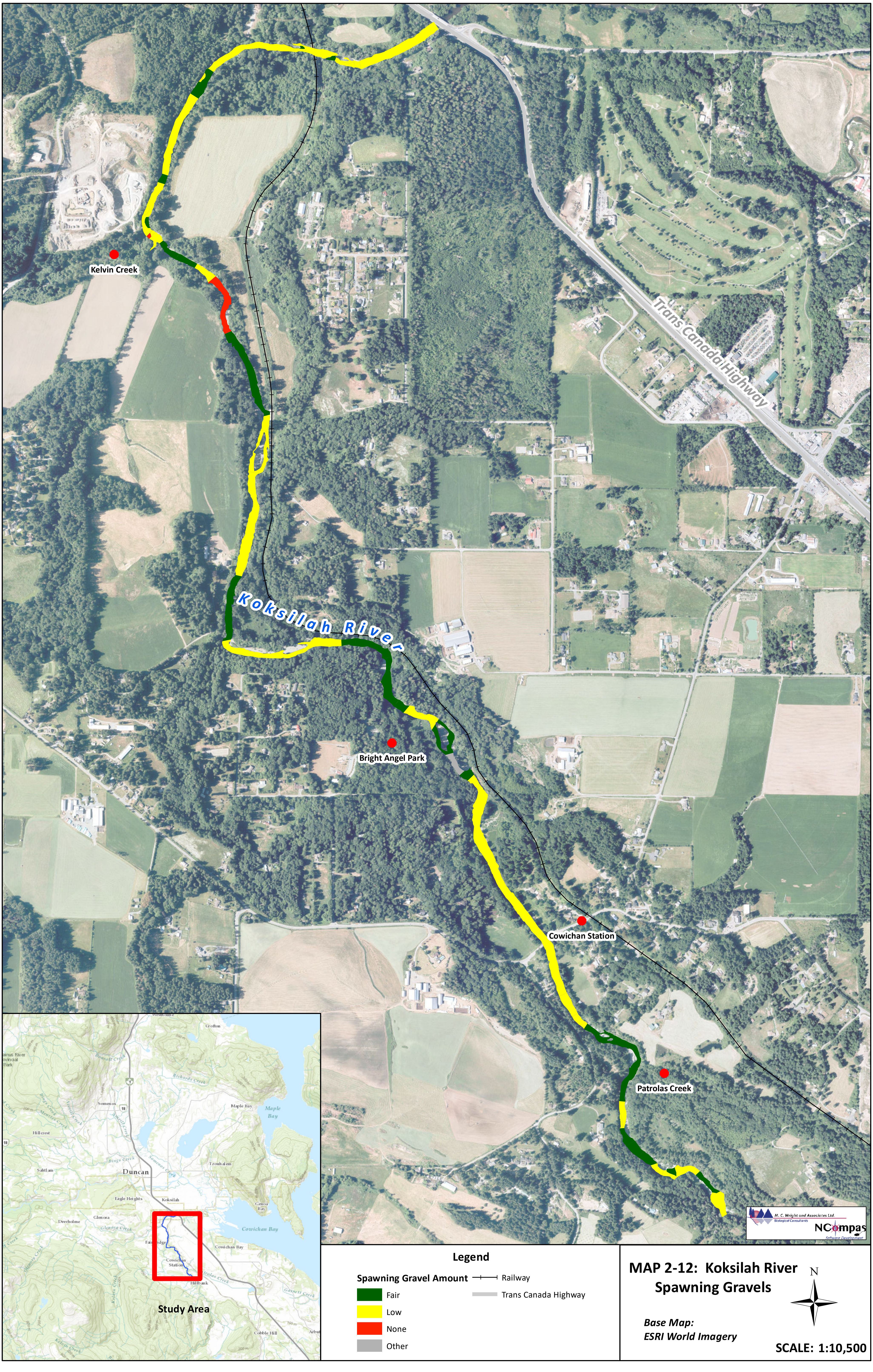
Base Map: ESRI World Imagery

SCALE: 1:10,500

MAP 2-11: Koksilah River Stream Substrates

Base Map:
ESRI World Imagery

SCALE: 1:10,500



Legend

Spawning Gravel Amount

🟩 Fair

🟨 Low

🟥 None

⬜ Other

Railway

Trans Canada Highway

MAP 2-12: Koksilah River Spawning Gravels

Base Map:
ESRI World Imagery

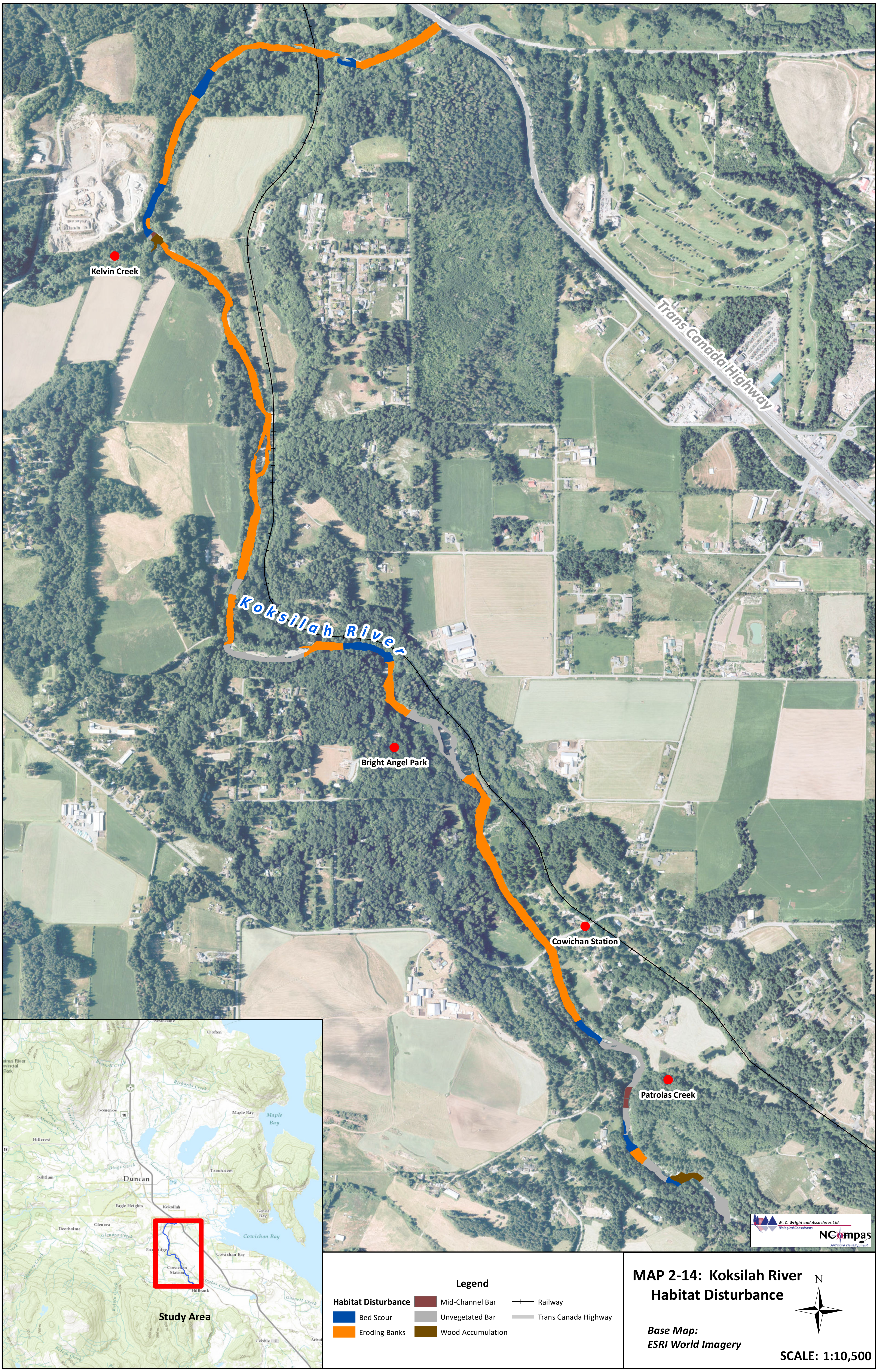
SCALE: 1:10,500

MAP 2-13: Koksilah River Width - Depth Ratio

N

Base Map:
ESRI World Imagery

SCALE: 1:10,500



MAP 2-14: Koksilah River Habitat Disturbance

Base Map:
ESRI World Imagery

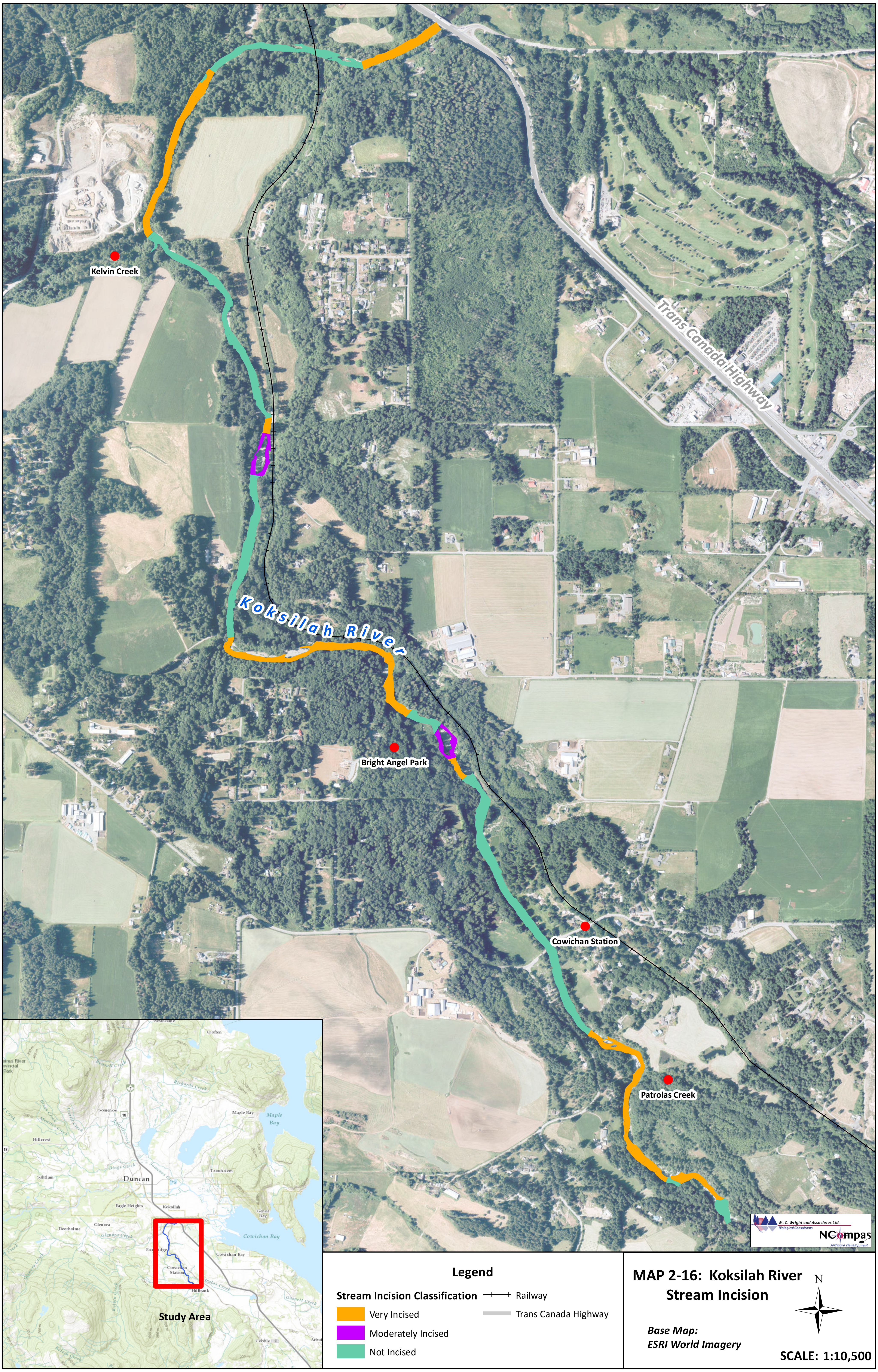
SCALE: 1:10,500

MAP 2-15 Koksilah River Channel Entrenchment

N

Base Map:
ESRI World Imagery

SCALE: 1:10,500



Legend

Stream Incision Classification

🟧 Very Incised

🟪 Moderately Incised

🟩 Not Incised

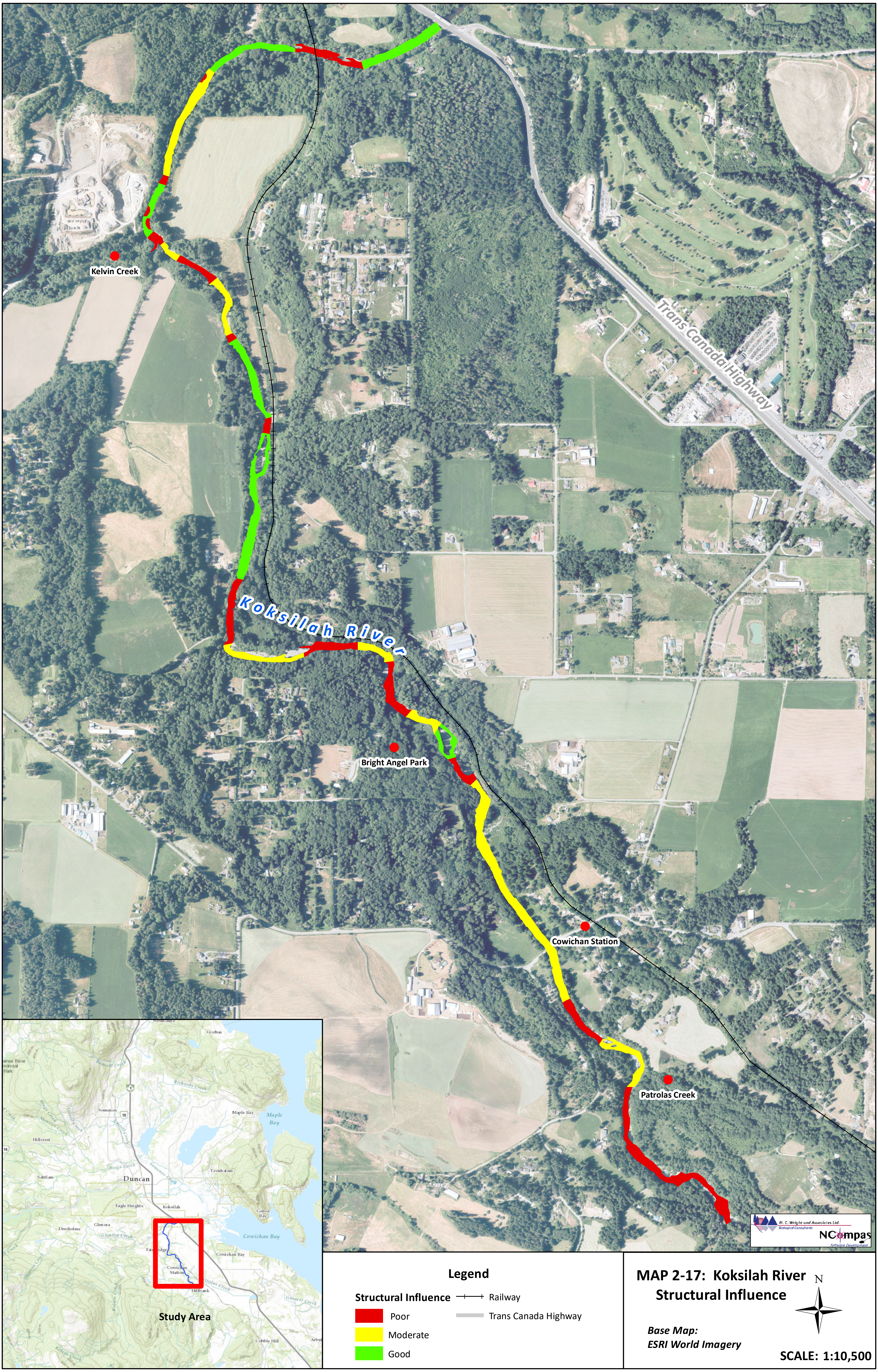
┼ Railway

▬ Trans Canada Highway

MAP 2-16: Koksilah River Stream Incision

Base Map:
ESRI World Imagery

SCALE: 1:10,500



MAP 2-17: Koksilah River Structural Influence

Legend

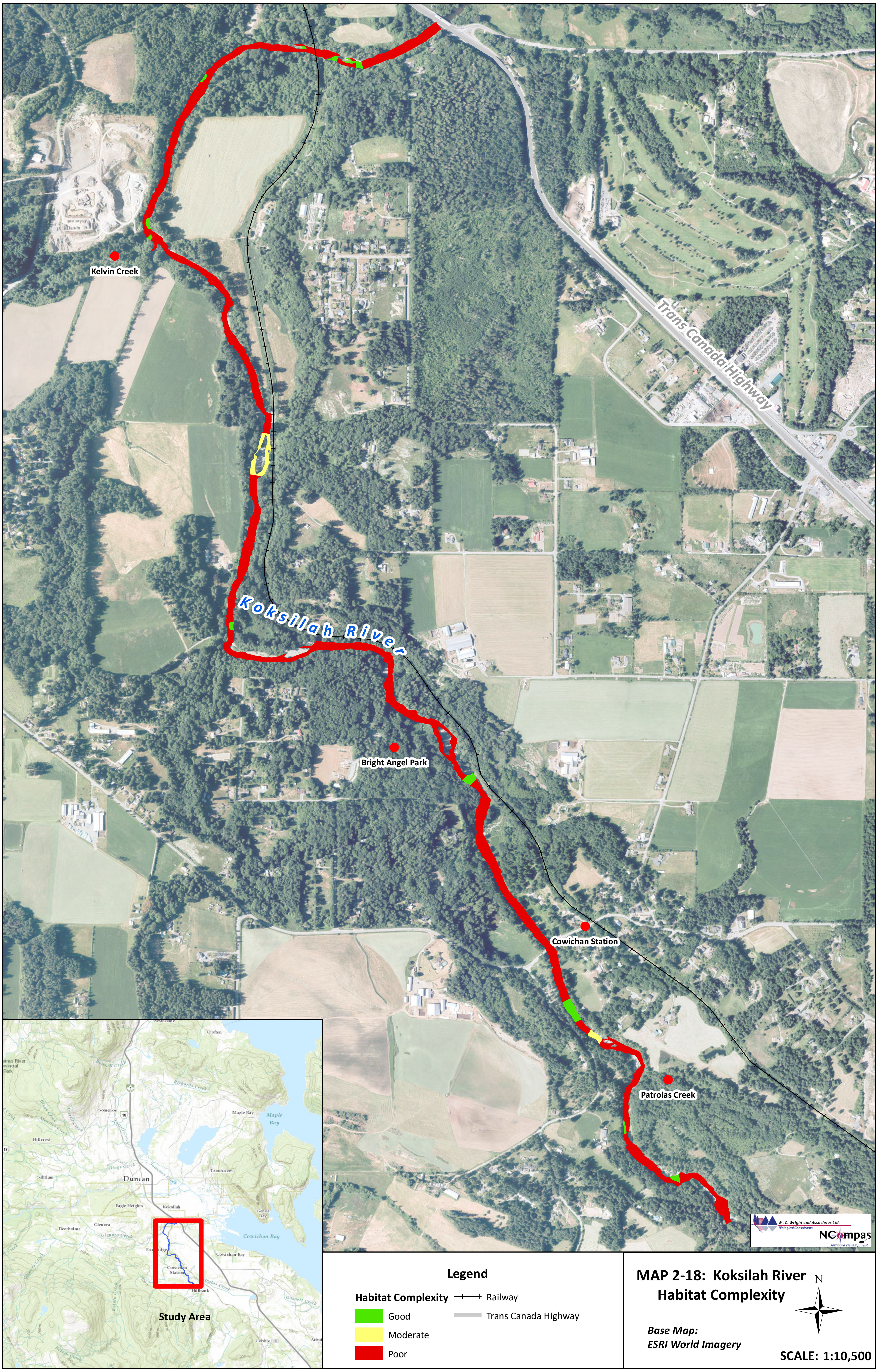
Structural Influence
- 🟥 Poor
- 🟨 Moderate
- 🟩 Good

- Railway
- Trans Canada Highway

N

Base Map:
ESRI World Imagery

SCALE: 1:10,500



Legend

Habitat Complexity

🟩 Good

🟨 Moderate

🟥 Poor

Railway

Trans Canada Highway

MAP 2-18: Koksilah River Habitat Complexity

N

Base Map:
ESRI World Imagery

SCALE: 1:10,500

MAP 2-19: Koksilah River Geomorphic Condition (SEM)

Base Map:
ESRI World Imagery

SCALE: 1:10,500

MAP 2-20: Koksilah River Geomorphic Condition (REM)

Legend

Geomorphic Condition (REM)

- ▬ Aggrading and Widenig
- ▬ Widening
- ┼┼ Railway
- ▬ Trans Canada Highway

Base Map:
ESRI World Imagery

N

SCALE: 1:10,500

MAP 2-21: Koksilah River Geomorphic Influence (SET)

Legend

Geomorphic Influence (SET)

- 🟦 Hydrology
- 🟫 Hydrology-Geology

- ┼┼ Railway
- ▬ Trans Canada Highway

Base Map:
ESRI World Imagery

N

SCALE: 1:10,500

M. C. Wright and Associates Ltd.
Biological Consultants

NCompas
Software Development

MAP 2-22: Koksilah River Floodplain Availability

Base Map:
ESRI World Imagery

SCALE: 1:10,500

Chapter 3 Appendices

Appendix 3A: Standard Setting Approaches

Tier 1 Review of Existing Methods

Method 1 – Tennant

The Tennant Method, also known as the Montana Method, is one of the original methods for determining IFN (Tennant 1976). The Tennant method has arguably garnished the most notoriety and is still used widely throughout the world today (Jowett 1997; Reiser et al., 1989).

The method was based on 17 years of field studies on 11 cold water and warm water streams in Nebraska, Wyoming and Montana. Hydraulic and habitat quality data from cross section transects were combined to define relationships between streamflow and aquatic habitat quality. As the relationship is with streamflow the recommendations are based on percentages of MAD (Table 3-2).

Table 3-2. Instream flow regimes (Tennant 1976). Flows are expressed as percentages of MAD.

Flow Requirement	October – March	April – September
Flushing or Maximum	200%	200%
Optimum Range	60-100%	60-100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degraded	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	0-10%	0-10%

The Tennant Method is easy to use, requires no field work, is based on a single data source (existing hydrometric data) and produces consistent results. Critiques of the Tennant Method have predominantly focused on two aspects including: (i) the high degree of professional judgement embedded in the method; and (ii) the lack of biological validation – albeit his method is based on combining hydraulic and habitat quality cross section data.

Method 2 - BC Modified Tennant

The BC Modified Tennant Method is touted as the “Made in British Columbia” alternative to the Tennant Method which has varying levels of application in certain streams in BC, particularly streams with coastal hydrographs. However, it is no mistake that Tennant was the framework for the BC method, as it is well known for its robustness and reliable results. The BC Modified-Tennant has been evolving over the past 30 years and continues to be updated.

There are two main modifications between the original Tennent Method (Tennant 1976) and the BC Modified-Tennant. These are the (i) inclusion of life stages and (ii) ecological flow requirements (Table 3-3). This very effectively pairs the fish life stage with the flow requirements for that life stage (e.g., spawning or passage flows), based on both the work of Tennant (1976) and extensive observations on BC streams. Additionally, it recognizes the need for channel maintenance flows, wetland linkages and provides the necessary durations for each.

The BC Modified-Tennant Method is more difficult to implement as it requires a periodicity table for the species of interest; although it is still a desktop method and, like Tennant (1976), relies upon a single data source (existing hydrometric data). Critiques of the BC Modified-Tennant are similar to those listed above for the Tennant Method, they focus on (i) professional judgement and the (ii) lack of biological validation.

Table 3-3 BC modified-Tennant Method recommended to maintain physical and ecological processes for BC streams

Physical, Ecological, Biological Requirement	Flow Recommendation (%MAD)	Duration
A. Rearing	20%	Months
Juvenile	20%	Months
Adult	> 55%	Months
B. Over-wintering	20%	Months
C. Incubation	20%	Months
D. Migration and Spawning	30-200%	Days-Weeks
Summer Steelhead Passage	50-100%	Days
Spawning	Equation: $1.56 * MAD^{0.63}$	Days-Weeks
Smolt Migration	50%	Weeks
E. Short-term Maintenance	10%	Days to a Week
F. Channel Maintenance	> 400%	Days
G. Wetland Linkage	100%	Weeks

Method 3 – BC Desktop

The BC Desktop, like the BC Modified-Tennant, has been an evolving method in BC for over 30 years. The BC Desktop was first presented at a joint DFO/MOE workshop on Instream Flow Methods in 1985 (Newcombe and Ptolemy, 1985). Newcombe and Ptolemy (1985) presented at this workshop and recommended the use of the percentiles approach (of MAD) to prescribe instream flows for fish. The scientific underpinning of this method was the observation that habitat conditions for fish are comparable between streams when related to percent MAD.

The percentiles approach is essentially an adoption of the “natural flow regime” in that it uses percentiles of mean monthly flow (MMF) to preserve the natural variability of the hydrograph (Poff et al., 1997; Richter at al., 1996, 1997). As such, due to the direct relationship between stream width and percent MAD, it is therefore appropriate to make generalizations about the quality of instream flow for fish needs.

Method 4 – Rule of Thumb

The term “Rule-of-Thumb” has been applied many different ways in instream flow science. More frequently it is referring to a standard setting, historical approach, that recommends percentages of MAD to predict fish flows. These approaches tend to rely on conservative science and are used to recommend minimum flows. With that, what makes Rule-of-Thumb approaches desirable for many applications is that they present a reliable ‘ground floor’. Thus, when a method like Rule-of-Thumb predicts a minimum flow threshold (ground floor), that agrees with hydrological statistics like the 10 year, 7-day-low flow (7Q10), then a clear understanding of fish-flow relationships can be inferred.

Rule-of-Thumb values for the EFN model were obtained from the BC Instream Flow Standards for Fish (Hatfield et al., 2003).

Method 5 – Ecological Flows

Ecological flows have been described as: “The flows and water levels required in a water body to sustain the ecological function of the flora and fauna and habitat processes present within that water body and its margins” (DFO, 2013). Ecological flows are intended to maintain specified, or valued features of the aquatic ecosystem including, but not limited to, channel maintenance flows, wetland linkage flows, overbank flows, and flushing flows (Tharme, 2003). It is the natural variability in seasonal streamflow – both within the season as well as from one year to the next – that is an essential element of river form and function (Poff et al., 1997; Stanford et al., 1996).

Appendix 3B: Low Flow Study

SWIFTWATER CONSULTING

Swiftwater Consulting Ltd.
900-580 Hornby Street
Vancouver, BC
Canada
V6C 3B6
+1-778-952-3569

Geomorphic Consulting
Attn: Jeff Anderson
3820 Alfred Avenue
Smithers, BC
Canada
V0J 2N0

RE: CHEMAINUS RIVER AND KOKSILAH RIVER LOW FLOW STUDY

Dear Jeff,

Geomorphic Consulting (Geomorphic) retained Swiftwater Consulting Ltd. (Swiftwater) to conduct an analysis of streamflow records of the Chemainus River and the Koksilah River, which are both located on the southeast coast of Vancouver Island, near the township of Duncan, where they drain into the Strait of Georgia. Low flows are of particular interest as it has been suggested that streamflow is being impacted by multiple concurrent factors, including a changing and variable climate, urbanization, forestry, and agriculture. The objective of this study was to perform a characterization the *variability* of low flows over time, using commonly understood metrics for low flow analyses (*i.e.* the one in ten year seven day low flow, or 7Q10).

Background

Figure 1 and Figure 2 show the Chemainus River and Koksilah River watersheds, respectively. The majority of the area in both watersheds consists of forested and deforested land, as well as some urban and agricultural, concentrated largely at the most downstream extents. The Water Survey of Canada (WSC) monitoring stations are situated in the lower reaches of each river.

- Chemainus River Near Westholme (08HA001) has 63 years of record (1953 to 2019). 1954, 1972, 1973, and 1974 were incomplete years and were not included in the analysis.
- Koksilah River at Cowichan Station (08HA003) also has 59 years of record (1960 to 2019). 2012 was an incomplete year and was not included in the analysis.

Low Flow Analysis

Long-term daily streamflow records were analyzed using 30-year climate normals windows, for successive 10-year periods, to derive the 7Q10 statistics. Data from 1961 through 2019 were considered, corresponding to four (4) largely complete climate normal windows.

- 1990, 1961 to 1990
- 2000, 1971 to 2000
- 2010, 1981 to 2010
- 2020, 1991 to 2019

For each climate normal period, a moving average 7-day flow was calculated for the entire dataset. These low flows were then used to generate a series of minimums for each month, in each year, of the 30-year record. A statistical analysis was then completed for each monthly dataset, and a distribution selected based on goodness of fit tests (Kolmogorov-Smirnov, Anderson-Darling, and Chi-Squared). The Generalized Extreme Value (GEV) distribution was found to be the best match across the majority of months and for each climate window. The probability density function (PDF) of each distribution was then used to estimate the 7Q10.

Results

Relative changes in monthly 7Q10 at the Chemainus and Koksilah Rivers were observed to be similar. For the Chemainus River, Figure 3 shows how the monthly 7Q10 magnitude has changed and Figure 4 shows the relative (%) change, when comparing the 1961 to 1990 climate normal to each of the subsequent climate normal periods. The same is shown in Figure 5 and Figure 6, respectively, for the Koksilah River.

Table 1. Chemainus River 7Q10 Flows (m^3/s)

Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961-1990	3.05	5.75	6.59	8.00	3.23	1.04	0.33	0.21	0.22	0.27	1.63	4.57
1971-2000	3.54	6.21	6.33	6.01	2.06	0.78	0.34	0.24	0.21	0.29	1.06	5.16
1981-2010	5.08	5.53	5.42	5.96	2.26	0.92	0.33	0.17	0.17	0.26	1.47	4.63
1991-2009	5.78	4.93	4.88	4.83	1.49	0.69	0.29	0.16	0.17	0.31	2.28	5.42

Table 2. Koksilah River 7Q10 Flows

Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961-1990	2.88	3.11	3.03	2.40	1.13	0.48	0.21	0.17	0.19	0.30	0.68	2.60
1971-2000	3.02	3.16	3.13	1.88	0.86	0.42	0.20	0.17	0.18	0.28	0.54	2.55
1981-2010	3.54	3.31	3.24	1.94	0.81	0.39	0.19	0.16	0.16	0.24	0.73	2.49
1991-2009	3.97	3.38	2.98	1.82	0.69	0.34	0.19	0.14	0.16	0.23	1.10	2.44

Discussion

The trends for the relative changes in monthly 7Q10 at the Chemainus River and Koksilah River were observed to be similar. For the Chemainus River, Figure 3 shows how the monthly 7Q10 magnitude has changed and Figure 4 shows the relative (%) change, when comparing the 1961 to 1990 climate normal to each of the subsequent climate normal periods. The same is shown in Figure 5 and Figure 6, respectively, for the Koksilah River. The monthly 7Q10 flows were observed to:

- decrease in April through September,
- increase in November through January, and
- vary in shoulder months.

The flow duration curves are shown in Figure 7 and Figure 8 for Chemainus and Koksilah River, respectively. These figures demonstrate the changes in the distribution of daily flow magnitudes over time. For example, data from the Chemainus River indicates that throughout the four (4) climate windows the 90th percentile exceedance flow decreased from 0.665 m^3/s to 0.516 m^3/s. Similarly, the 90th percentile flow in the Koksilah River decreased from 0.370 m^3/s to 0.270 m^3/s.

Figure 7 and Figure 8 suggest that the mid to high percentile streamflows have decreased, while the low percentile flows (<5% exceedance for Chemainus and <14% for Koksilah) have increased.

Closing

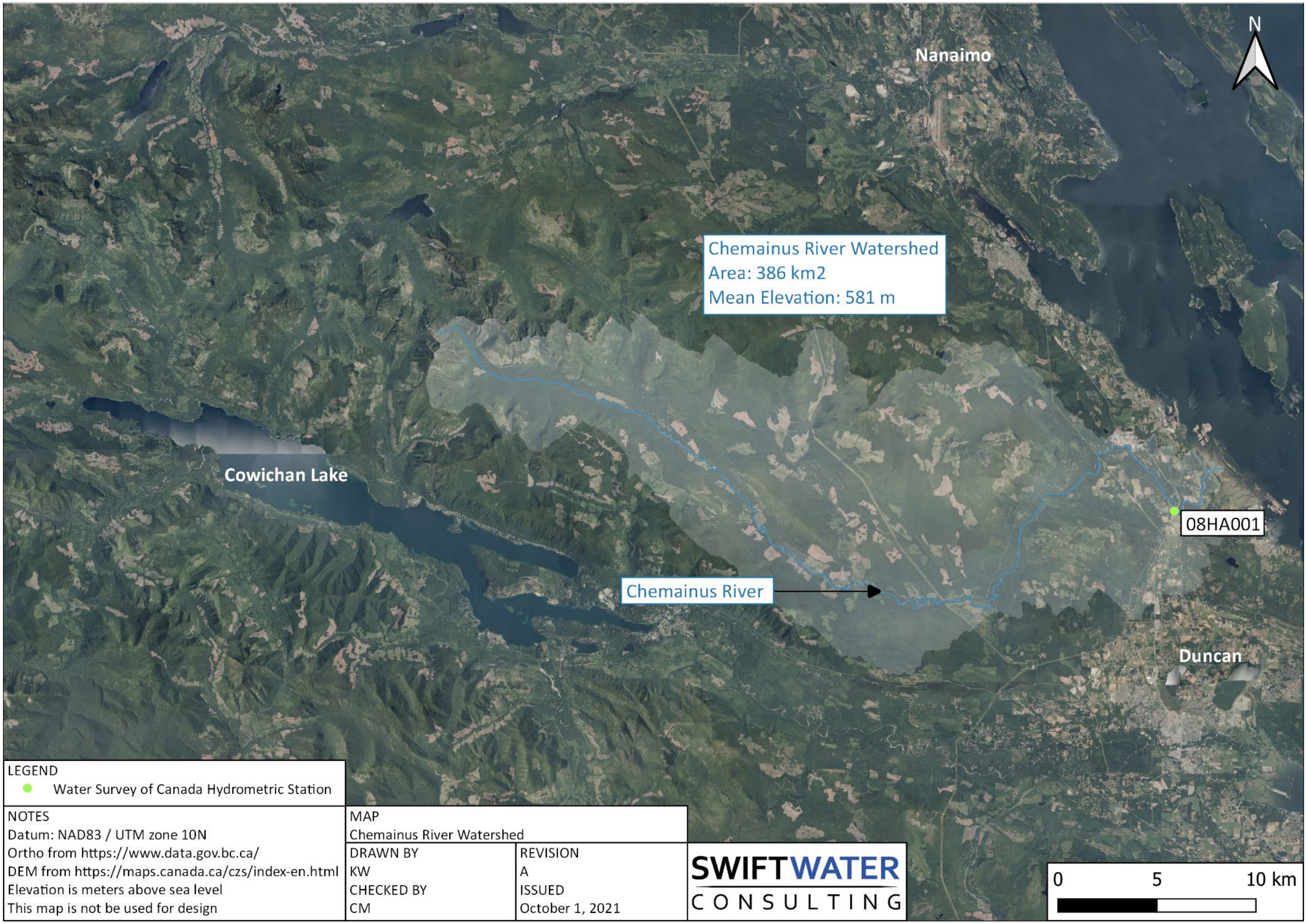
We trust that this letter satisfies your requirements. If you have any questions or concerns, please do not hesitate to contact the undersigned.

SWIFTWATER CONSULTING LTD.

Kyle Winslow

Kyle Winslow, EIT, B.Eng.
Water Resource Engineer-in-Training

Cameron McCarthy, M.A.Sc., P.Eng., P.Geo., P.Tech.
Principal Water Resource Engineer



LEGEND
● Water Survey of Canada Hydrometric Station

NOTES
Datum: NAD83 / UTM zone 10N
Ortho from https://www.data.gov.bc.ca/
DEM from https://maps.canada.ca/czs/index-en.html
Elevation is meters above sea level
This map is not be used for design

MAP
Chemainus River Watershed

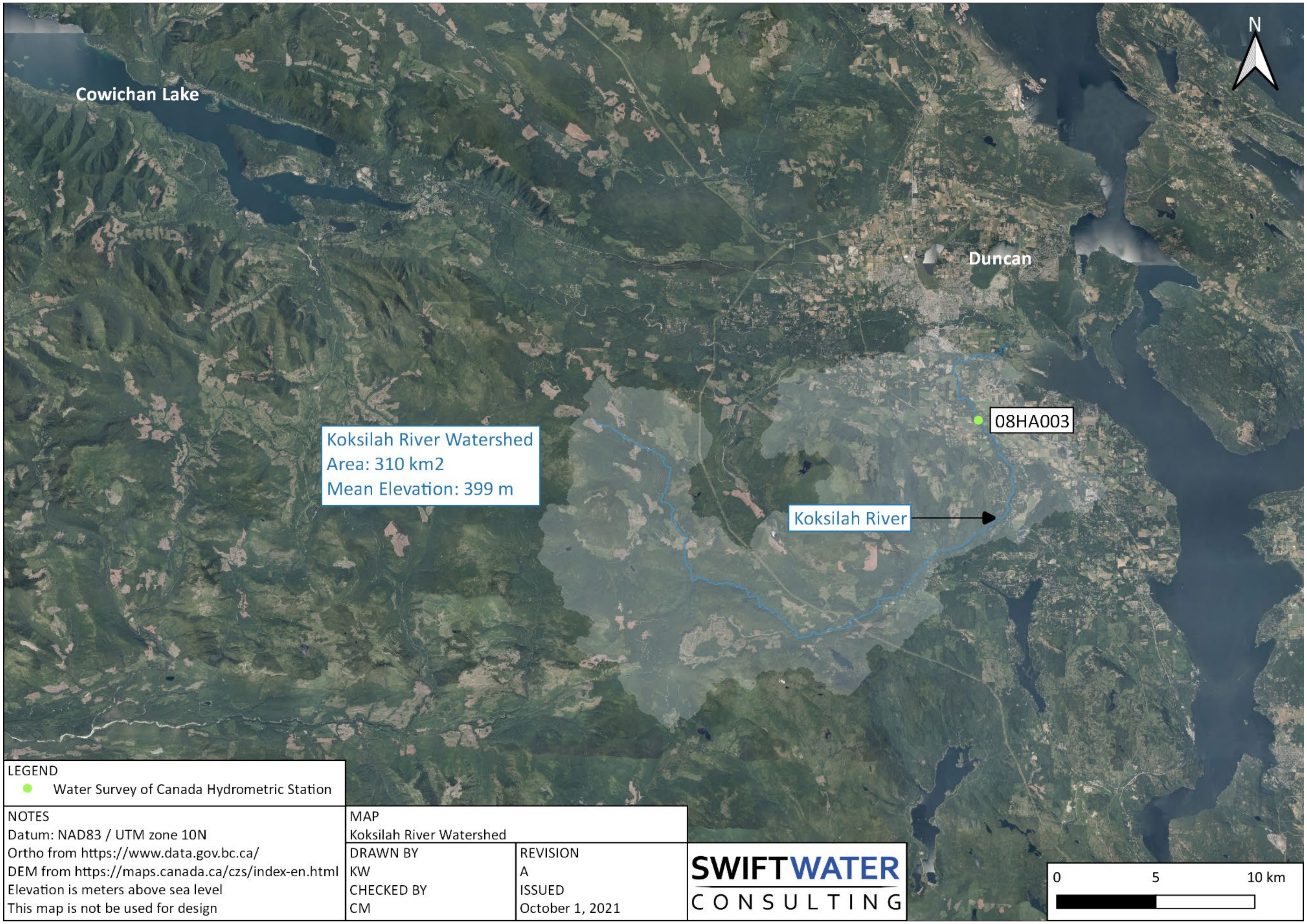
DRAWN BY
KW

CHECKED BY
CM

REVISION
A

ISSUED
October 1, 2021

SWIFTWATER
CONSULTING



LEGEND
● Water Survey of Canada Hydrometric Station

NOTES
Datum: NAD83 / UTM zone 10N
Ortho from https://www.data.gov.bc.ca/
DEM from https://maps.canada.ca/czs/index-en.html
Elevation is meters above sea level
This map is not be used for design

MAP
Koksilah River Watershed

DRAWN BY KW	REVISION A
CHECKED BY CM	ISSUED October 1, 2021

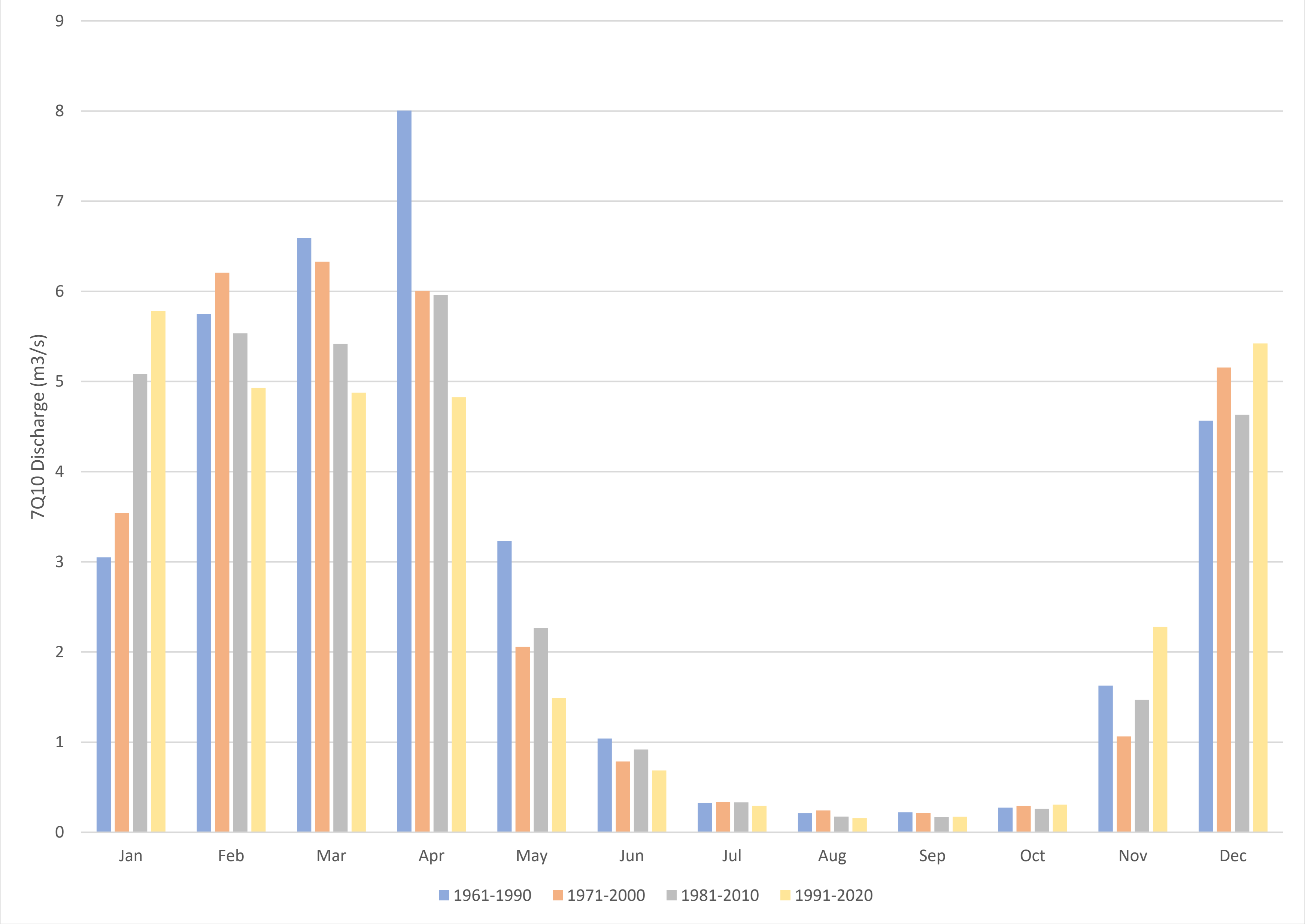


Figure 3. Chemainus River 7Q10 Discharge

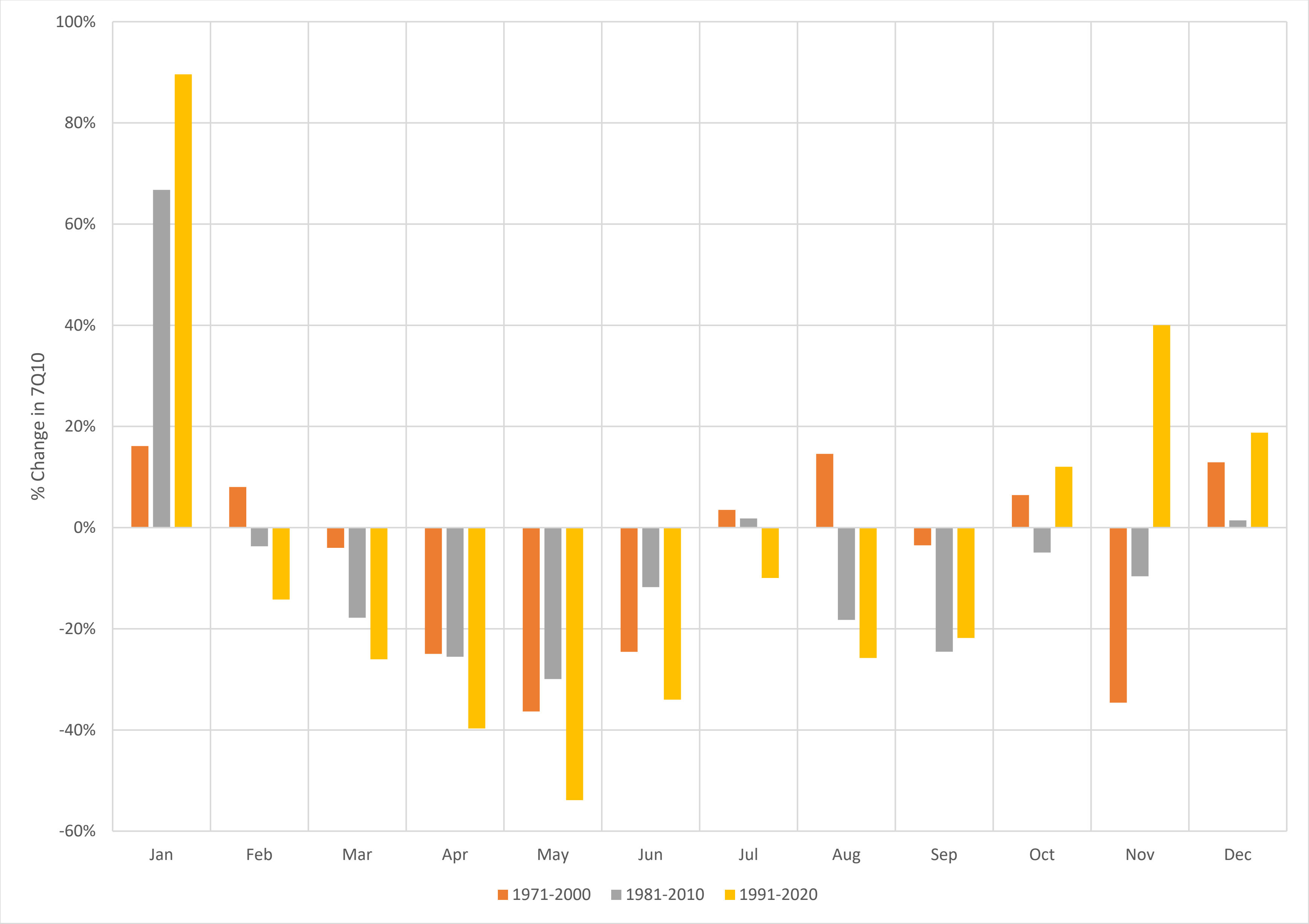


Figure 4. Chemainus River Change in 7Q10 Discharge from 1961-1990

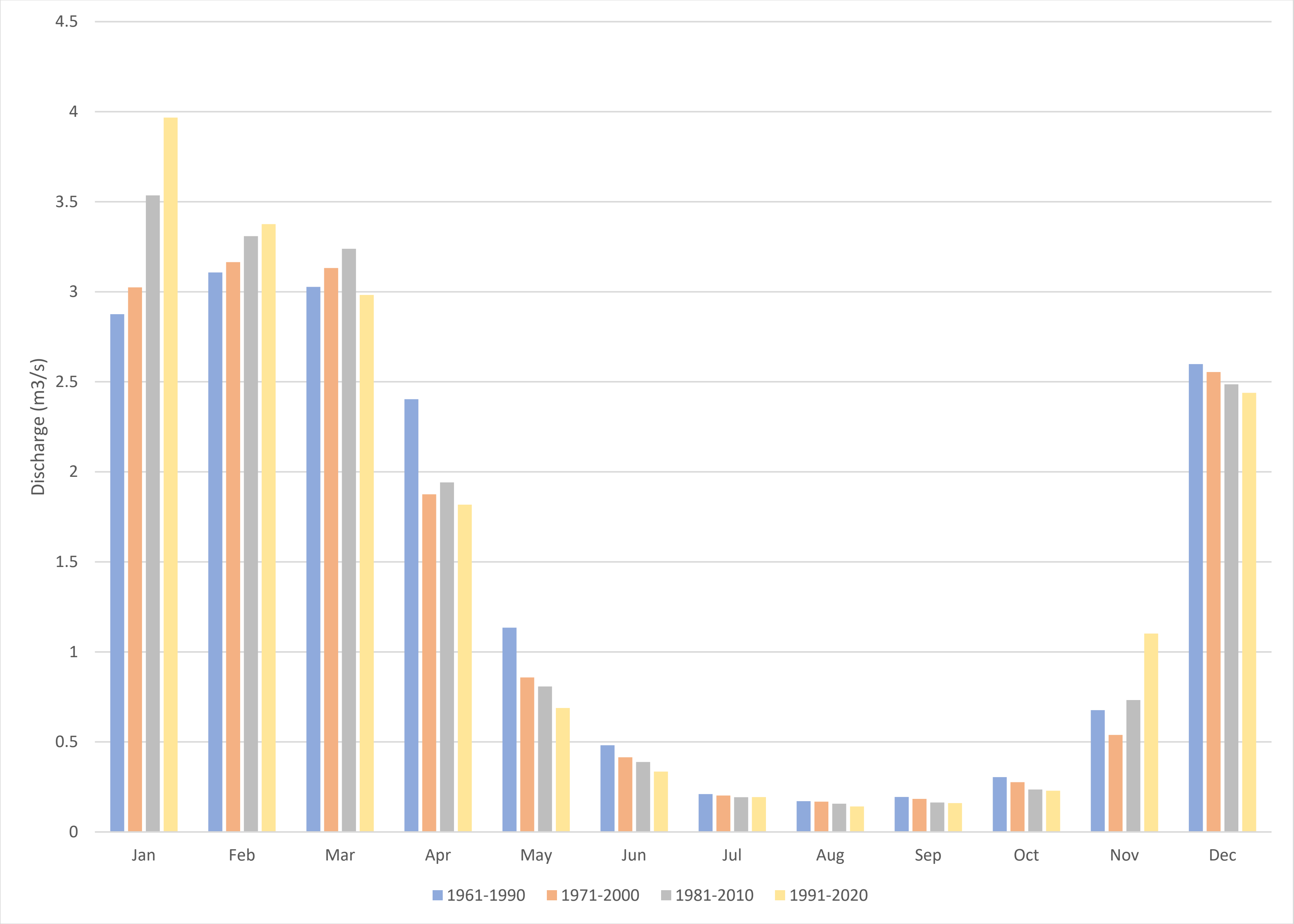


Figure 5. Koksilah River 7Q10 Discharge

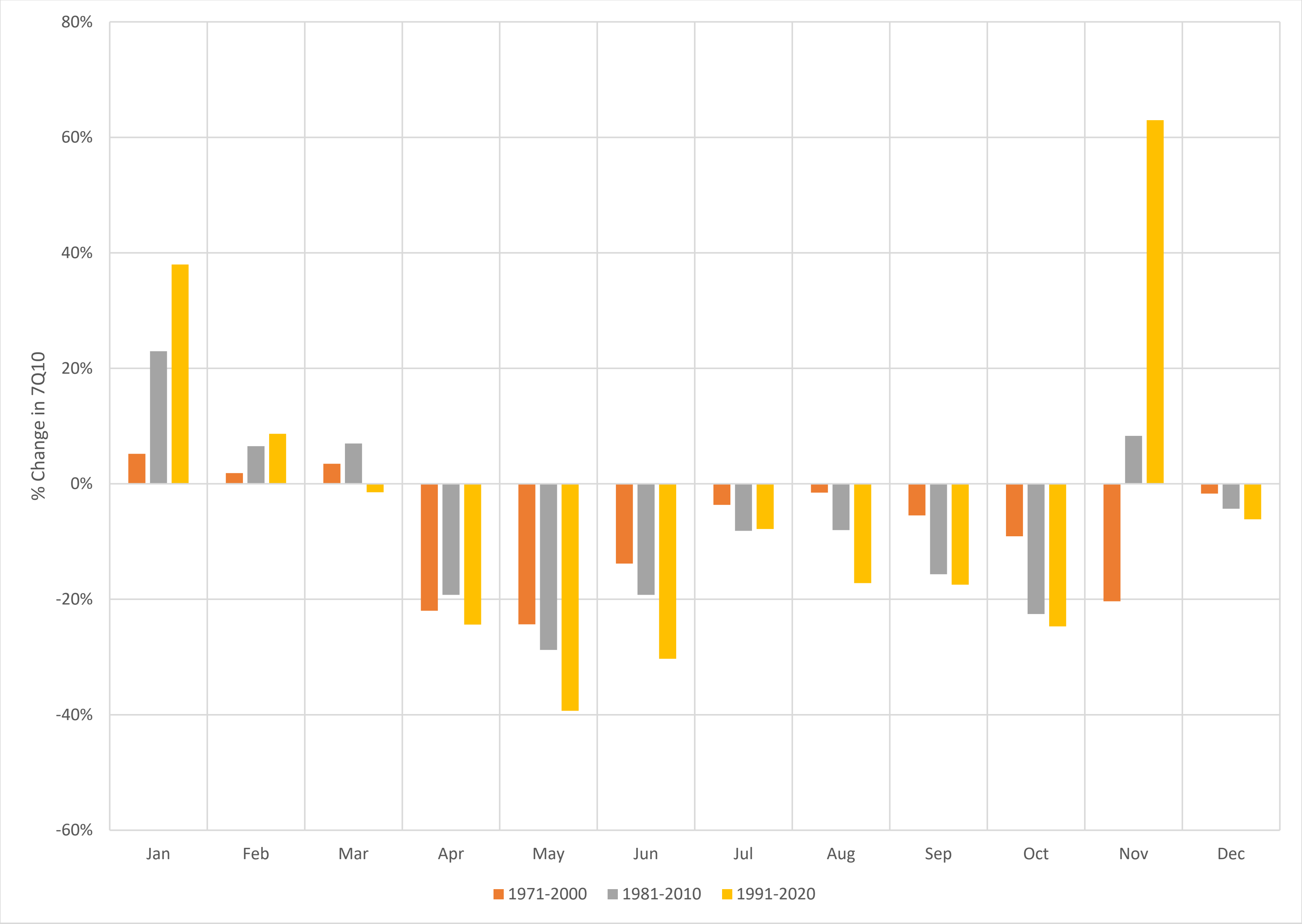


Figure 6. Koksilah River Change in 7Q10 Discharge from 1961-1990

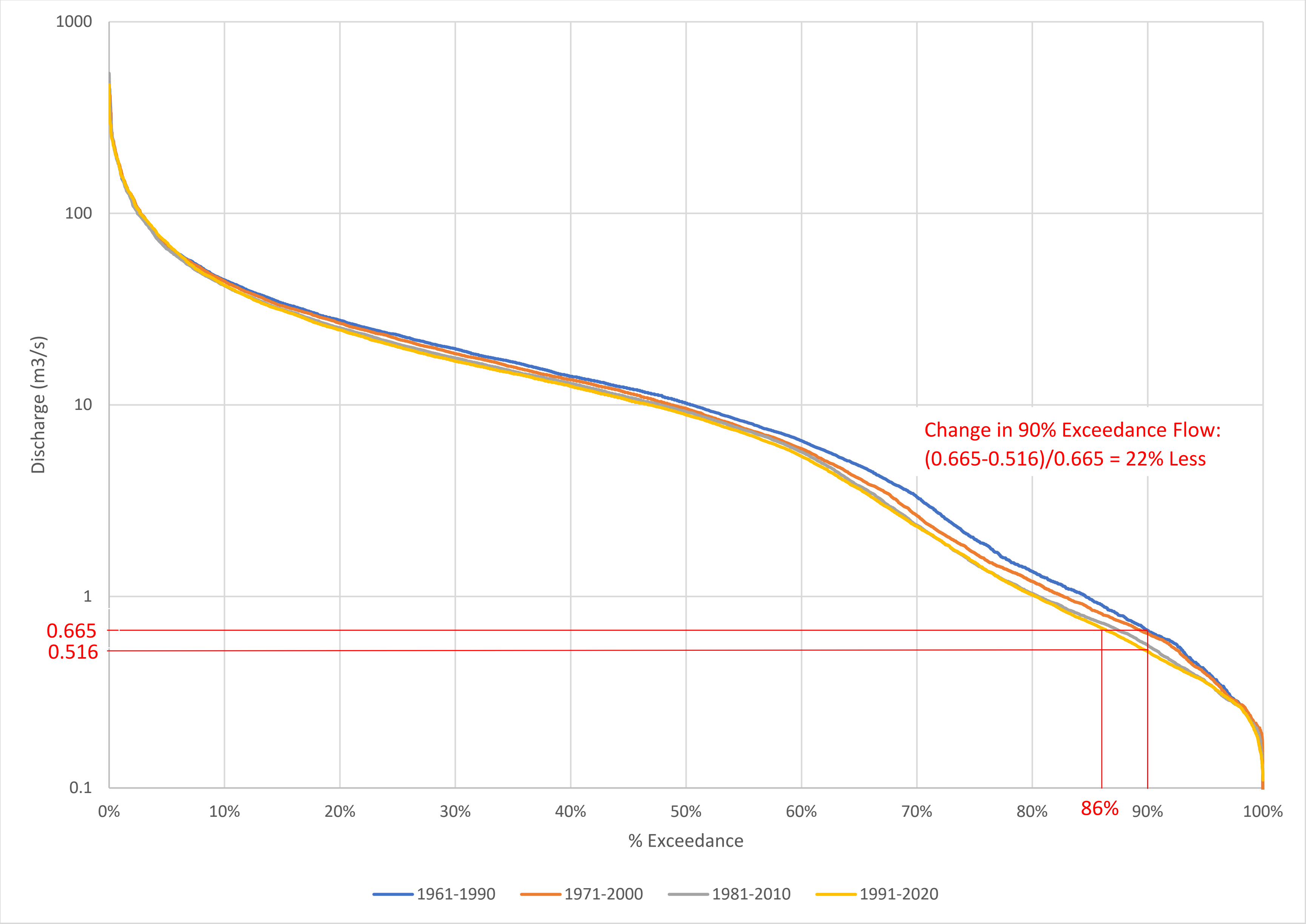


Figure 7. Chemainus River Flow Duration Curve

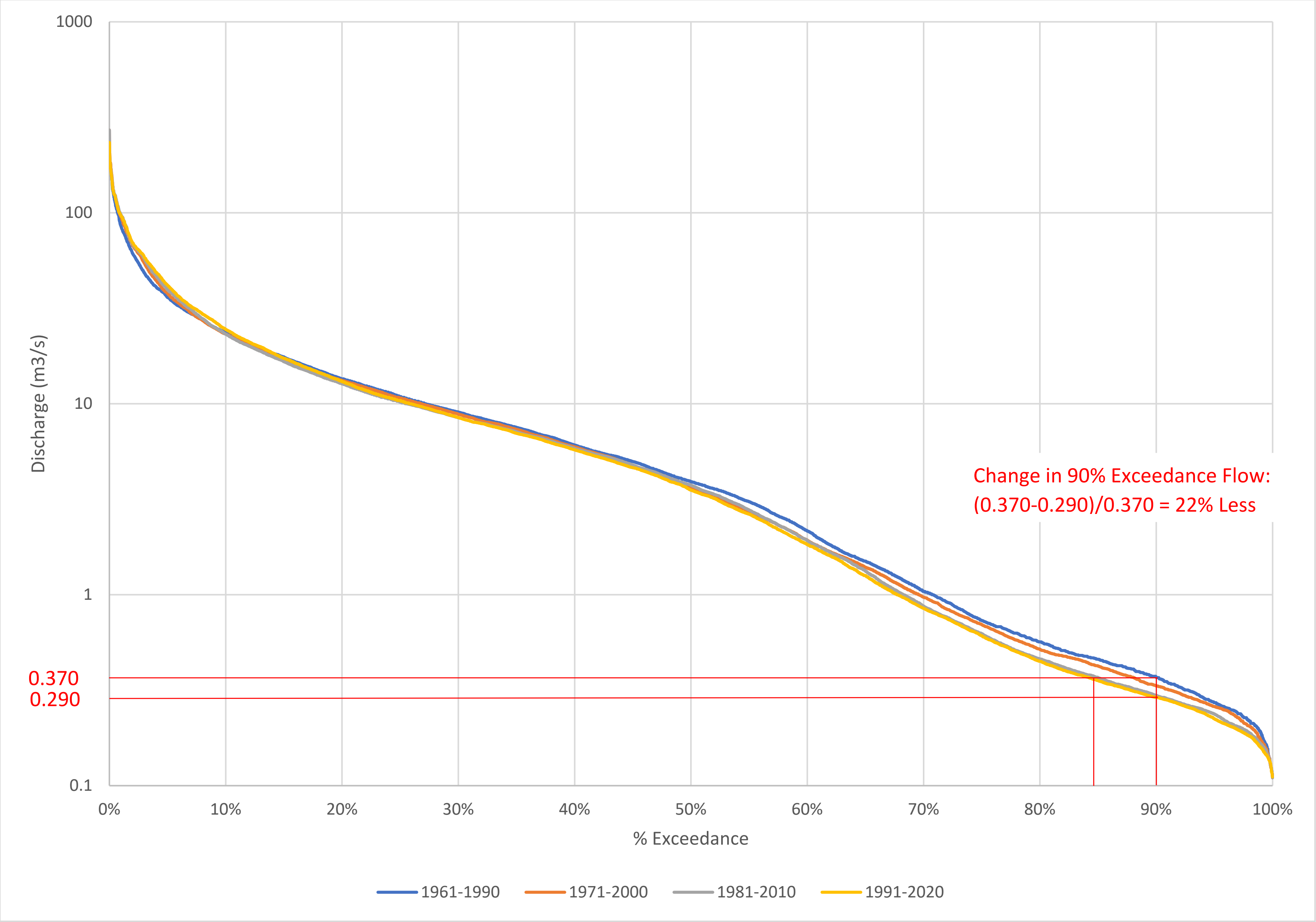


Figure 8. Koksilah River Flow Duration Curve

Appendix 3C: Integration Study

SWIFTWATER CONSULTING

Swiftwater Consulting Ltd.
900-580 Hornby Street
Vancouver, BC
Canada
V6C 3B6
+1-778-952-3569

Geomorphic Consulting
Attn: Jeff Anderson
3820 Alfred Avenue
Smithers, BC
Canada
V0J 2N0

RE: CHEMAINUS RIVER AND KOKSILAH RIVER REGIONAL INTEGRATION STUDY

Dear Jeff,

Geomorphic Consulting (Geomorphic) retained Swiftwater Consulting Ltd. (Swiftwater) to conduct an analysis of streamflow records of the Chemainus River and the Koksilah River, which are both located on the southeast coast of Vancouver Island, near the City of Duncan, where they drain into the Strait of Georgia. The objective of this study was to compare changes in statistical low flows in the Chemainus and Koksilah watersheds with changes to low flows in other regional watersheds, to infer potential causation.

Background

Streamflow may be impacted by concurrent factors including but not limited to a changing climate, urbanization, de- and reforestation, and agriculture. In a previous letter (1-17-21-00003), the variability of low flows over time were characterized using the one in ten year seven day low flow (7Q10), on a rolling window corresponding to established climate normal periods[1]. Monthly 7Q10 flows in both rivers were generally observed to:

- decrease in April through September,
- increase in November through January, and
- vary in shoulder season months.

Regional Hydrometric Data

The Chemainus River and the Koksilah River watersheds are shown in Figure 1 and Figure 2, respectively. Both monitoring stations have 74 years of continuous records, with relatively minor record loss throughout this time. Table 1 and Figure 3 show all active Water Survey of Canada (WSC) stations within a 50 km radius of the two watersheds.

---

[1] 1961-1990, 1971-2000, 1981-2010, and 1991-2020 Climate Normal Periods

Table 1. Active WSC Hydrometric Stations

Station Number	Station Name	Lat (dms)	Long (dms)	Catchment (km^2)	Record (years)	Attenuation
08HA001	Chemainus River near Westholme	48° 52' 42"N	123° 42' 16"W	355	74	-
08HA002	Cowichan River at lake Cowichan	48° 49' 33"N	124° 03' 10"W	594	91	Cowichan Lake
08HA003	Koksilah River at Cowichan Station	48° 43' 40"N	123° 40' 14"W	209	74	-
08HA011	Cowichan River near Duncan	48° 46' 23"N	123° 42' 52"W	826	68	Cowichan Lake
08HA016	Bings Creek near the Mouth	48° 47' 21"N	123° 43' 31"W	15.5	61	-
08HA070	Harris Creek near lake Cowichan	48° 43' 09"N	124° 13' 33"W	28.0	25	-
08HA072	Cottonwood Creek Headwaters	48° 56' 00"N	124° 14' 57"W	13.0	24	-
08HB041	Jump Creek at the Mouth	49° 01' 29"N	124° 11' 12"W	62.2	52	Jump Lake
08HB069	Renfrew Creek near Port Renfrew	48° 38' 12"N	124° 17' 30"W	8.12	25	-
08HE006[1]	Zeballos River near Zeballos	50° 00' 44"N	126° 50' 36"W	178	63	Zeballos Lake

Some of the criteria listed in Table 1 were important for identifying watersheds with similar record lengths, land cover, catchment area, and attenuation characteristics (*i.e.* lakes). Bings Creek Near the Mouth and Zeballos River Near Zeballos were found to fit best.

Bings Creek

Bings Creek is a 15.5 km^2 watershed near the City of Duncan, between the Chemainus and Koksilah Rivers. The WSC station is located at Cowichan Lake Road, upstream of the mouth where it drains into Somenos Lake. The landcover in the headwaters is forested land which is somewhat impacted by forestry (based on observations from aerial photos from 1985 to 2020). Aerial imagery shows some agricultural land near the lower reaches of the creek. Due to its close proximity to the Chemainus and Koksilah Rivers, this station provides spatial value to this study. For example, spatial variation in precipitation may be less prominent in a nearby watershed.

Zeballos River

The Zeballos River is a 178 km^2 watershed located on the northwest coast of Vancouver Island. Landcover is primarily forested land with some impact from forestry, and there is some attenuation from Zeballos Lake. However, the lake's surface area makes up less than 1% of the total watershed. Apart from forestry, which appears to be largely similar in aerial extent to the primary watersheds, this watershed has minimal anthropogenic alteration (*e. g.* agriculture, urbanization).

Low Flow Analysis Methodology

Long-term daily streamflow records were analyzed using 30-year climate normal windows, for successive 10-year periods, to derive the 7Q10 statistics. Data from 1961 through 2020 were considered, corresponding to four (4) largely complete climate normal windows, as shown in Table 2.

The low flow analysis performed on the Chemainus and Koksilah Rivers in the Low Flow Study (1-17-21-00003) was repeated for each of the additional regional stations. For each climate normal period, a moving average 7-day flow was calculated for the entire dataset. These low flows were then used to generate a series of minimums for each month, in each year, of the 30-year record. A statistical analysis was then completed for each monthly dataset, and a distribution selected based on goodness of fit tests (Kolmogorov-Smirnov, Anderson-Darling, and Chi-Squared). The Generalized Extreme Value (GEV) distribution was found

---

[1] 08HE006 is greater than 50 km from the two watersheds and not on the map shown in Figure 3.

to be the best match across most months and for each climate window. The probability density function (PDF) of each distribution was then used to estimate the 7Q10.

Table 2. Climate Normal Windows

Climate Normal	Years Included	Years with Incomplete Data[1]			
		Chemainus River	Koksilah River	Bings Creek	Zeballos River
1990	1961-1990	1972-1974		1961, 1966, 1967, 1983, 1984	1966
2000	1971-2000	1972-1974		1983, 1984	
2010	1981-2010			1983, 1984	
2020	1991-2020		2012		2013, 2020

Flow duration curves were developed to characterize how the entire flow regime (not just low flows) has changed over time. Flow percentiles of daily streamflow were calculated and plotted versus the percent of time that the flow is exceeded for each climate window.

Results

Results for the 7Q10 analysis are shown in Table 3 to Table 6 and Figure 4 to Figure 11. Flow duration curves are shown in Figure 12 to Figure 15.

Table 3. Chemainus River 7Q10 Flows (m^3/s)

Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961-1990	3.05	5.75	6.59	8.00	3.23	1.04	0.33	0.21	0.22	0.27	1.63	4.57
1971-2000	3.54	6.21	6.33	6.01	2.06	0.78	0.34	0.24	0.21	0.29	1.06	5.16
1981-2010	5.08	5.53	5.42	5.96	2.26	0.92	0.33	0.17	0.17	0.26	1.47	4.63
1991-2020	5.78	4.93	4.88	4.83	1.49	0.69	0.29	0.16	0.17	0.31	2.28	5.42

Table 4. Koksilah River 7Q10 Flows (m^3/s)

Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961-1990	2.88	3.11	3.03	2.40	1.13	0.48	0.21	0.17	0.19	0.30	0.68	2.60
1971-2000	3.02	3.16	3.13	1.88	0.86	0.42	0.20	0.17	0.18	0.28	0.54	2.55
1981-2010	3.54	3.31	3.24	1.94	0.81	0.39	0.19	0.16	0.16	0.24	0.73	2.49
1991-2020	3.97	3.38	2.98	1.82	0.69	0.34	0.19	0.14	0.16	0.23	1.10	2.44

Table 5. Bings Creek 7Q10 Flows (m^3/s)

Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961-1990	0.175	0.188	0.147	0.092	0.039	0.021	0.013	0.009	0.006	0.012	0.017	0.069
1971-2000	0.168	0.175	0.152	0.090	0.042	0.022	0.013	0.007	0.005	0.012	0.024	0.097
1981-2010	0.214	0.184	0.165	0.099	0.042	0.020	0.010	0.005	0.004	0.009	0.023	0.111
1991-2020	0.230	0.177	0.135	0.087	0.039	0.018	0.010	0.007	0.007	0.010	0.026	0.098

Table 6. Zeballos River 7Q10 Flows (m^3/s)

Normal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961-1990	6.94	6.53	7.03	8.19	10.13	8.62	5.30	3.84	3.43	3.95	6.66	7.37
1971-2000	6.49	6.55	7.47	8.43	9.25	7.81	4.59	3.35	3.35	3.61	6.44	7.31
1981-2010	6.73	6.50	6.95	8.22	8.90	7.43	4.74	3.30	3.25	3.18	6.52	7.10
1991-2020	6.05	5.09	5.64	7.79	6.16	5.07	3.67	2.66	3.03	3.50	6.44	7.11

---

[1] Incomplete years were not included in the analysis.

Discussion

Changes in runoff over time can be used to infer potential land-use characteristics that may be altering the flow regime. Comparable runoff trends for watersheds with varying amounts of land alteration, would suggest that flow changes result from climate drivers. Anthropogenic land-alteration in each of the watersheds inferred from aerial imagery is shown in Table 7, where the left end of the scale bars represents no alteration, and the right end represents extensive alteration. A summary of trends in the derived 7Q10 for all watersheds is included in Table 8.

Table 7. Anthropogenic Land Alteration[1]

Station Number	Station Name	Forestry	Urbanization	Agriculture
08HA001	Chemainus River near Westholme			
08HA003	Koksilah River at Cowichan Station			
08HA016	Bings Creek near the Mouth			
08HE006	Zeballos River near Zeballos			

Table 8. 7Q10 Trends

Season	7Q10 Trend Compared to 1990 Climate Normal (% Change in 2020 Climate Normal)			
	Chemainus River	Koksilah River	Bings Creek	Zeballos River
Winter (Nov – Jan)	Increasing (+49%)	Increasing (+32%)	Increasing (+43%)	Decreasing (-7%)
Summer (Apr – Sep)	Decreasing (-25%)	Decreasing (-23%)	Decreasing (-8%)	Decreasing (-26%)
Shoulder Months	Varies	Varies	Varies	Decreasing (-18%)

Comparing Figure 5, Figure 7, Figure 9, and Figure 11 suggests that all four watersheds have experienced similar changes in 7Q10 in the summer season – a decrease of approximately 8-26% since the 1990 climate normal. Likewise, the flow duration curves in Figure 12 to Figure 15 imply that the 90th percentile exceedance flow in each watershed may have decreased by 20-26%. Consequently, the similarity in the low flow statistics across four unique watersheds suggests that these trends may be primarily influenced by climate. Further, the Zeballos watershed derived 7Q10 has decreased in all months, which suggests that flow decreases may be occurring independent of effects from agriculture and urbanization.

From the available aerial imagery (1984 to 2020), there was insufficient data to relate the impact of forestry to changes in streamflow. Further analysis would be required to assess correlation between forestry and streamflow. Additionally, Government of Canada historical climate data was reviewed alongside the streamflow data. The 1990, 2000, and 2010 climate normals for Nanaimo A and Cowichan Lake Forestry climate station were reviewed but were inconclusive.

Conclusion

Low flows were observed to be decreasing in the summer months (April through September) for all of the watersheds that were studied. The relatively similar trends are observed over four unique watersheds, suggesting that they may be due to regional effects, such as a changing climate. Local sources may also be altering the flow regimes, including forestry, however further analysis would be required to quantify these effects.

---

[1] Pale coloring is no alteration, bold coloring is complete alteration

Closing

We trust that this letter satisfies your requirements. If you have any questions or concerns, please do not hesitate to contact the undersigned.

SWIFTWATER CONSULTING LTD.

C. J. S. MCCARTHY
34514

C. J. S. MCCARTHY
34514

Kyle Winslow

November 25th, 2021

Kyle Winslow, EIT, B.Eng.
Water Resource Engineer-in-Training

Cameron McCarthy, M.A.Sc., P.Eng., P.Geo., P.Tech.
Principal Water Resource Engineer

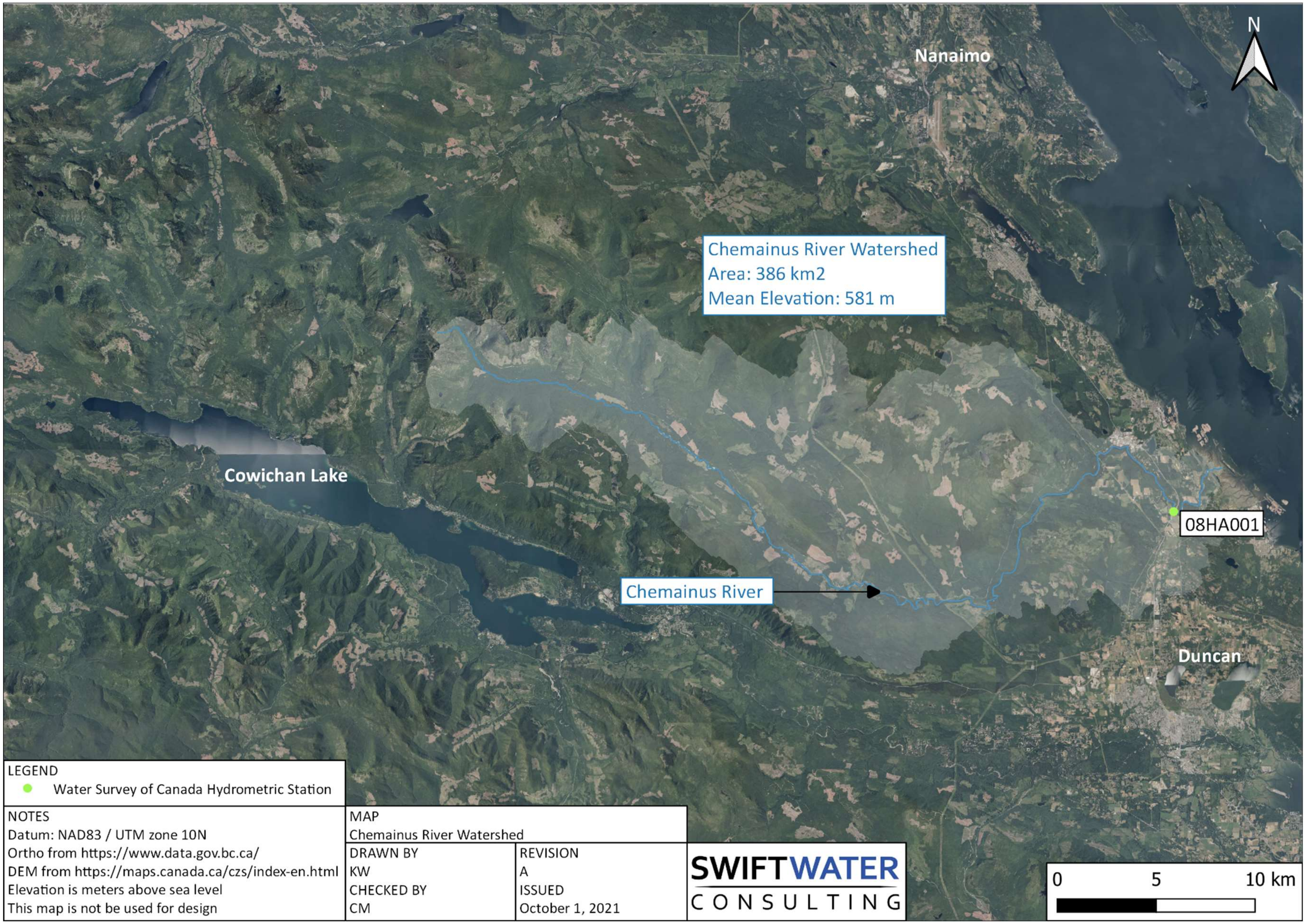


Figure 1. Chemainus River Watershed

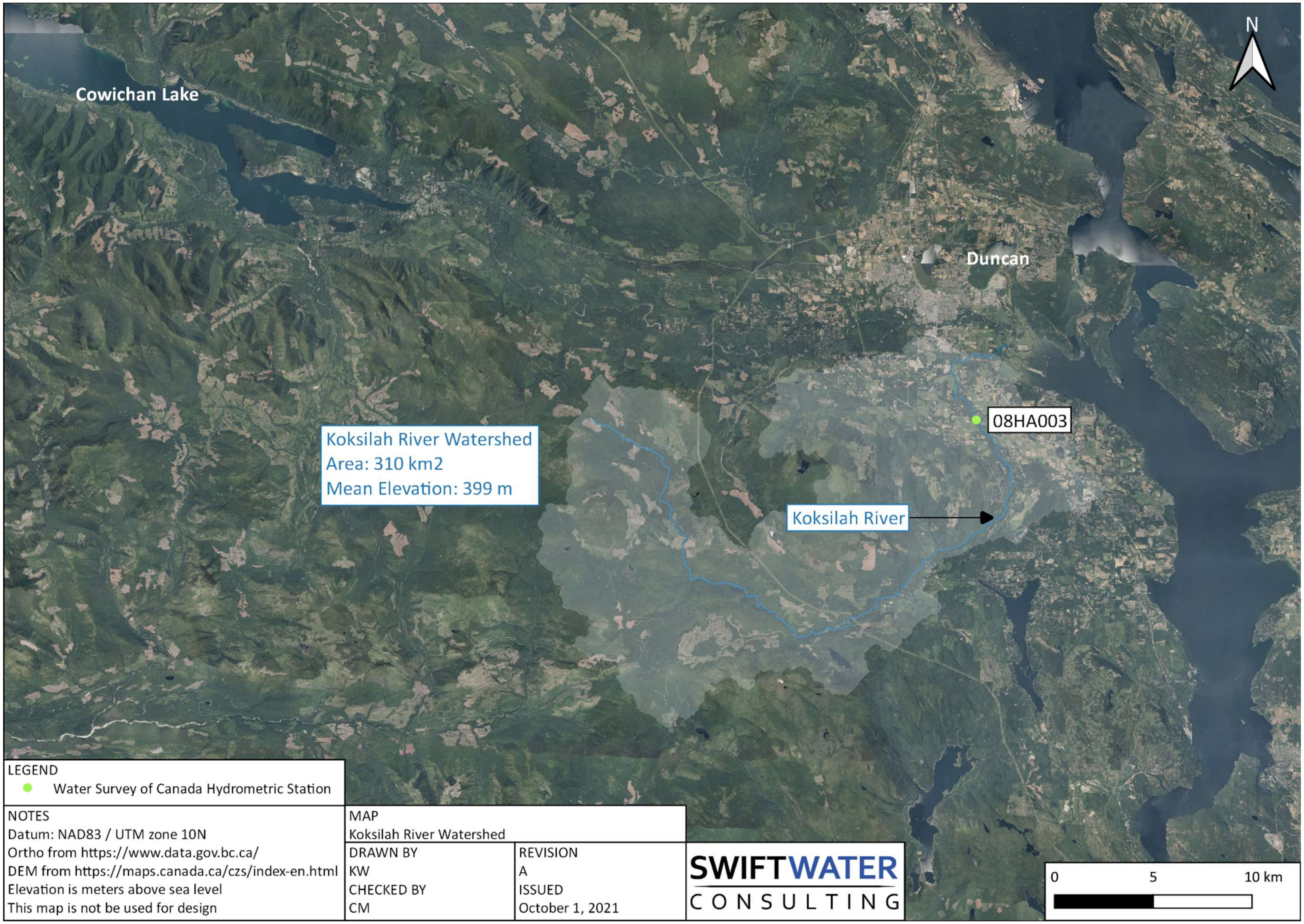


Figure 2. Koksilah River Watershed

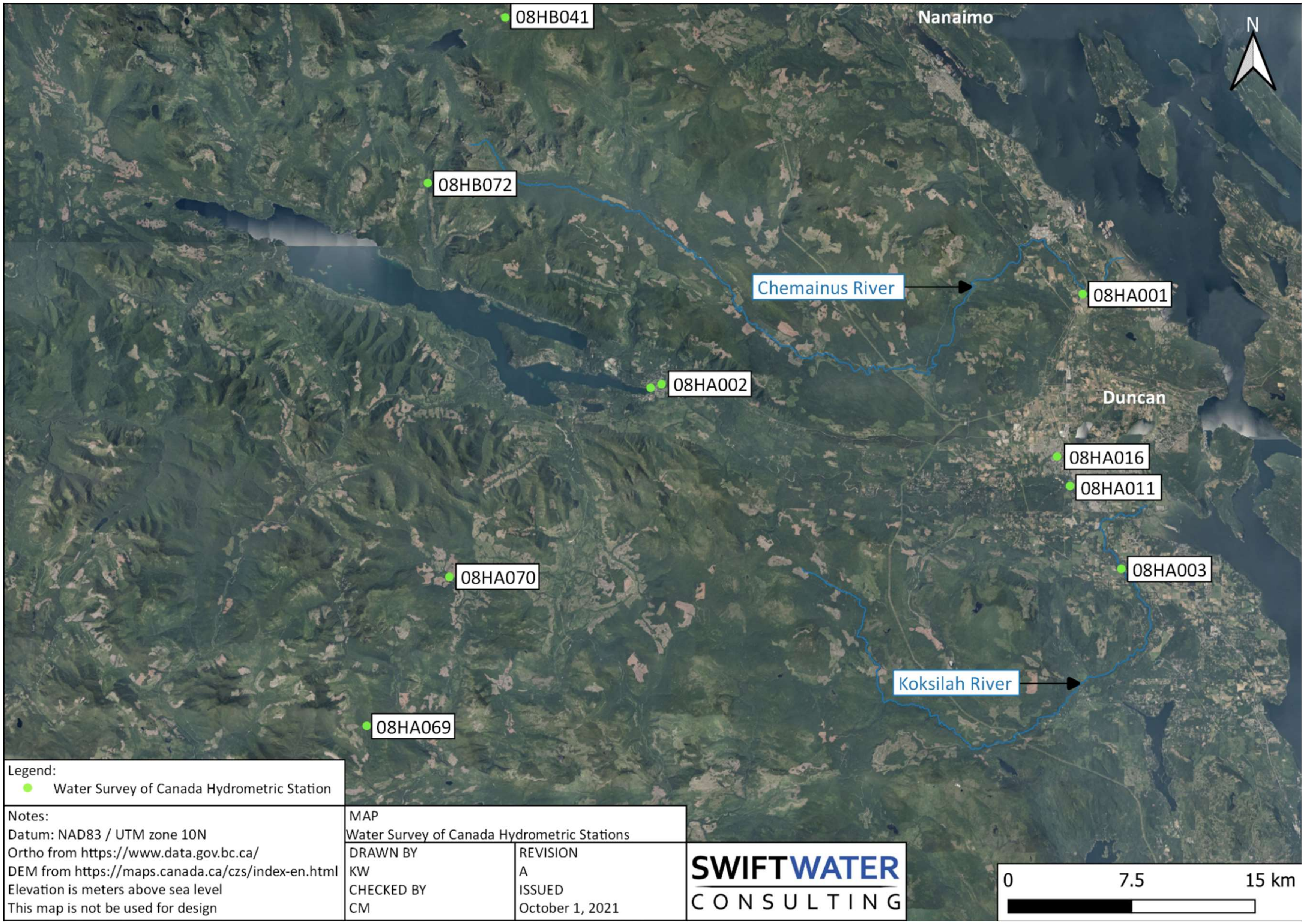


Figure 3. Nearby WSC Hydrometric Stations

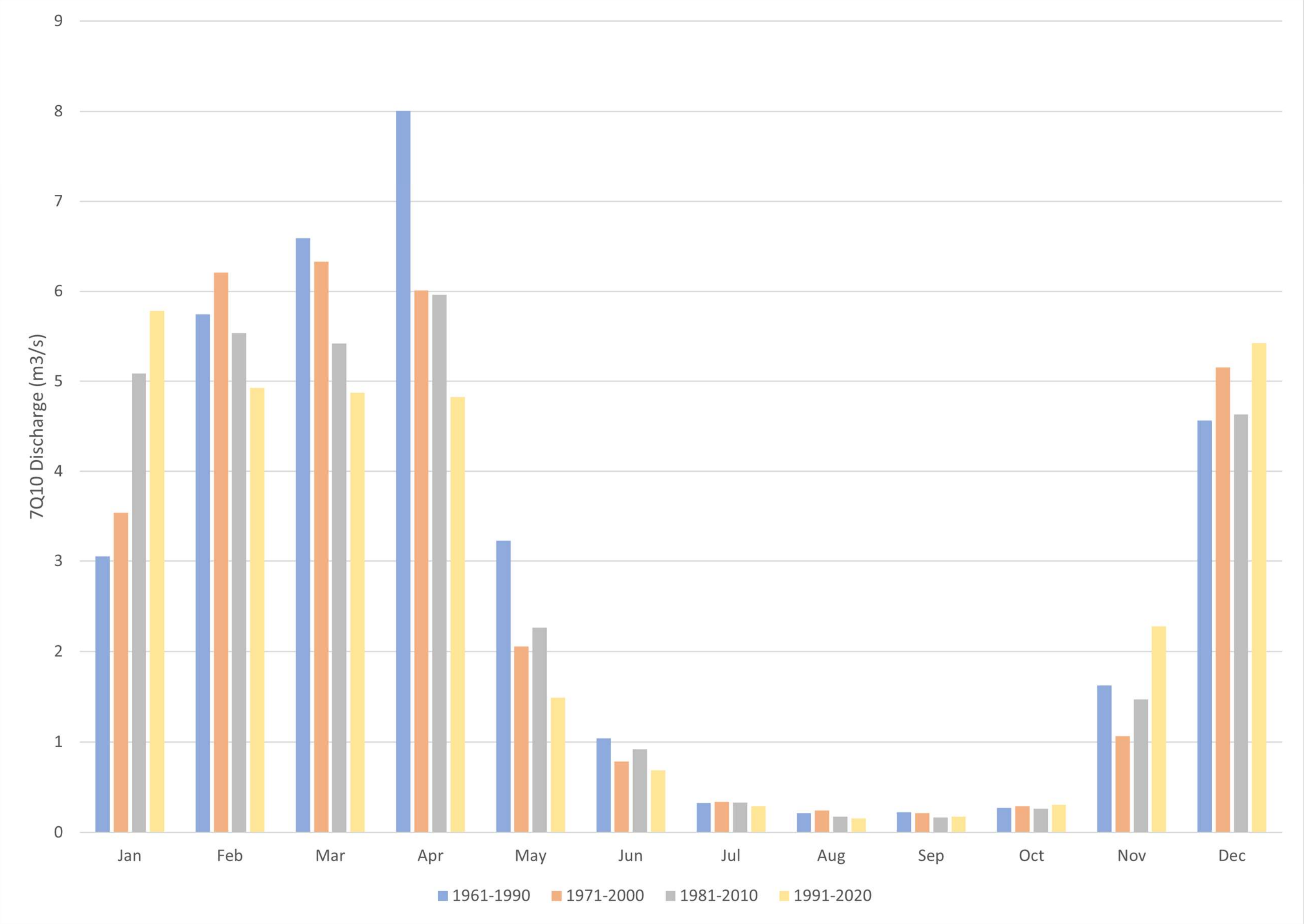


Figure 4. Chemainus River 7Q10 Discharge

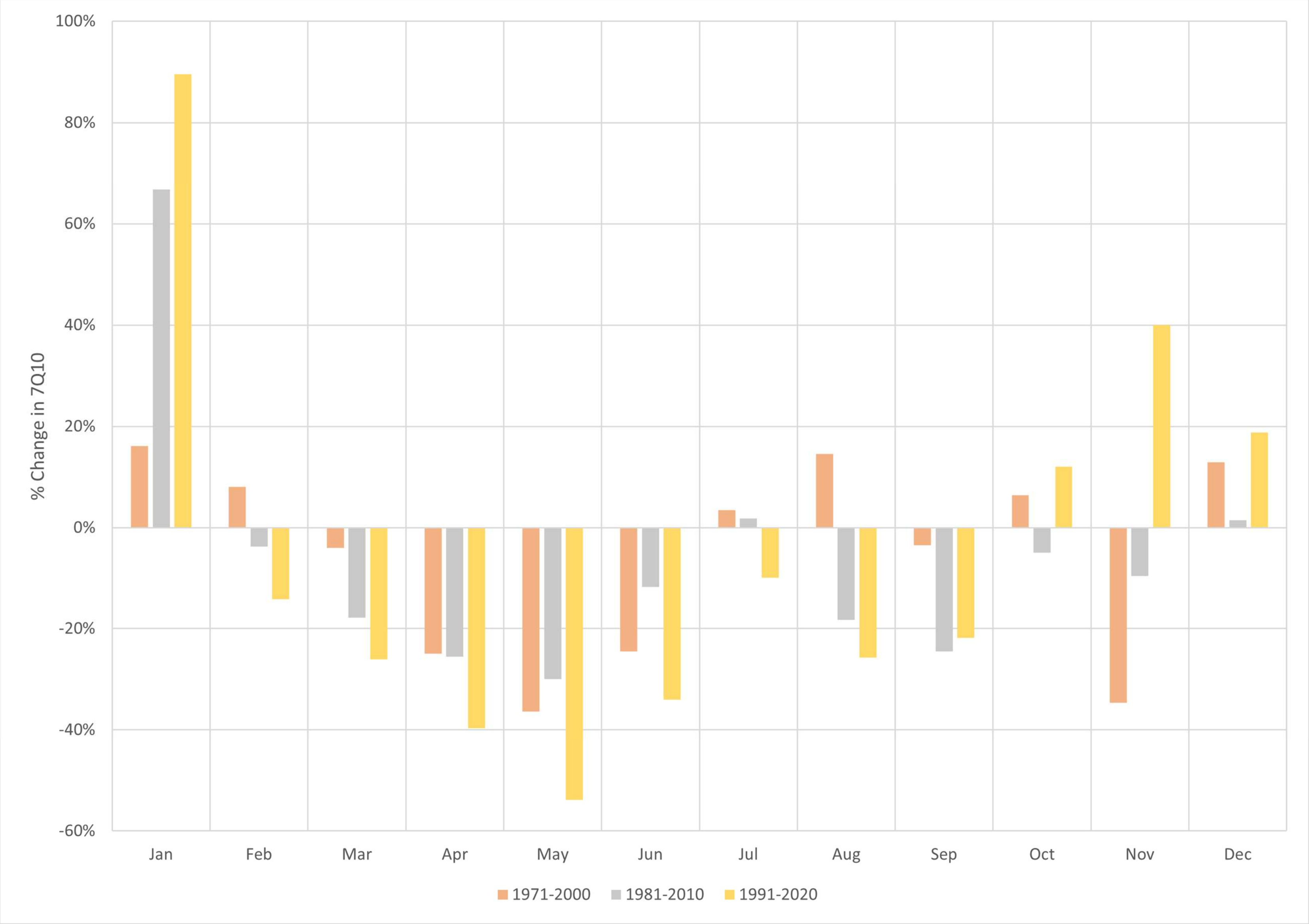


Figure 5. Chemainus River Change in 7Q10 Discharge from 1961-1990

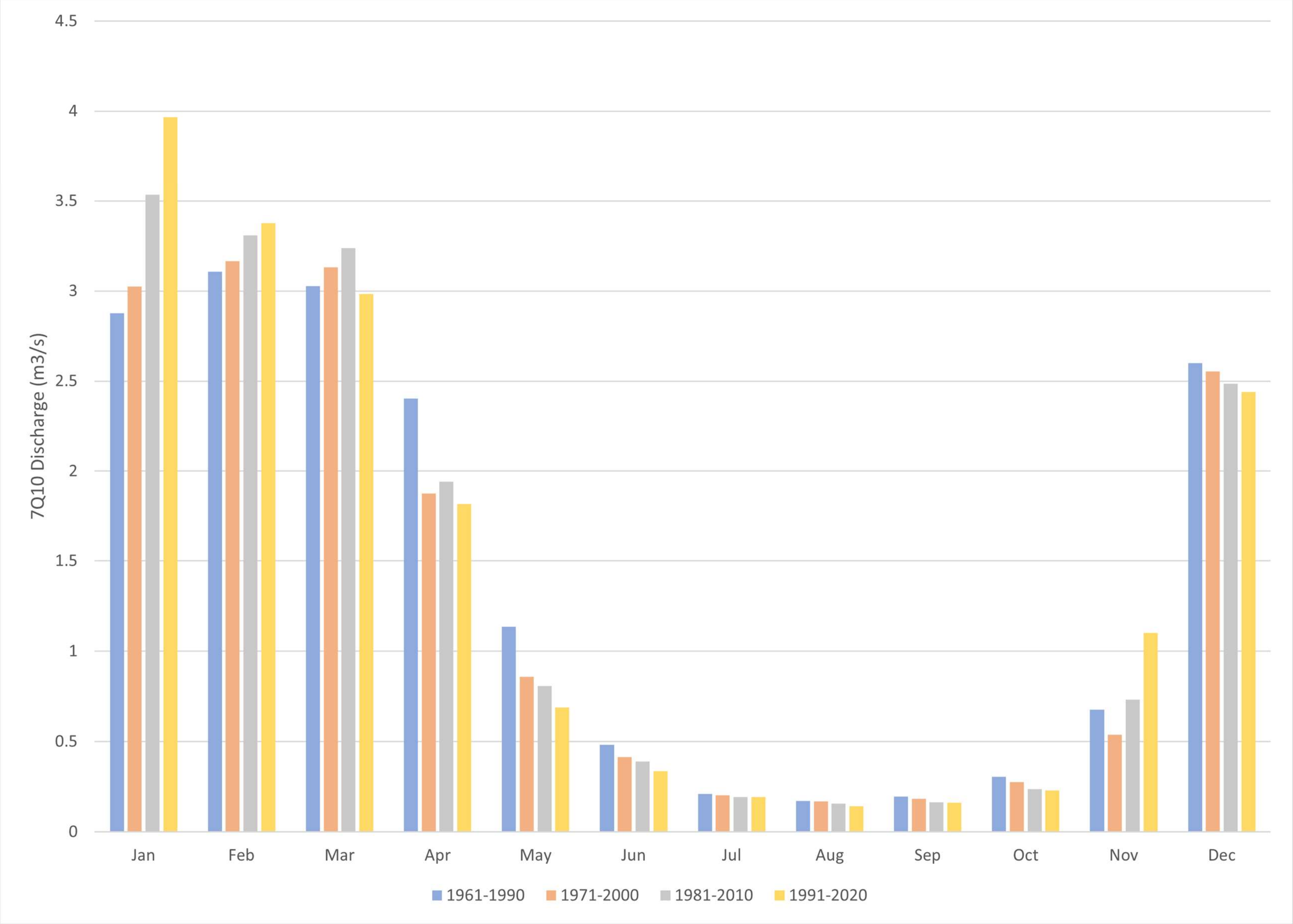


Figure 6. Koksilah River 7Q10 Discharge

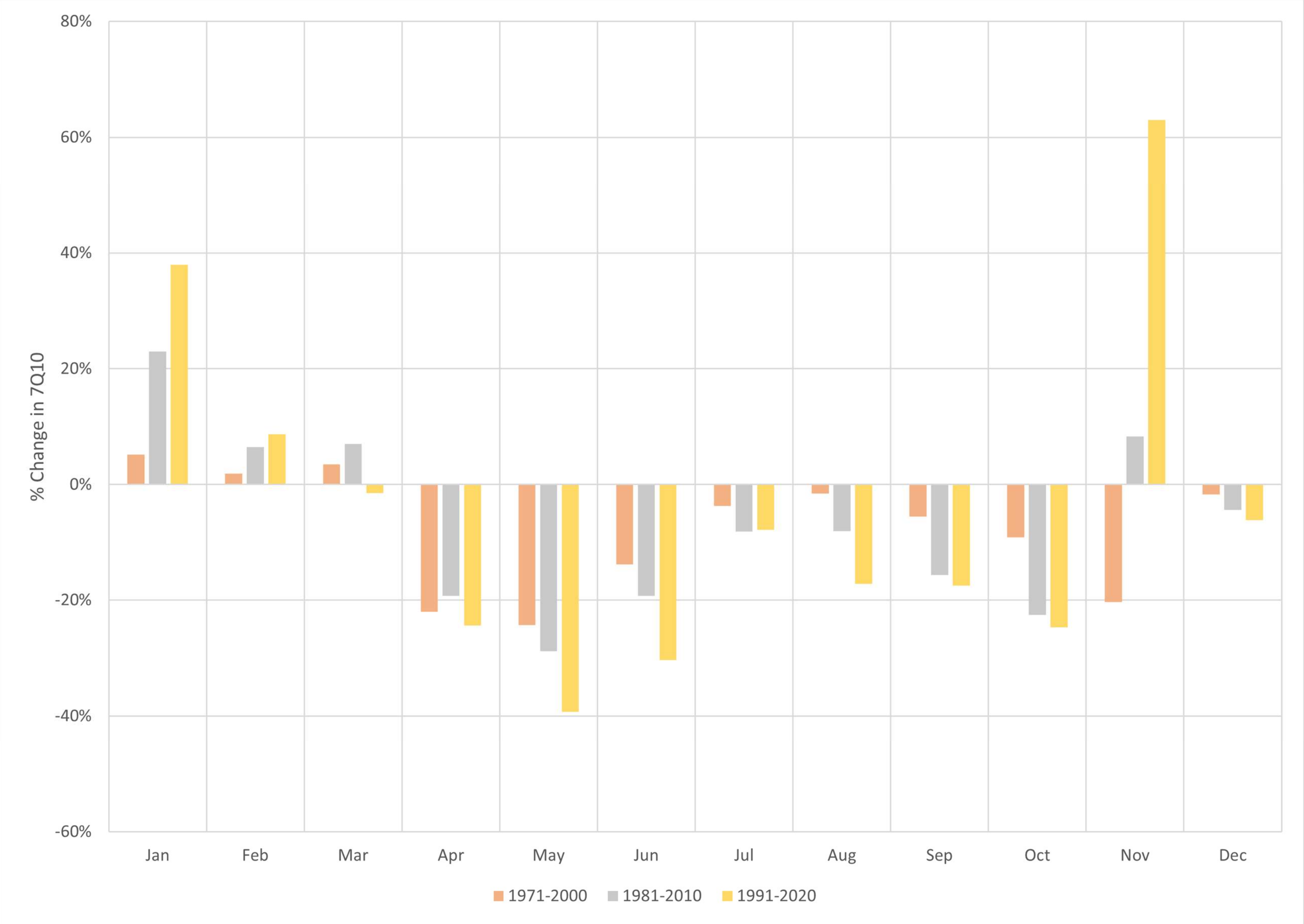


Figure 7. Koksilah River Change in 7Q10 Discharge from 1961-1990

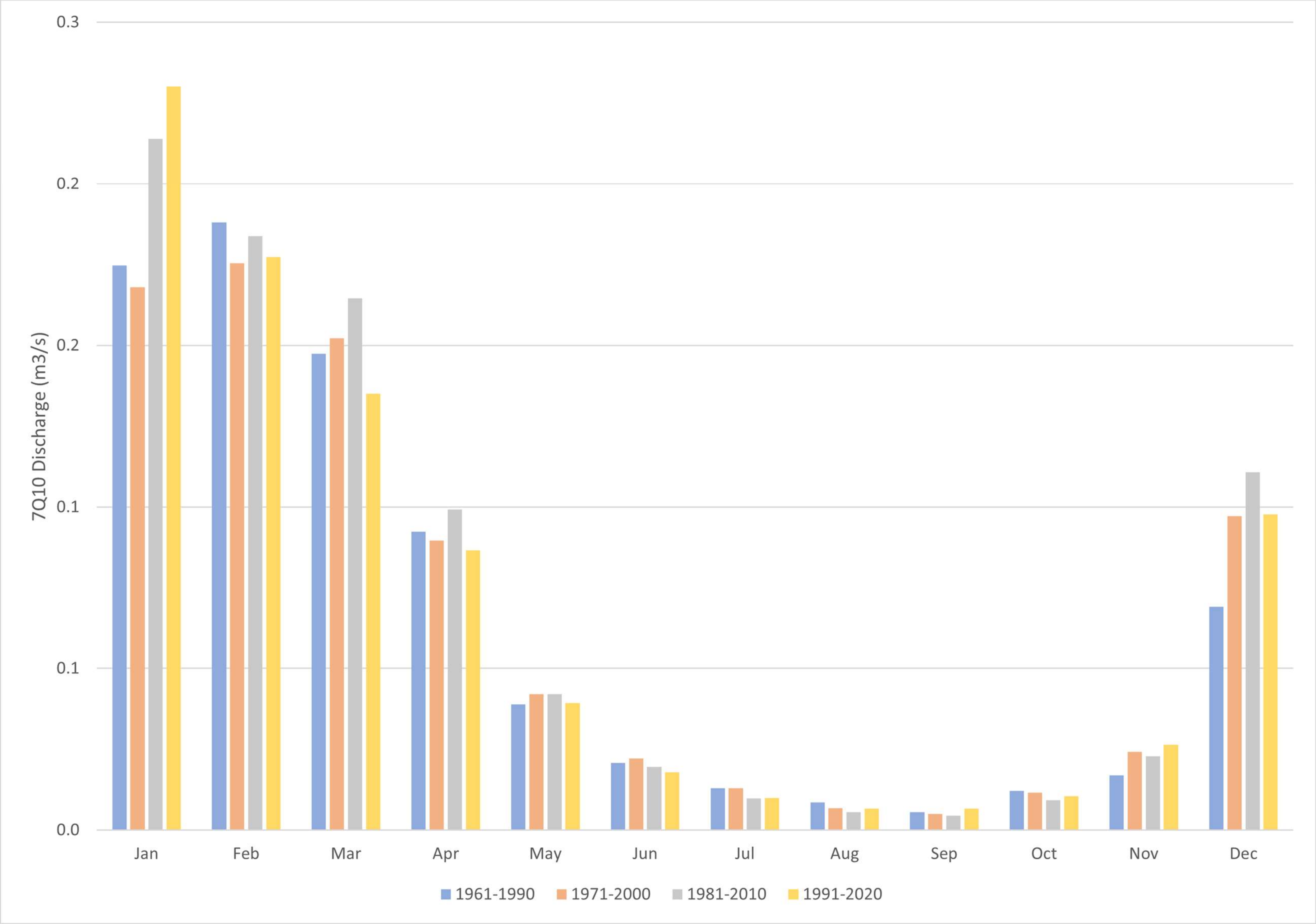


Figure 8. Bings Creek 7Q10 Discharge

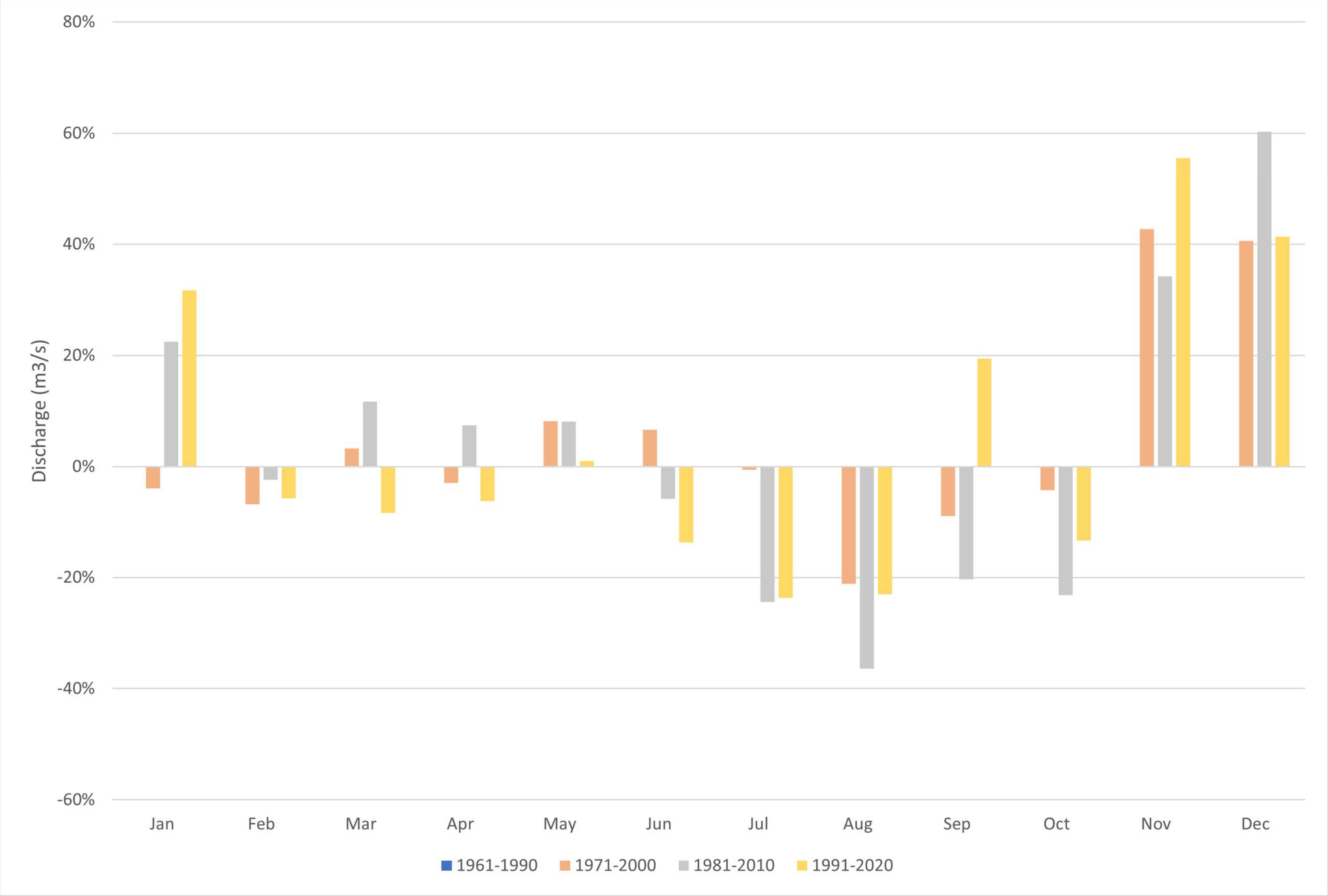


Figure 9: Bings Creek Change in 7Q10 Discharge from 1961-1990

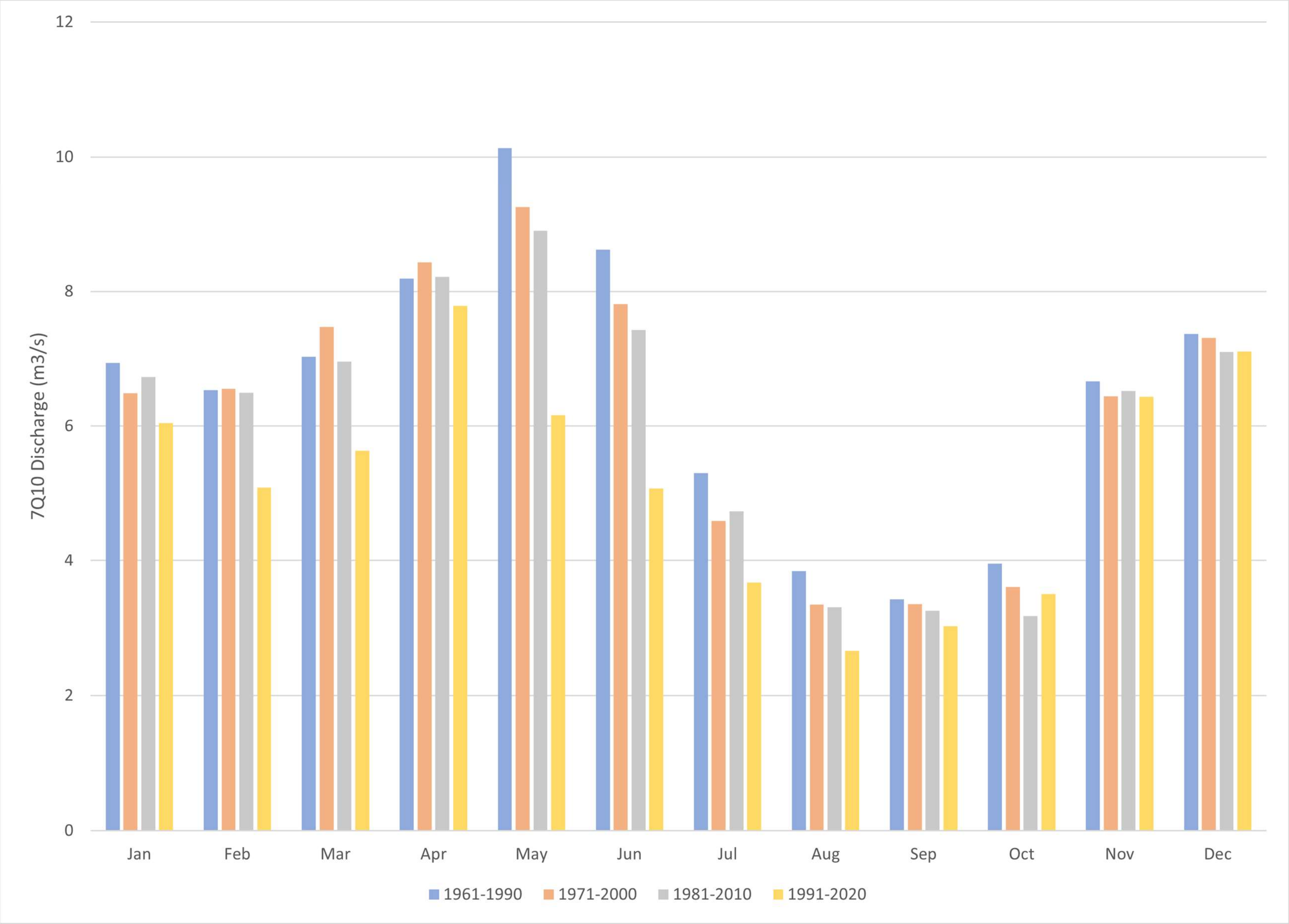


Figure 10. Zeballos River 7Q10 Discharge

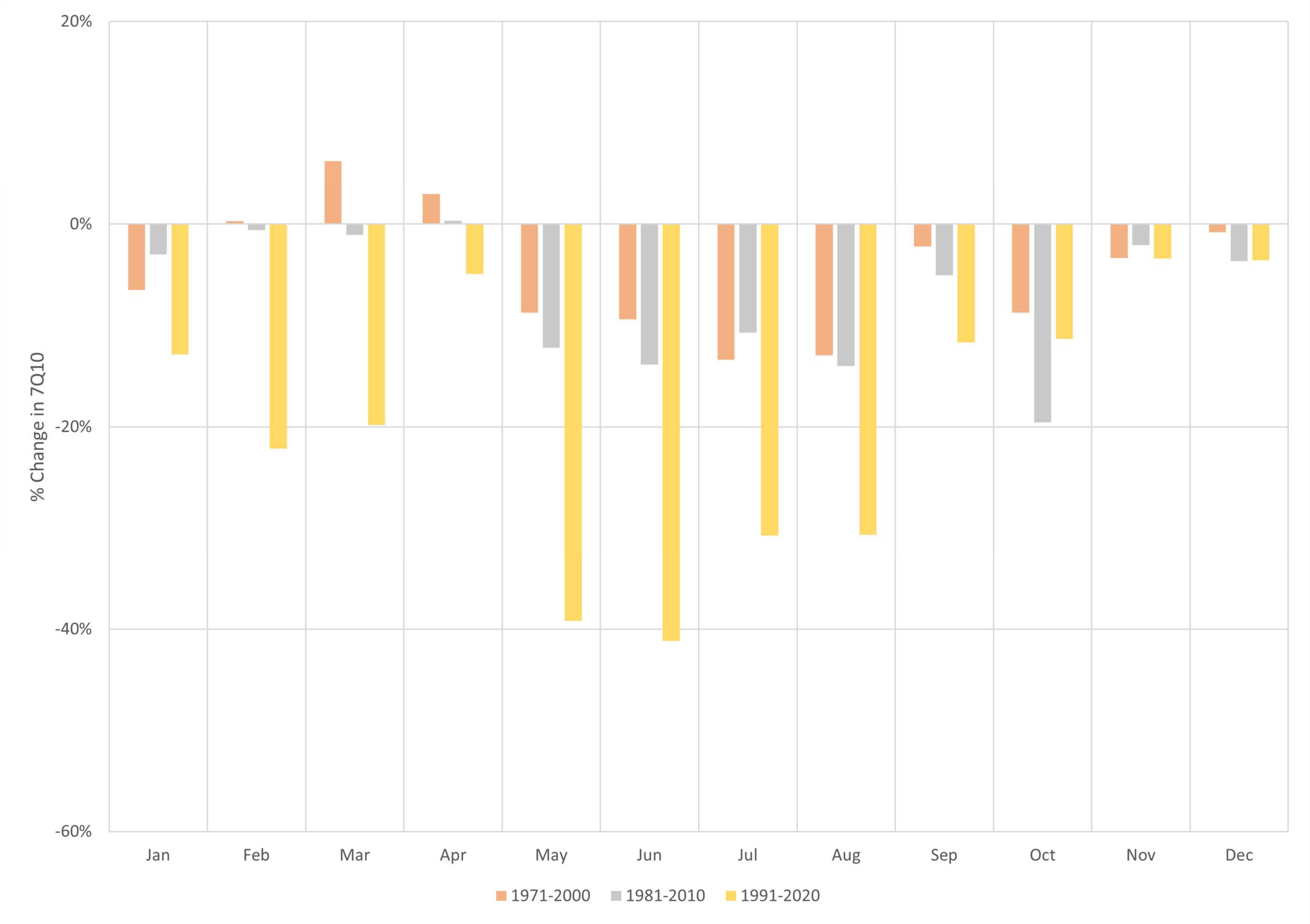


Figure 11. Zeballos River Change in 7Q10 Discharge from 1961-1990

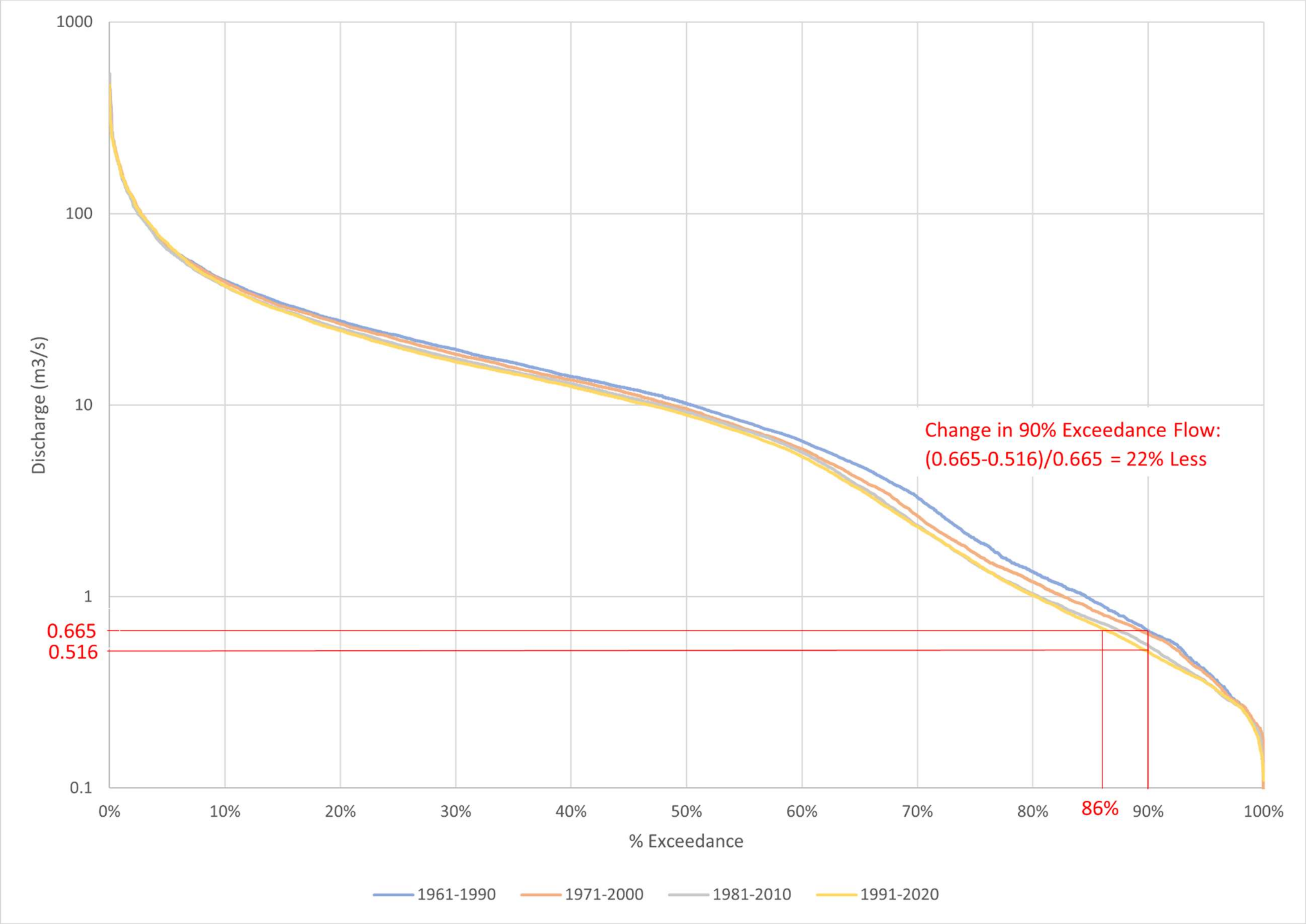


Figure 12. Chemainus River Flow Duration Curve

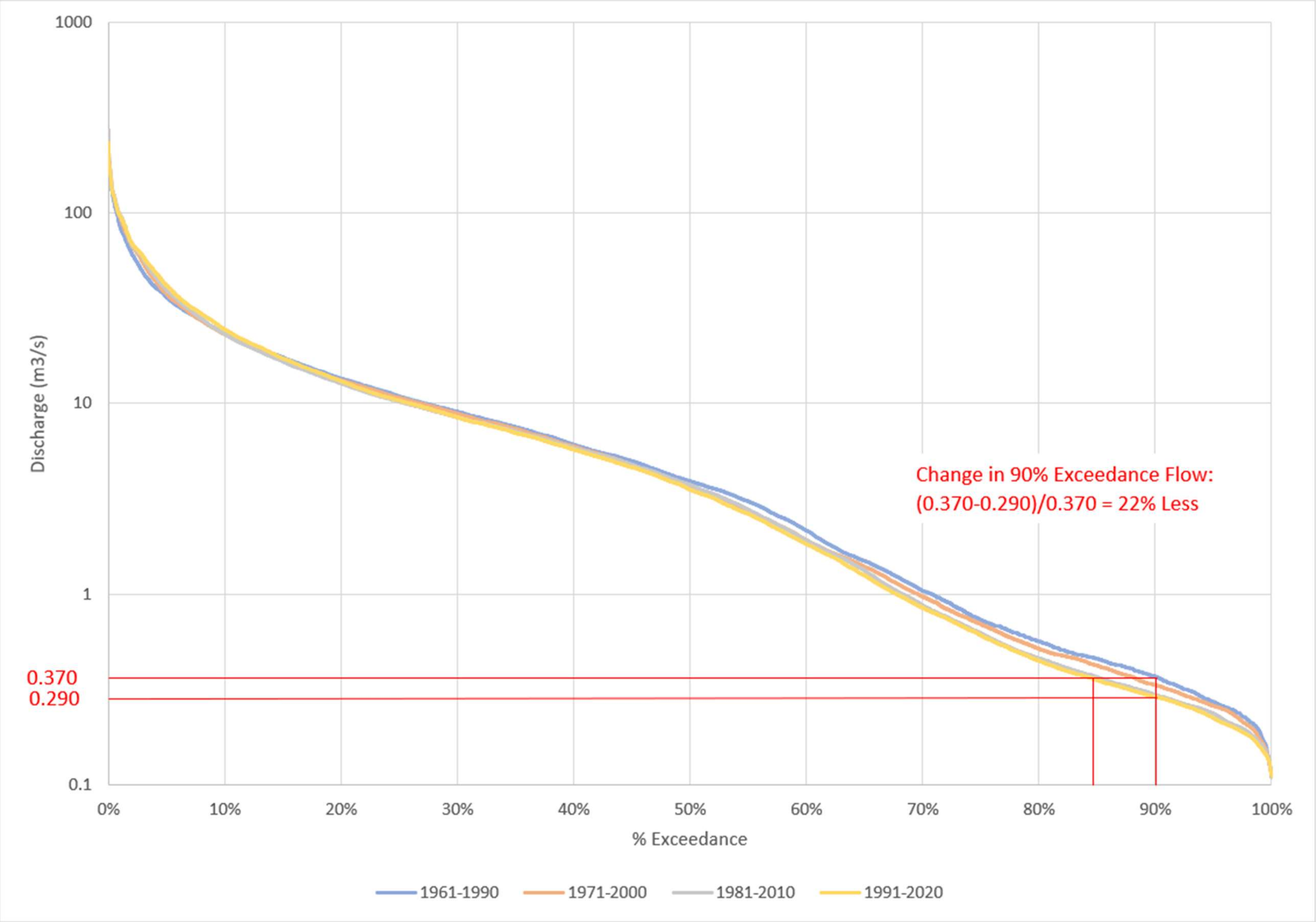


Figure 13. Koksilah River Flow Duration Curve

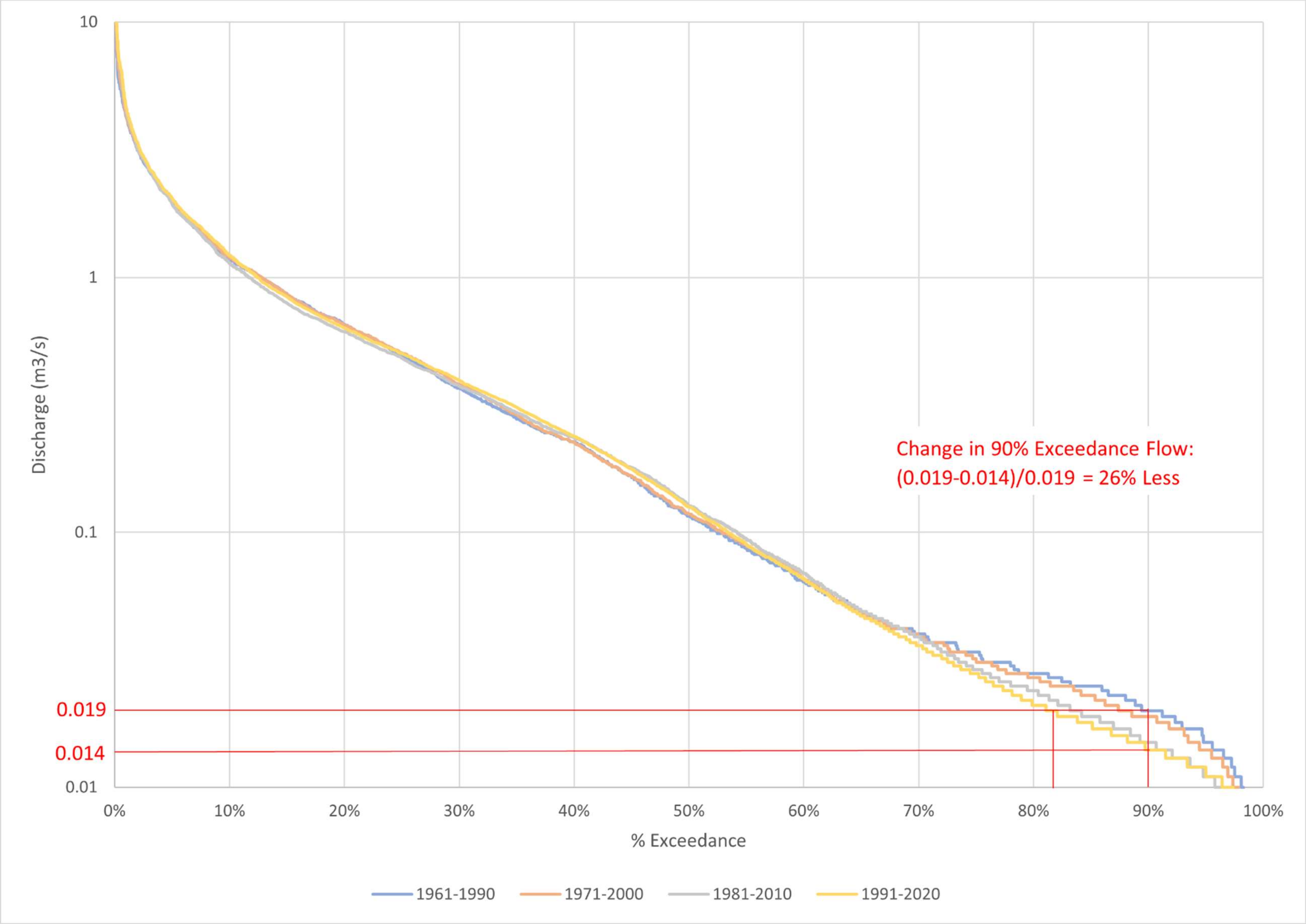


Figure 14. Bings Creek Flow Duration Curve

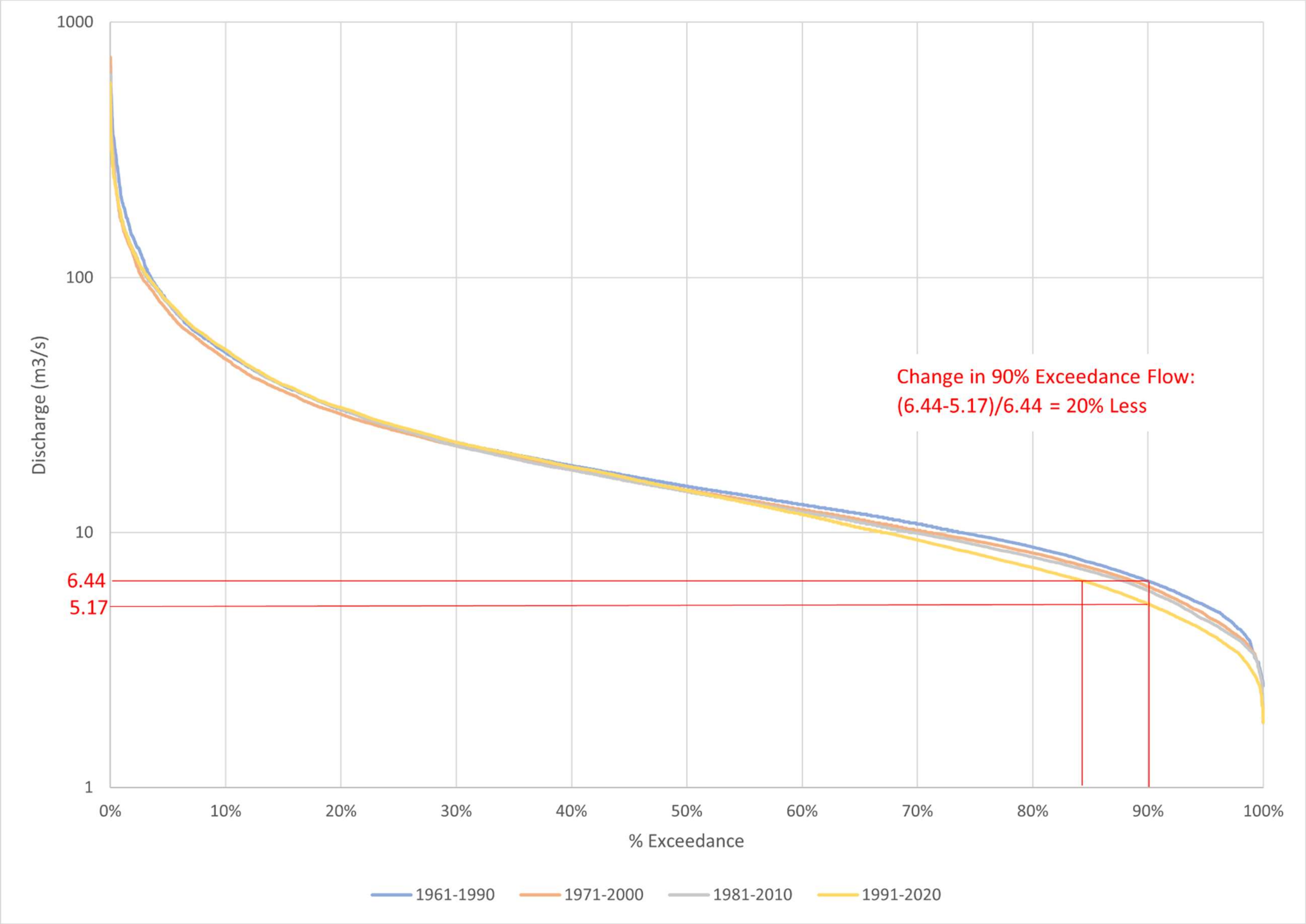


Figure 15. Zeballos River Flow Duration Curve

Appendix 3D: Koksilah River Figures

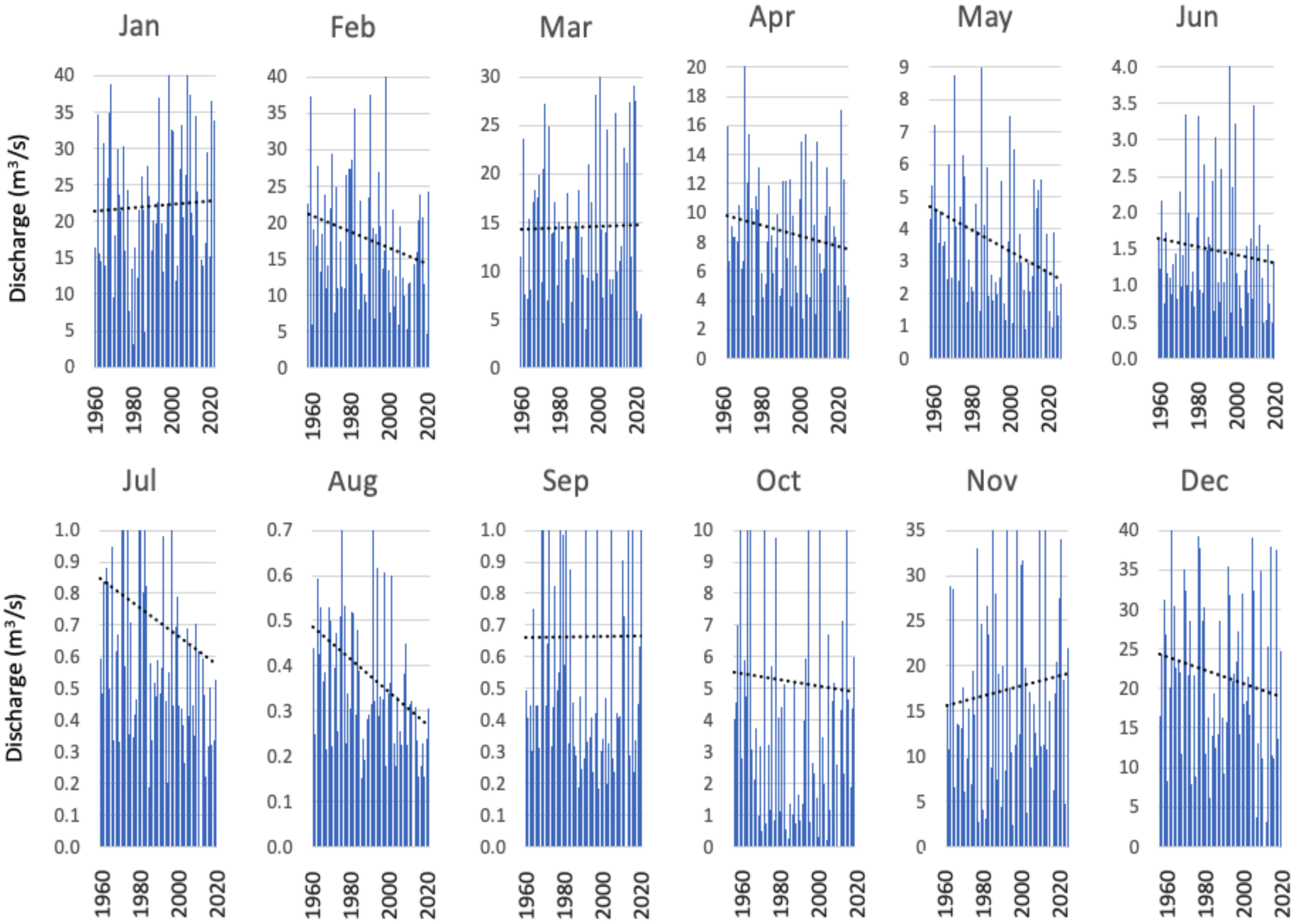


Figure 3-2. Long-term mean monthly flow for the Koksilah River based on data from Water Survey of Canada gauging station 08HA003. Noteworthy is how summer flows (May – November) are decreasing over time.

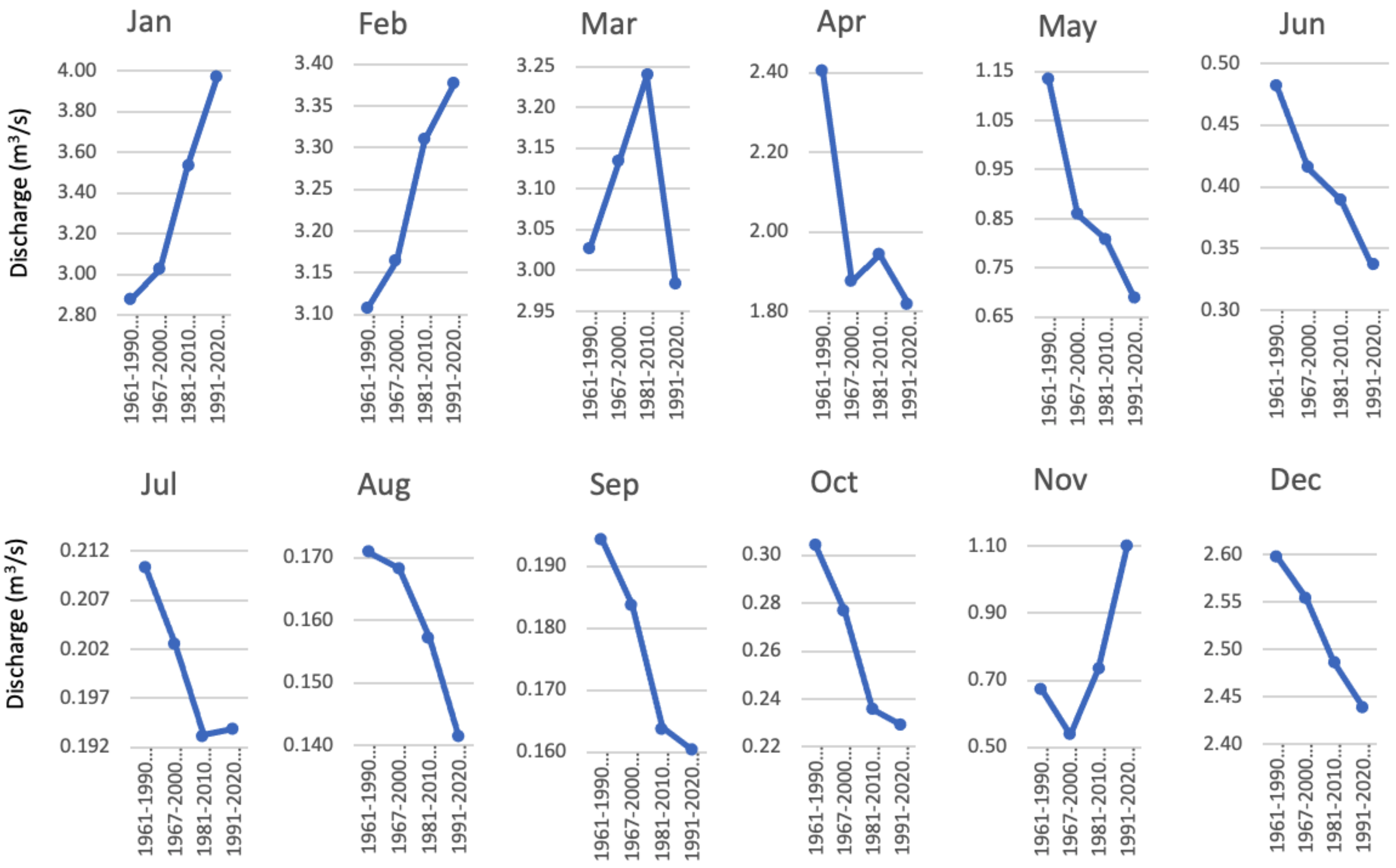


Figure 3-3. Long-term 7Q10 low flows for the Koksilah River based on data from Water Survey of Canada gauging station 08HA003. Long-term 7Q10 is grouped into Climate Normal windows to consider how low flows may be changing with climate. With the exception of March and November, low flows have decreased with each new Climate Normal window.

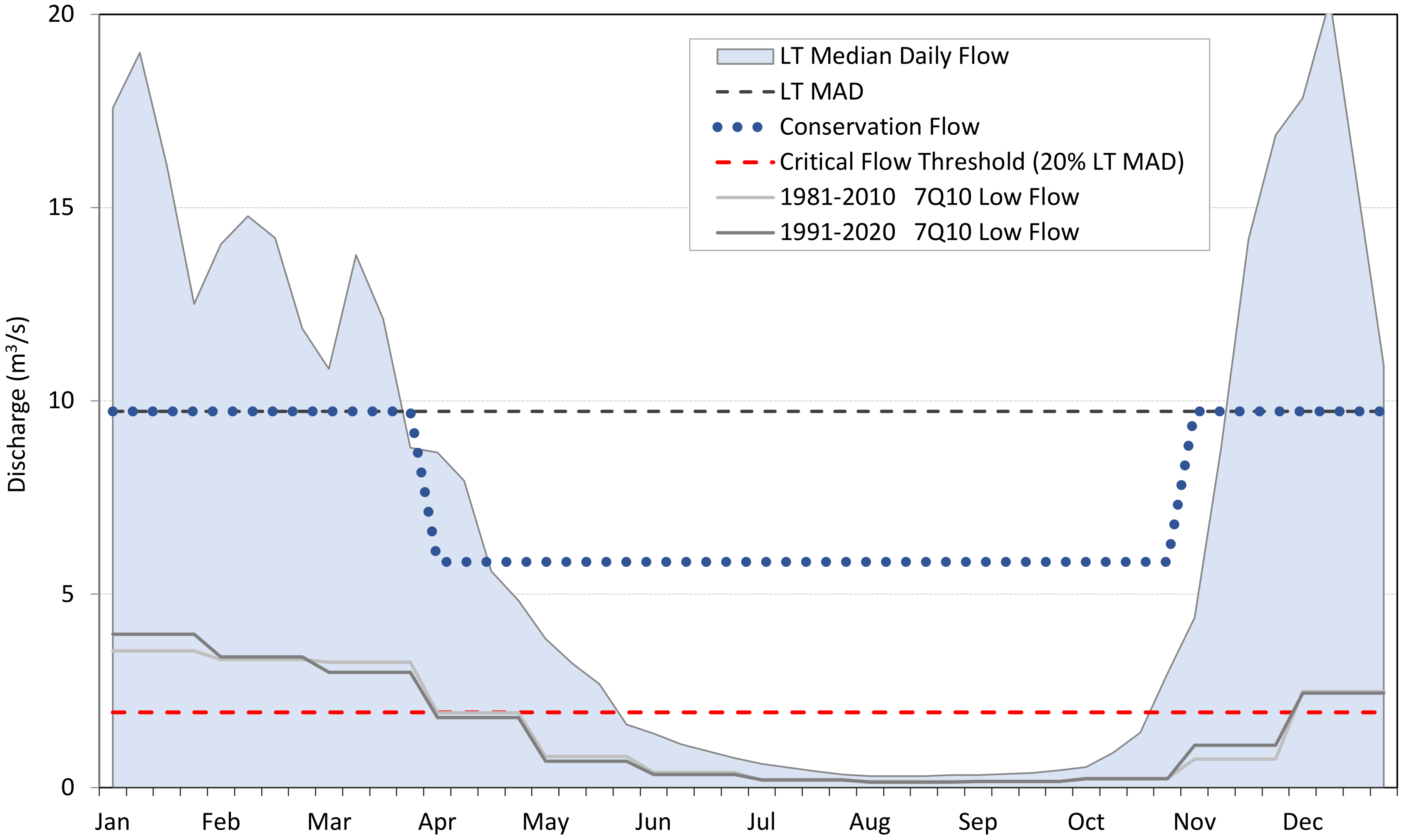


Figure 3-4. Tennant method applied to long-term mean daily flows for the Koksilah River. This Figure shows (i) how Tennant mimics the natural flow regime with optimum thresholds, and (ii) that from June to October flow conditions are well below the Tennent Conservation Flow. LT= long-term.

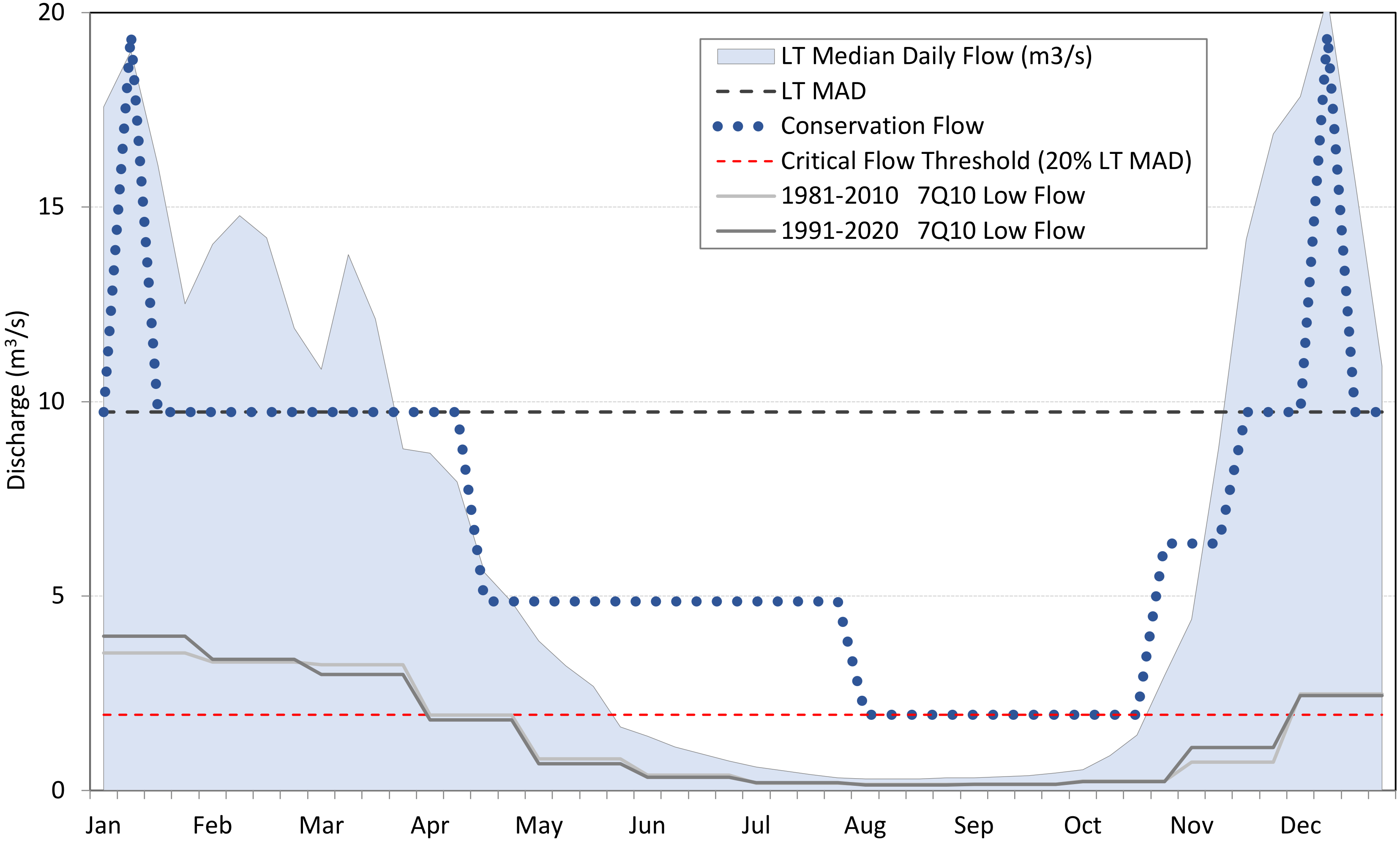


Figure 3-5. BC Modified Tennant method applied to long-term mean daily flows for the Koksilah River. Figure show (i) how the building block approach idealizes flow conditions and (ii) that flow conditions are very low in Koksilah River for much of the summer / autumn.

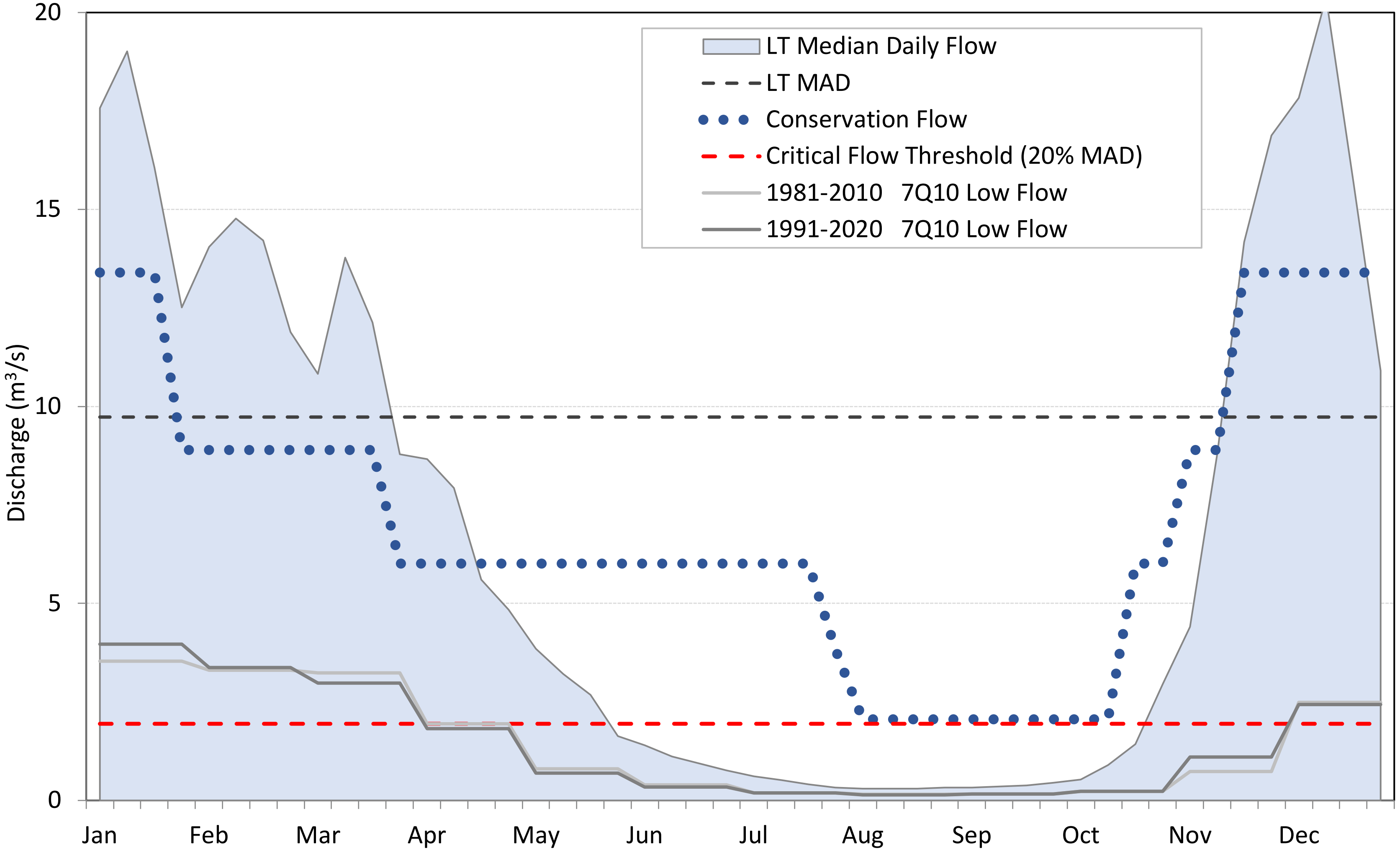


Figure 3-6. BC Desktop method applied to long-term synthetic mean daily flows for the Koksilah River. Figure show (i) how the percentile approach mimics the natural flow regime and (ii) that summer and winter flow conditions are well below the Conservation Flow and Critical Flow thresholds.

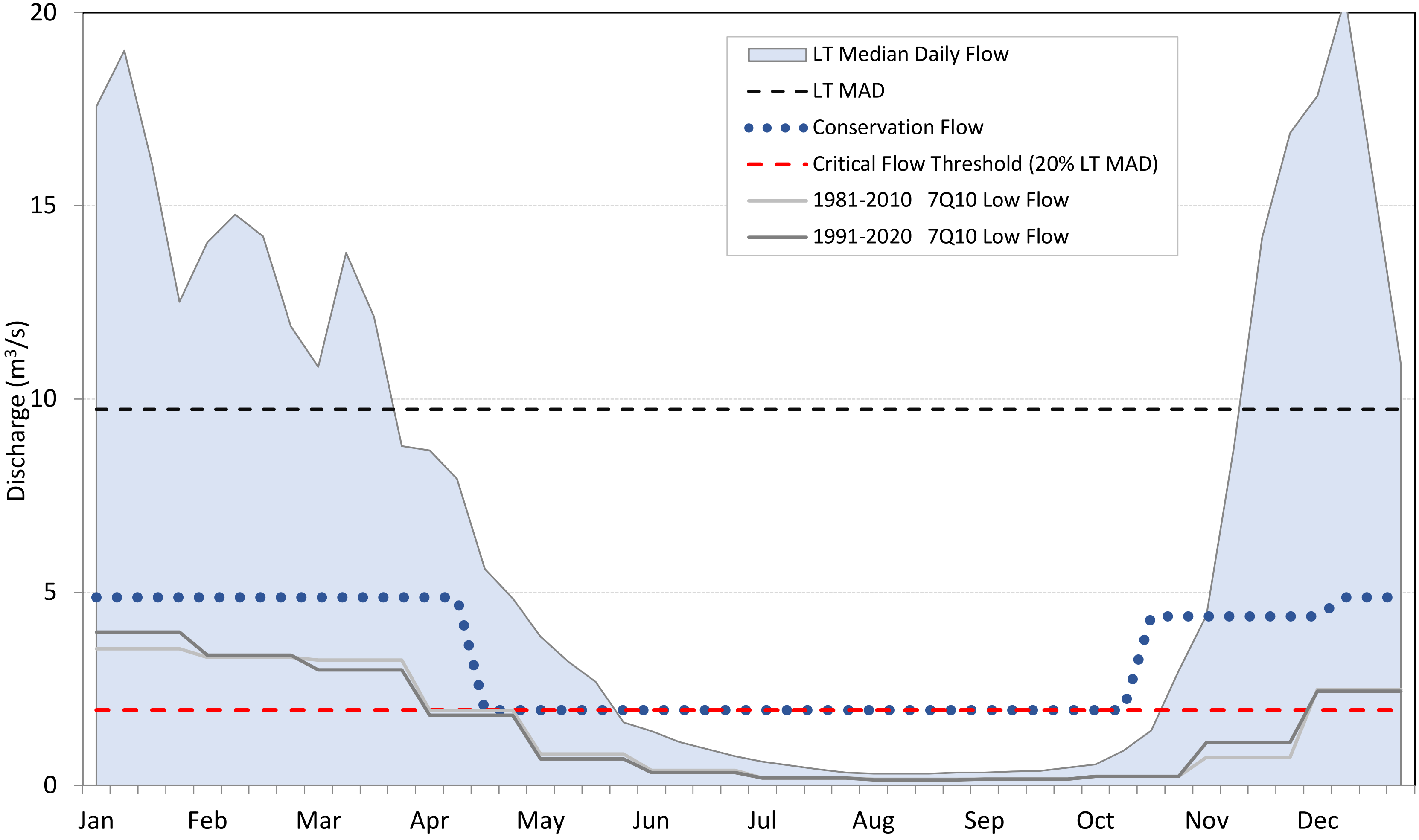


Figure 3-7. Rule of Thumb method applied to long-term mean daily flows for the Koksilah River. Figure show (i) how the Rule of Thumb advocates for spawning flows, and (ii) that summer flow conditions are well below the Conservation Flow and Critical Flow thresholds.

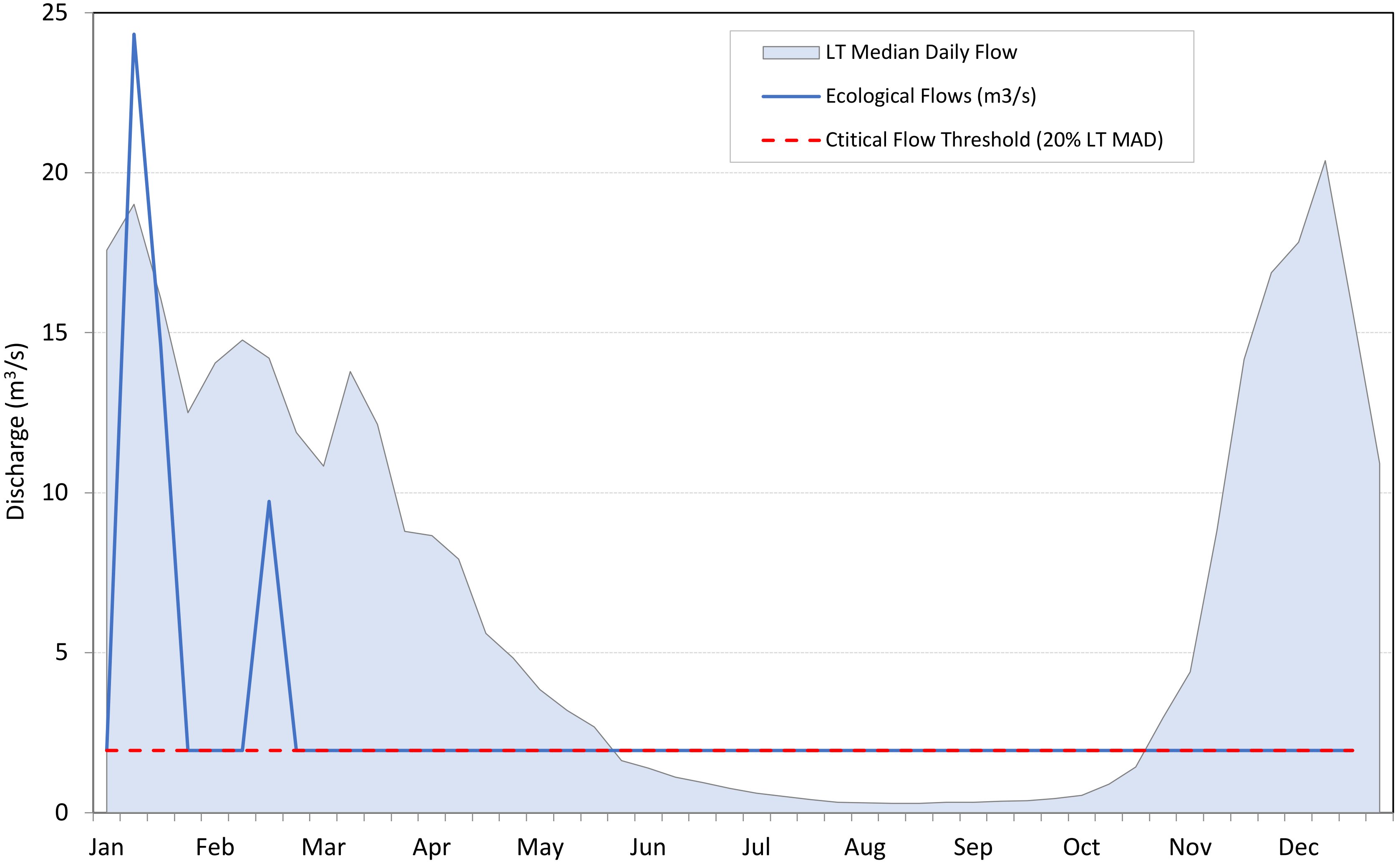


Figure 3-8. Ecological Flows applied to long-term mean daily flows for the Koksilah River. Figure show (i) the importance of channel maintenance flows that rework sediment and nutrients in the stream.

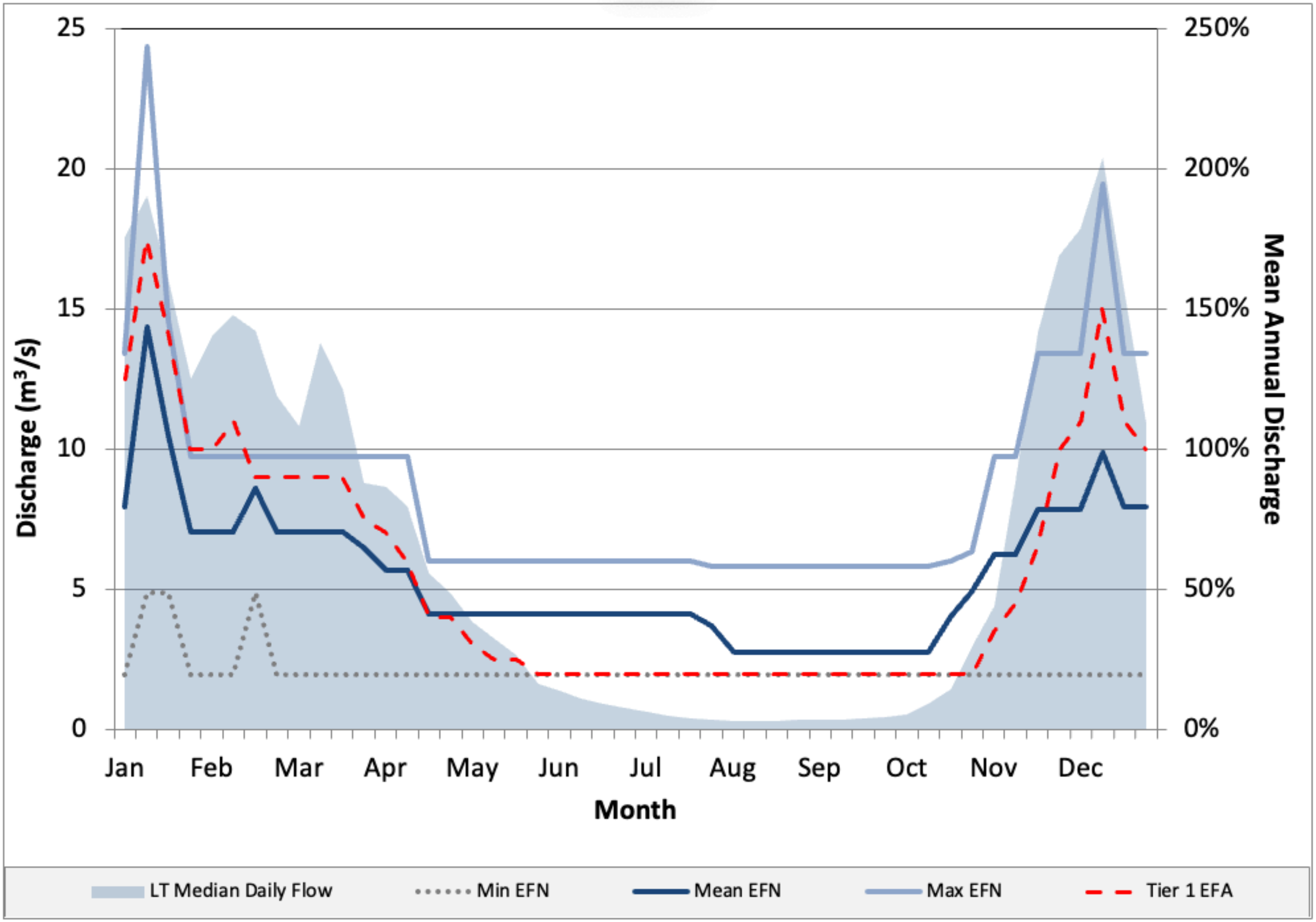


Figure 3-9. EFN applied to long-term mean daily flows for the Koksilah River. Figure shows (i) the min, mean, and max results for idealized/combined method flow to provide the EFN / EW for Chinook, Coho and Steelhead in the Koksilah River.

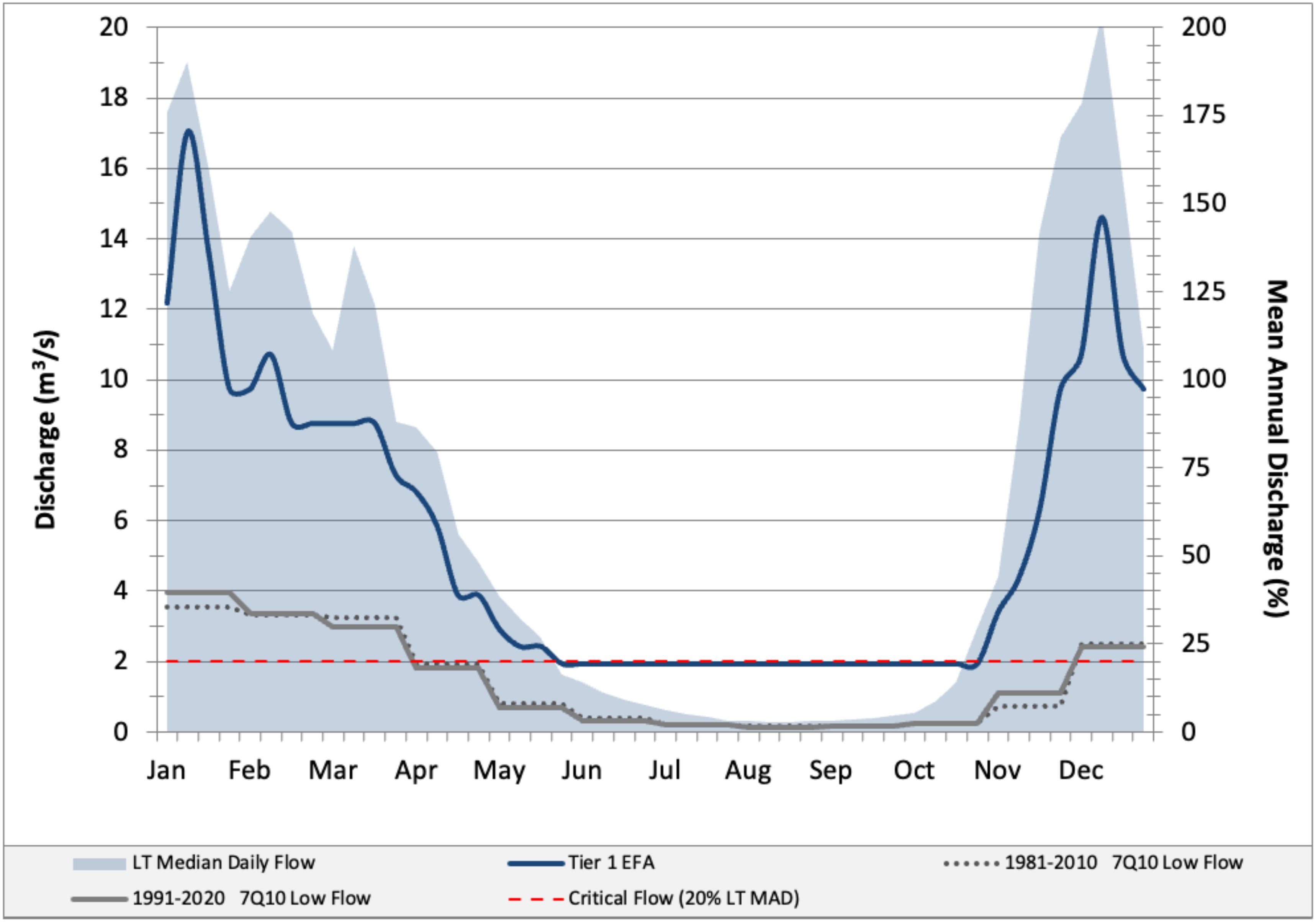


Figure 3-10. Koksilah River Tier 1 EFN applied to long-term mean daily flow and plotted with the long-term 7Q10 and critical flow threshold (20% MAD). Figure shows that flow is well below the EFN and Critical Flow threshold from June to October.

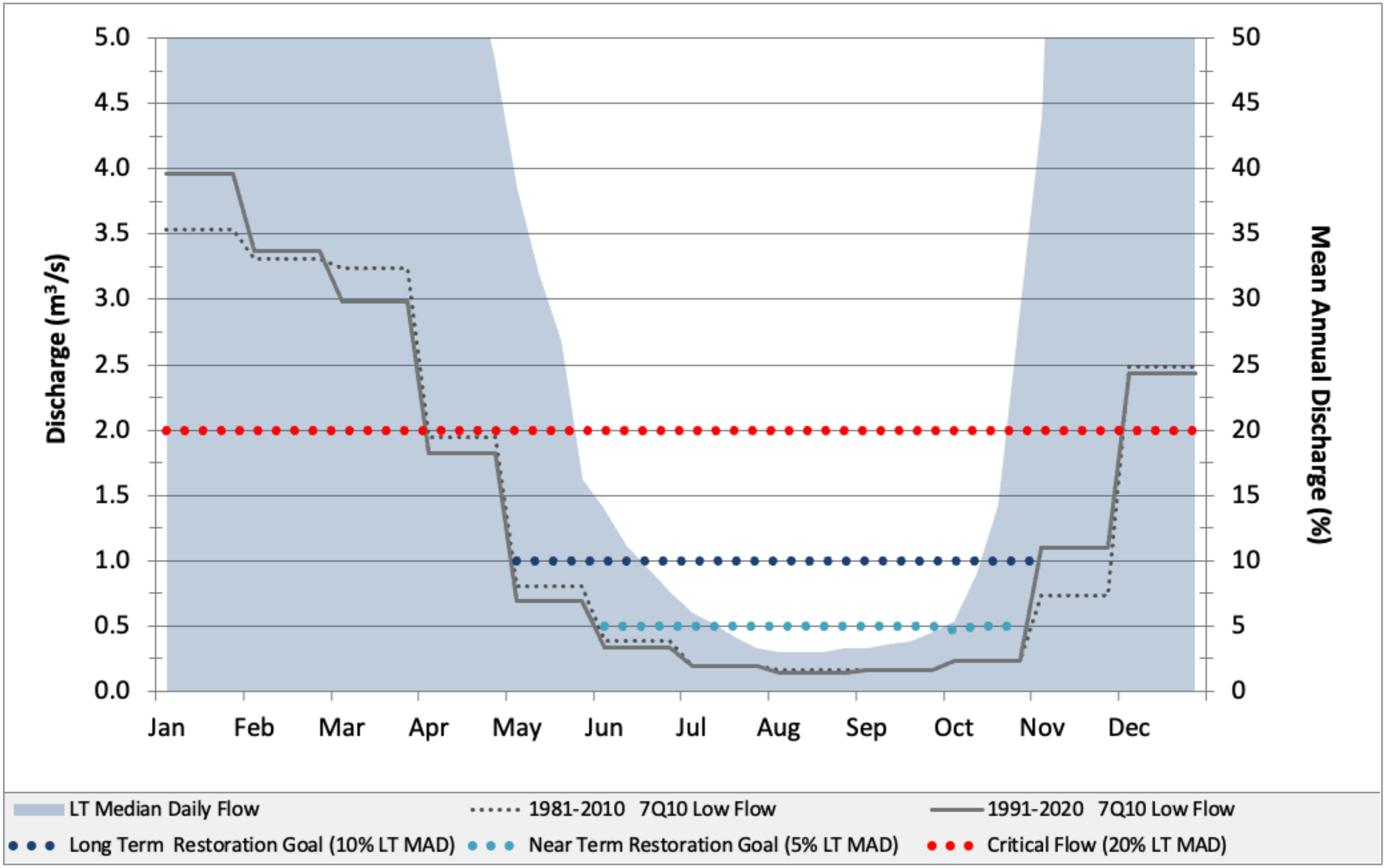


Figure 3-11. Koksilah River Restoration Goals. Figure shows near-term and long-term restoration goals for the Koksilah River which are to increase median daily flow to 5% MAD in the near-term and 10% MAD in the long-term.

Chapter 4 Appendices

Appendix 4A: SEFA Model Calibration

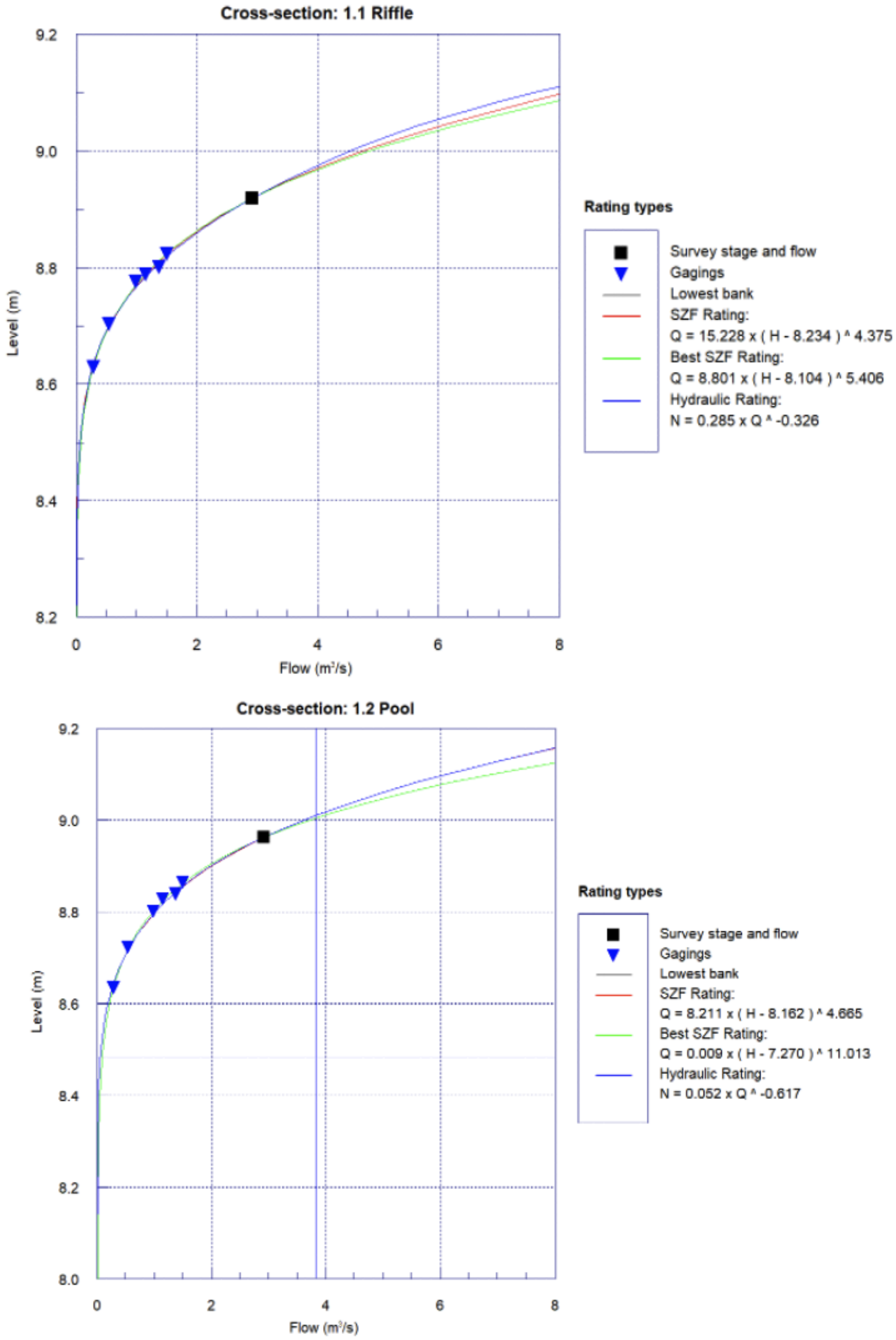
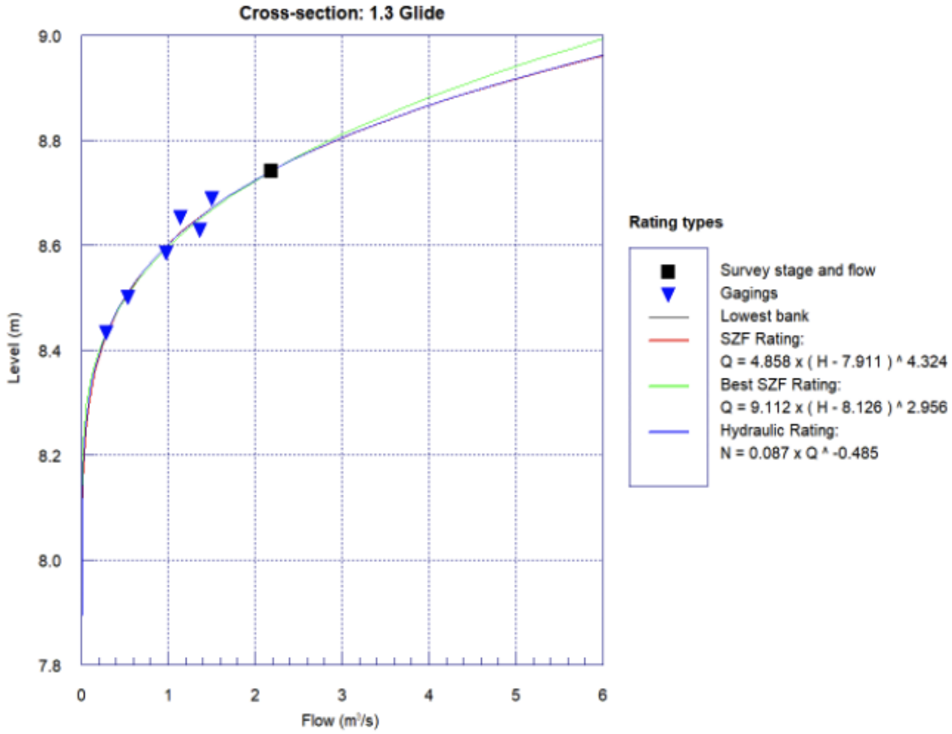


Figure 4 -1. Koksilah River EFA, Rating Curves for Transects 1.1 and 1.2.



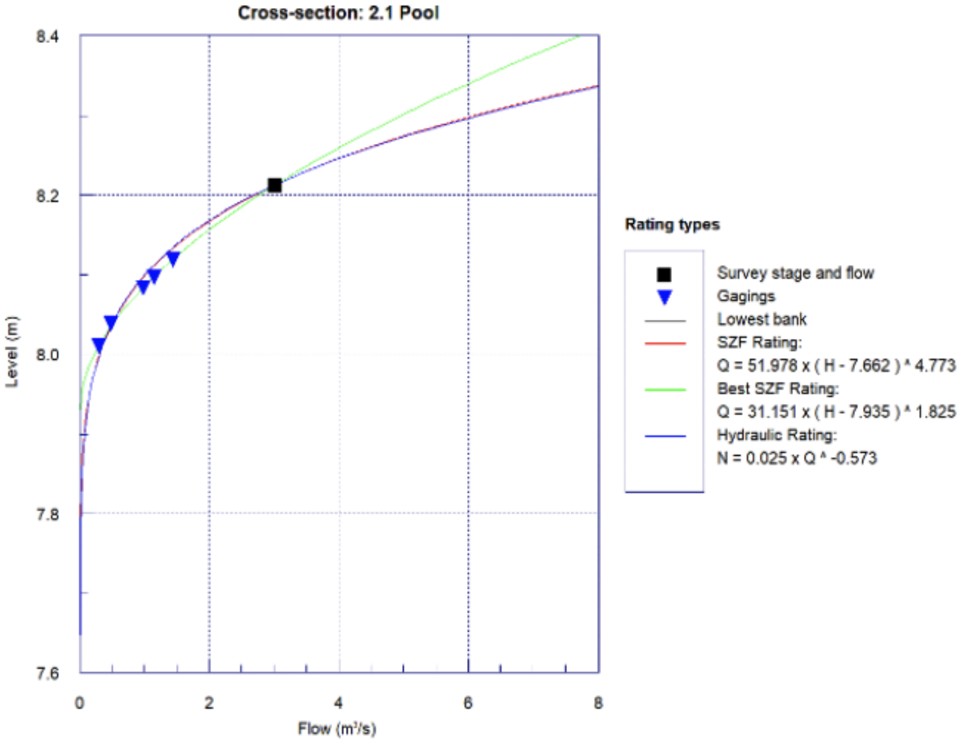


Figure 4-2. Koksilah River EFA, Rating Curves for Transects 1.3 and 2.1.

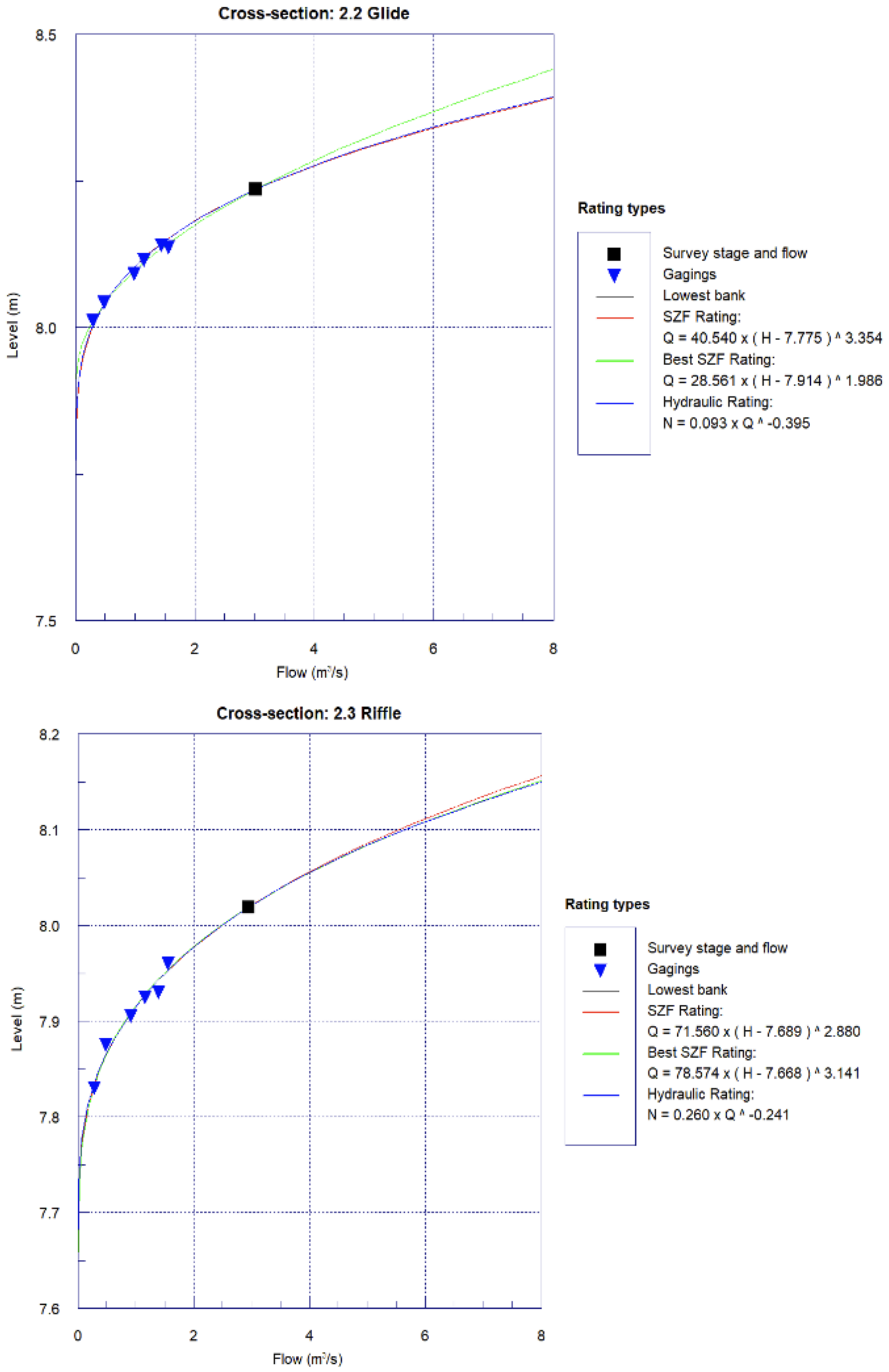


Figure 4-3. Koksilah River EFA, Rating Curves for Transects 2.2 and 2.3.

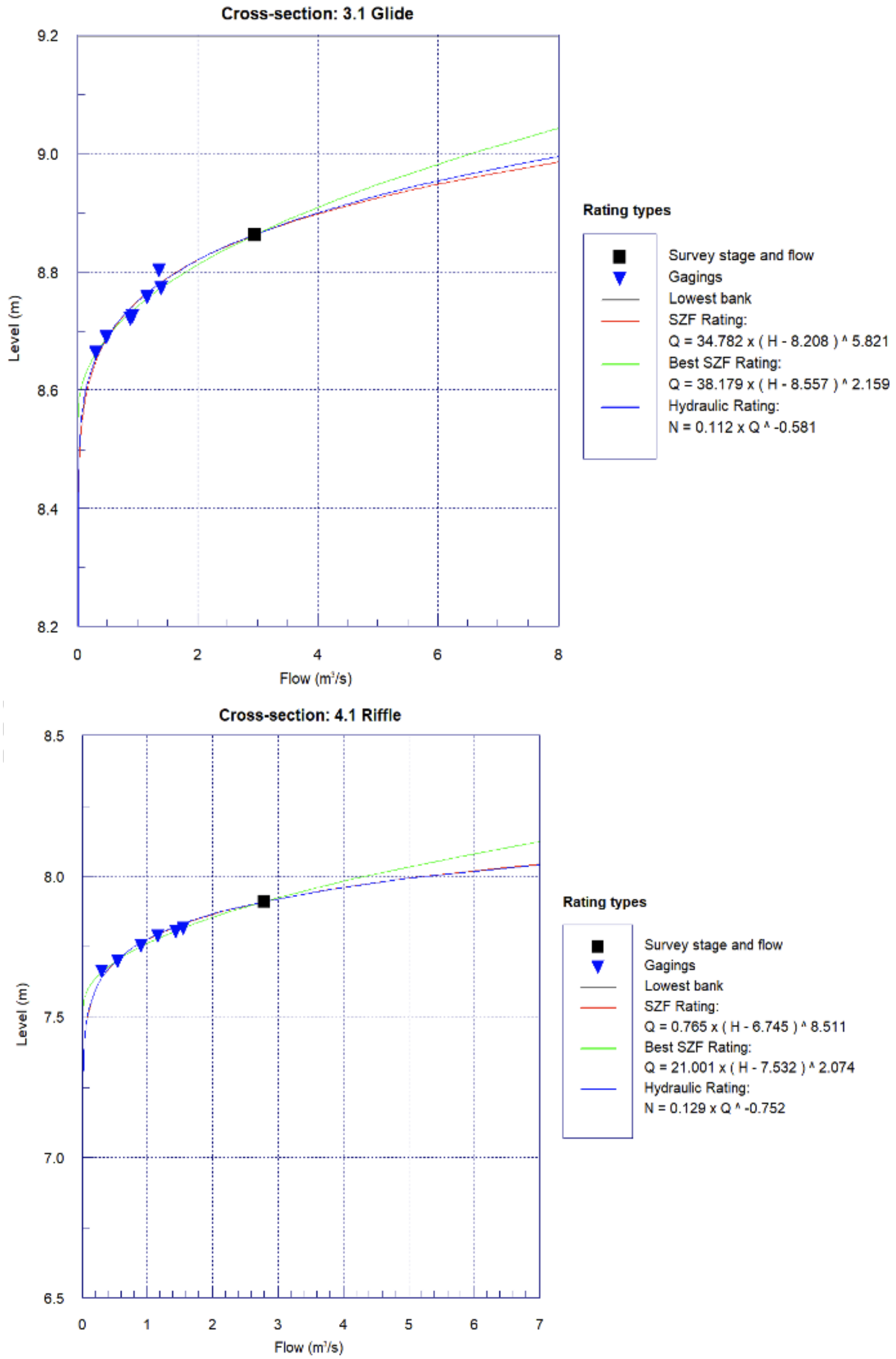


Figure 4-4. Koksilah River EFA, Rating Curves for Transects 3.1 and 4.1.

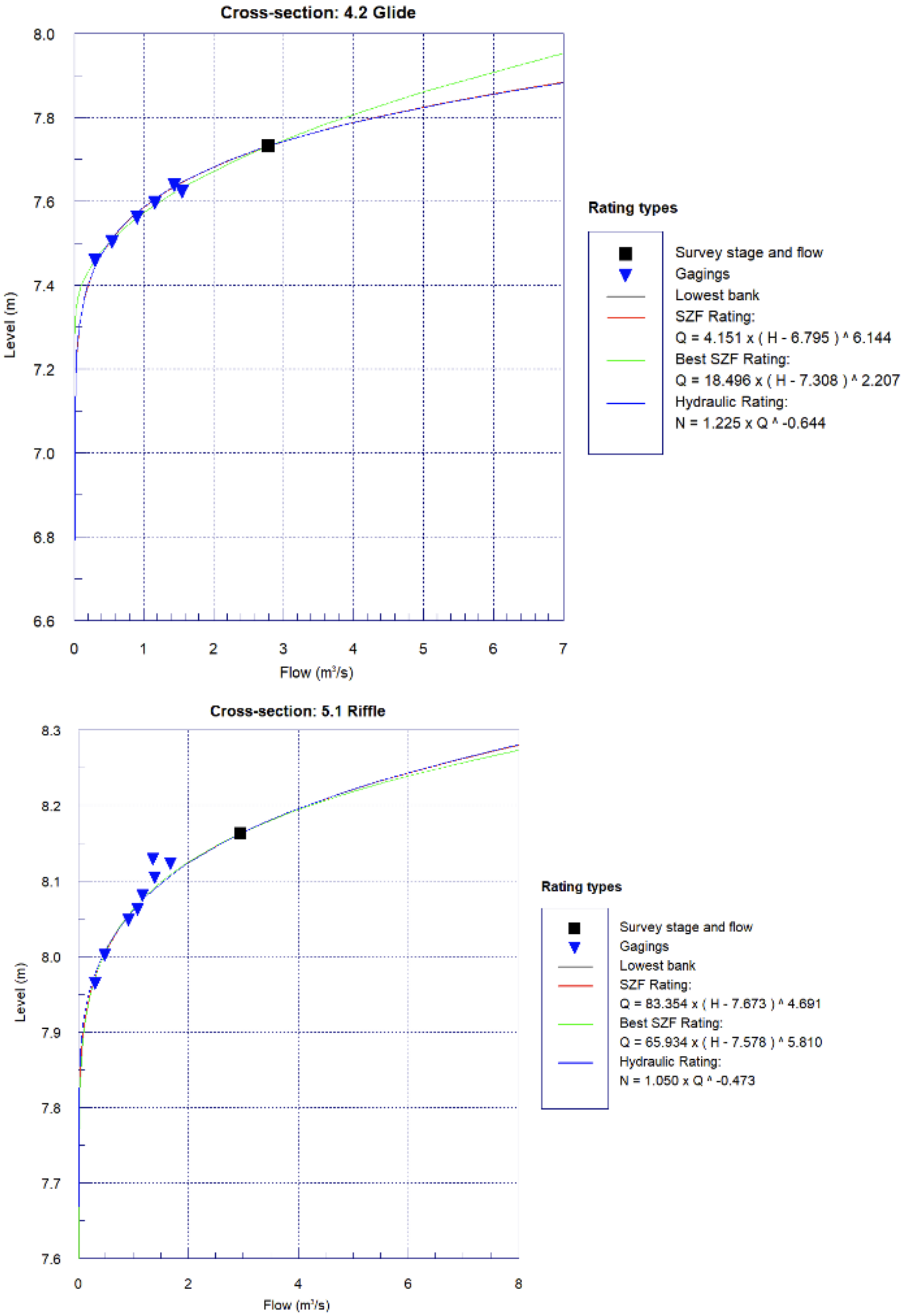


Figure 4-5. Koksilah River EFA, Rating Curves for Transects 4.2 and 5.1.

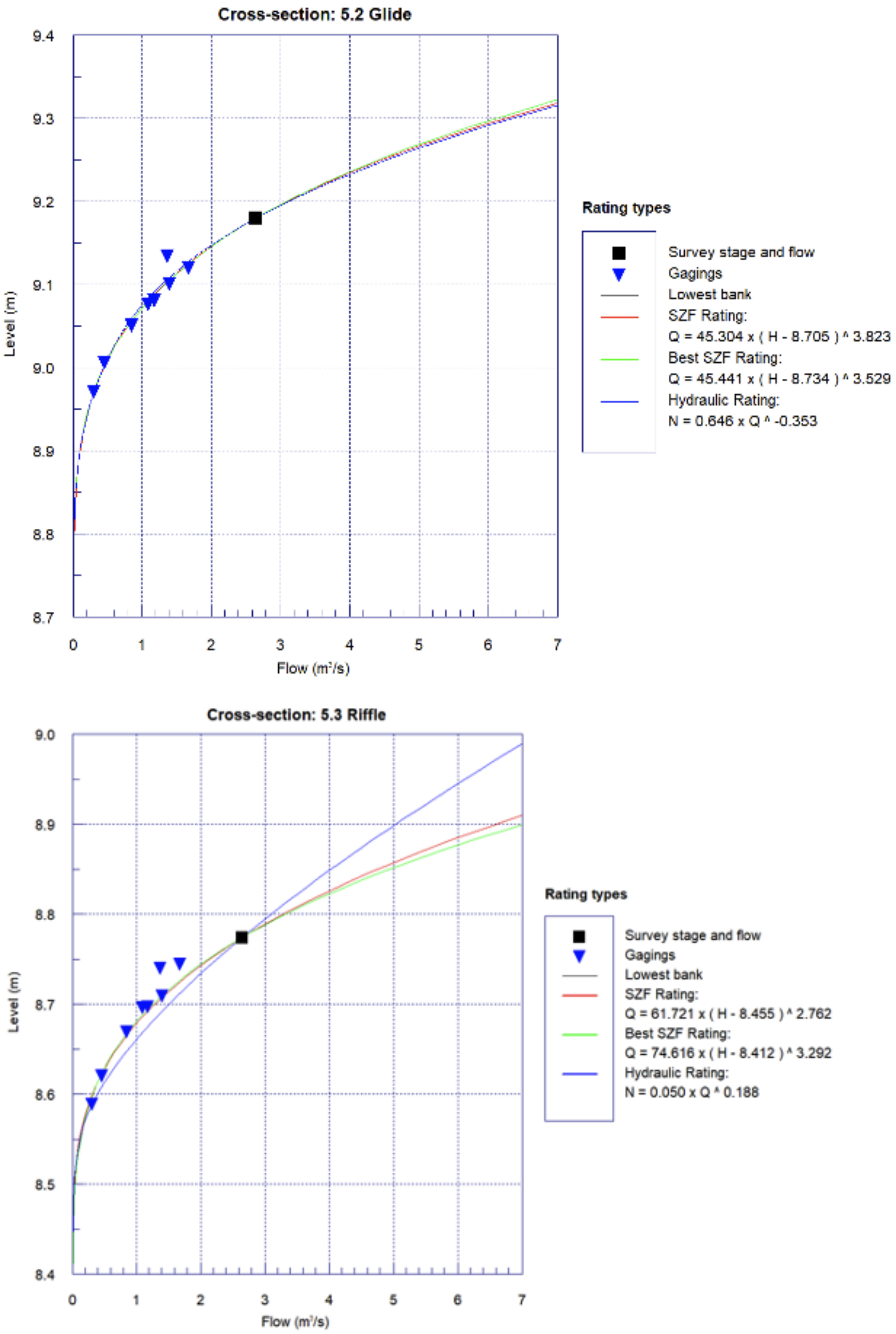


Figure 4-6. Koksilah River EFA, Rating Curves for Transects 5.2 and 5.3.

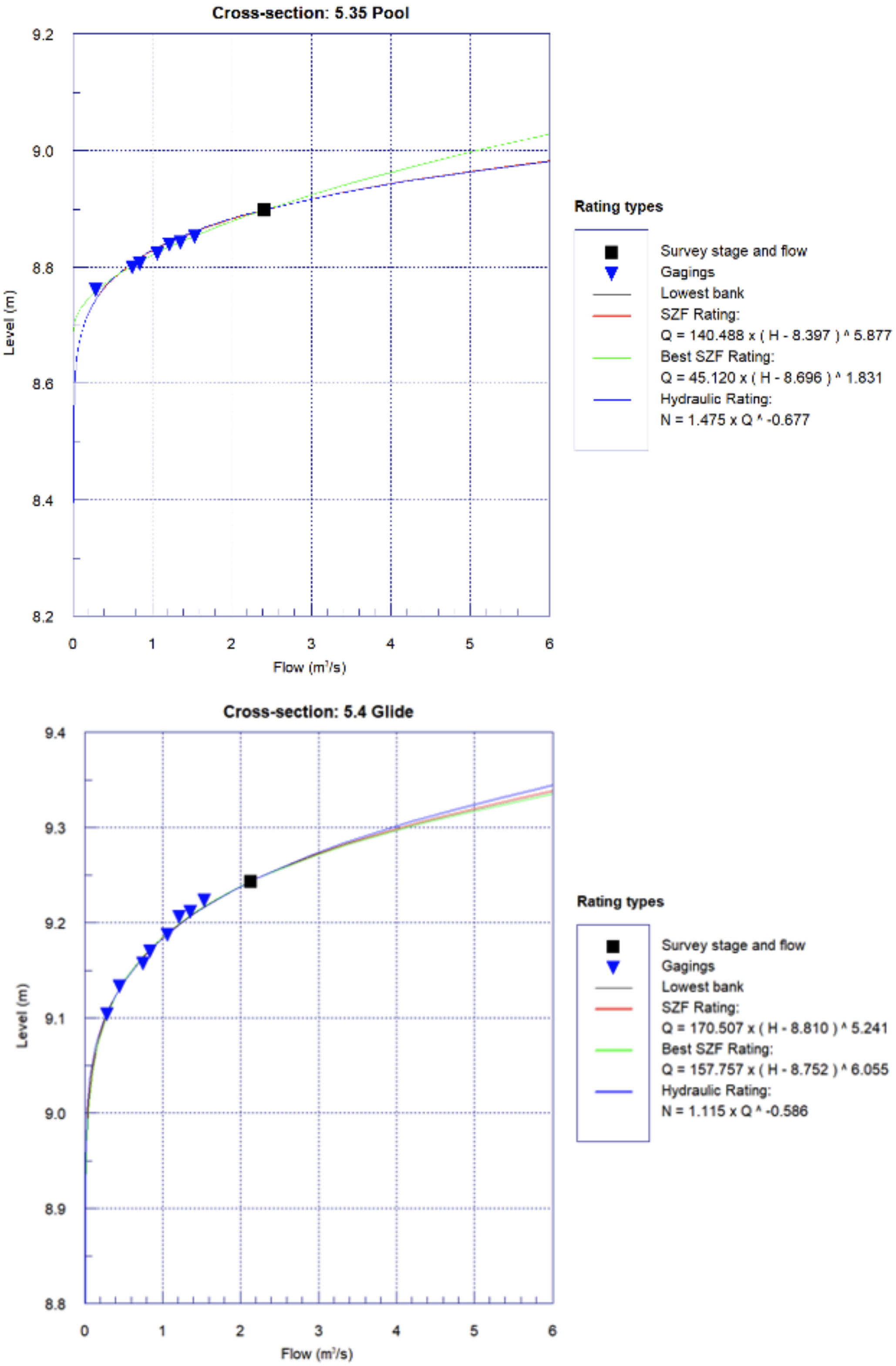


Figure 4-7. Koksilah River EFA, Rating Curves for Transects 5.35 and 5.4.

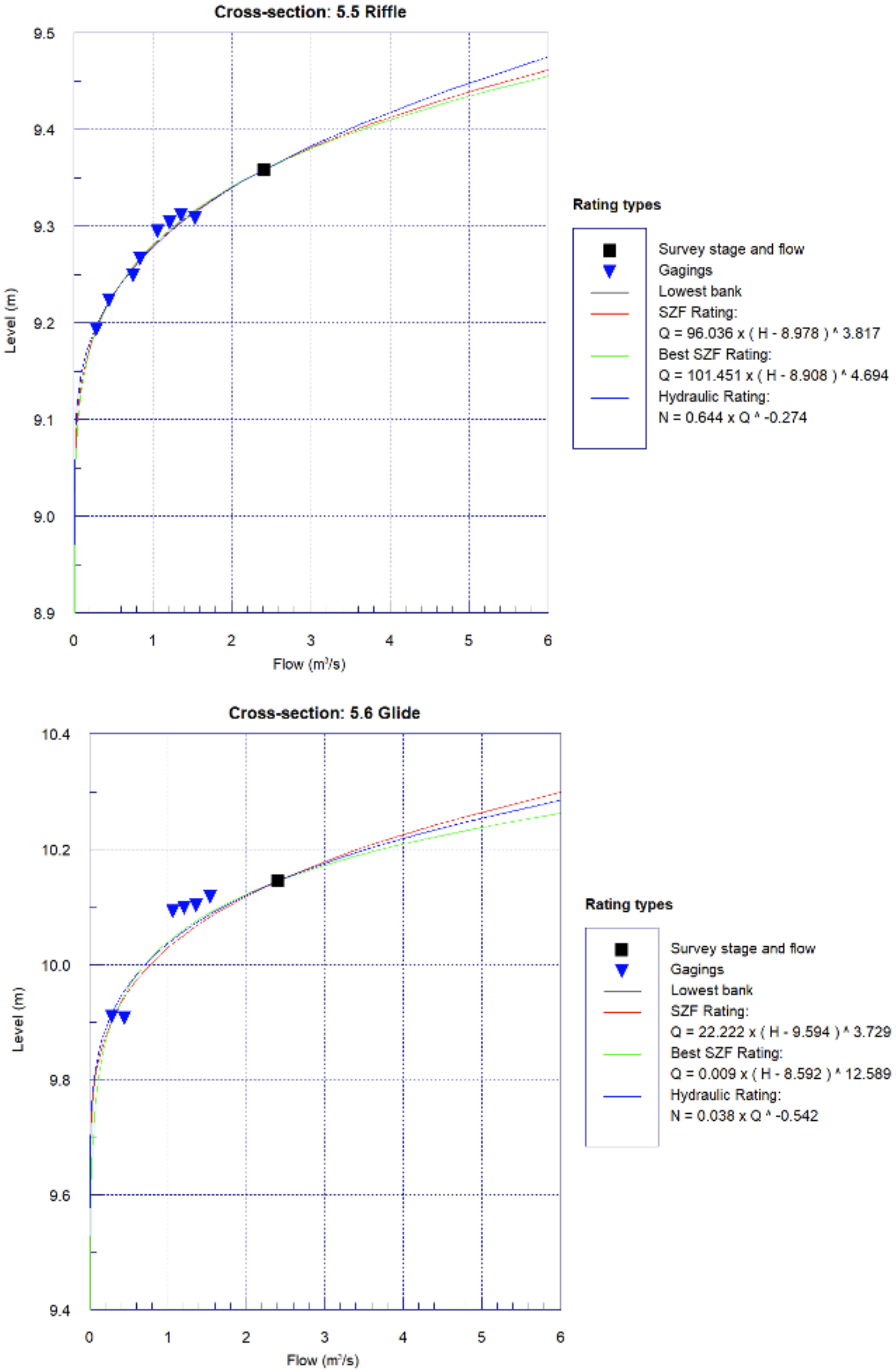


Figure 4-8. Koksilah River EFA, Rating Curves for Transects 5.5 and 5.6.

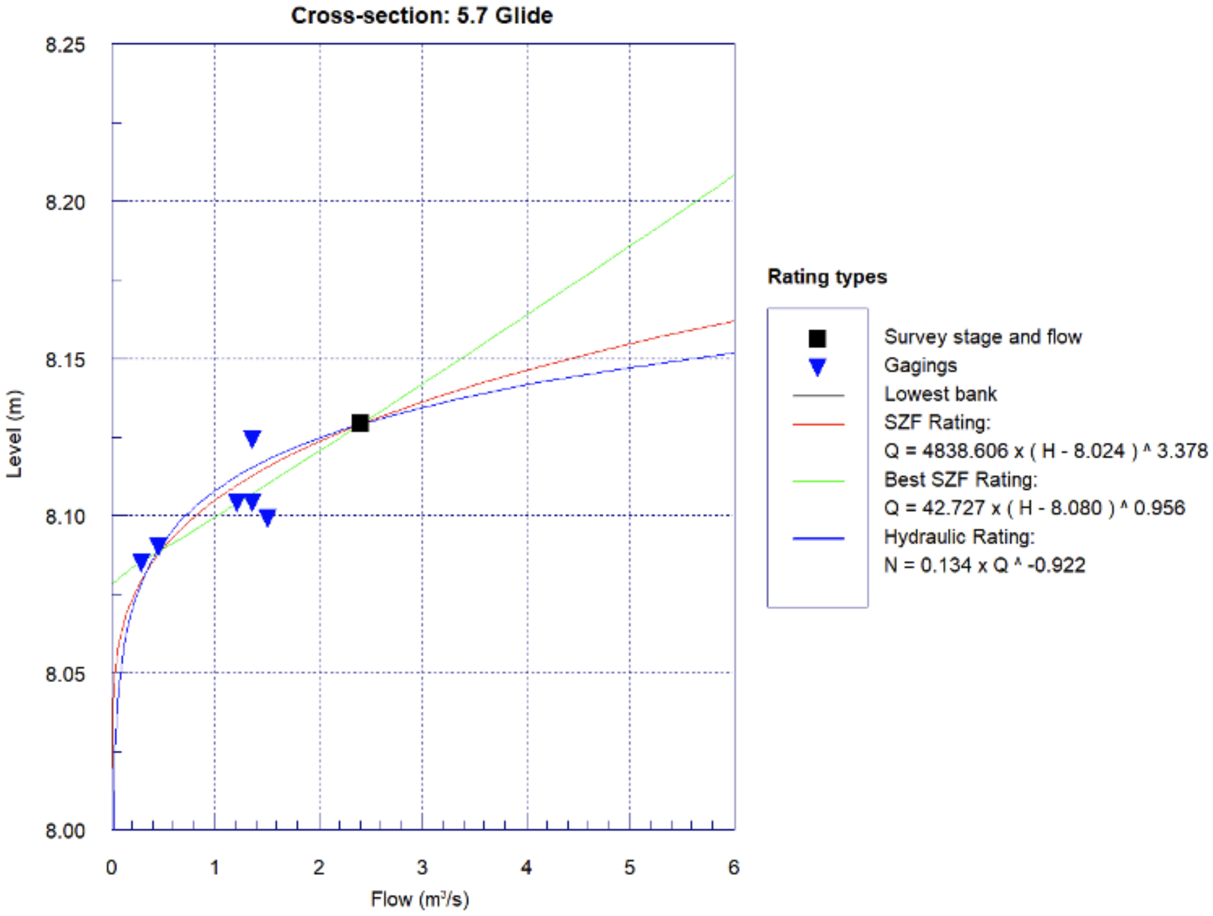


Figure 4-9. Koksilah River EFA, Rating Curve for Transect 5.7.

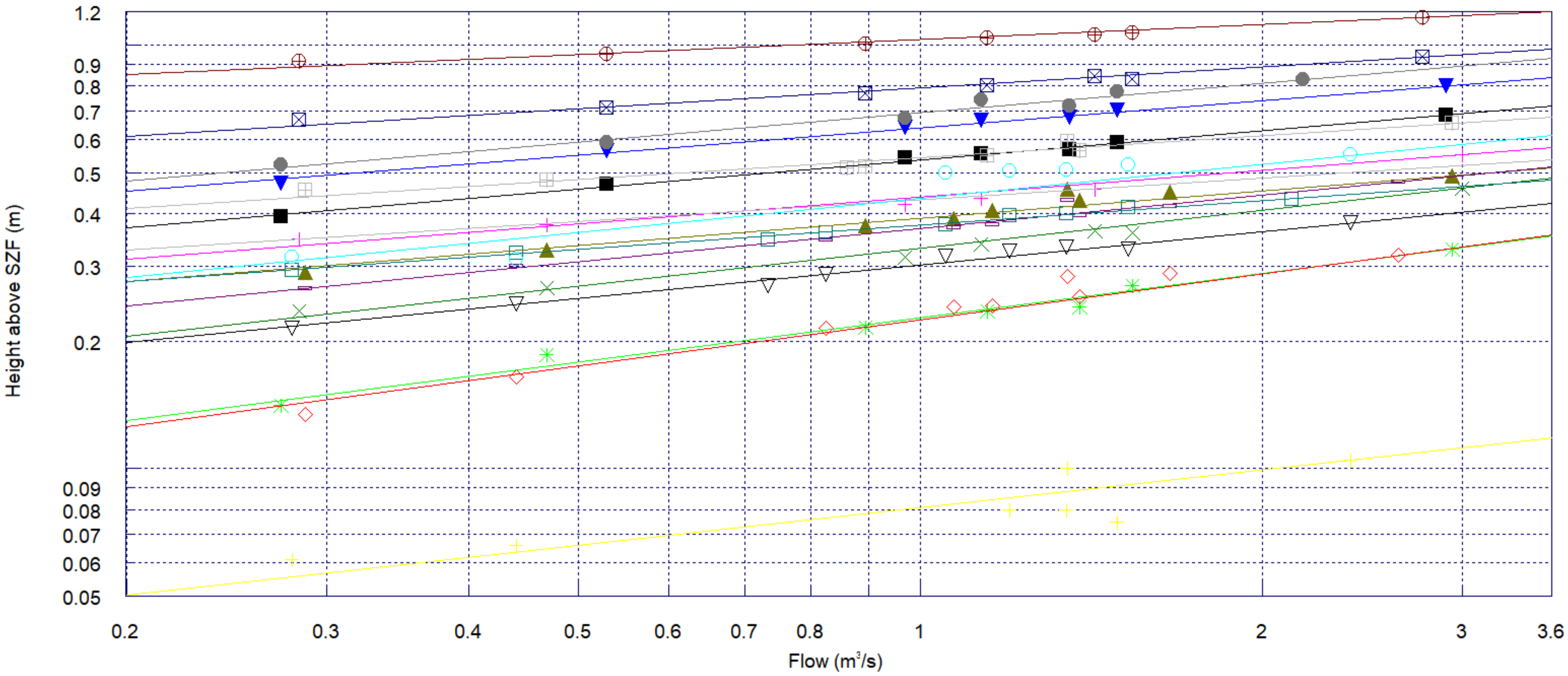


Figure 4-10. Koksilah River EFA, All Ratings.

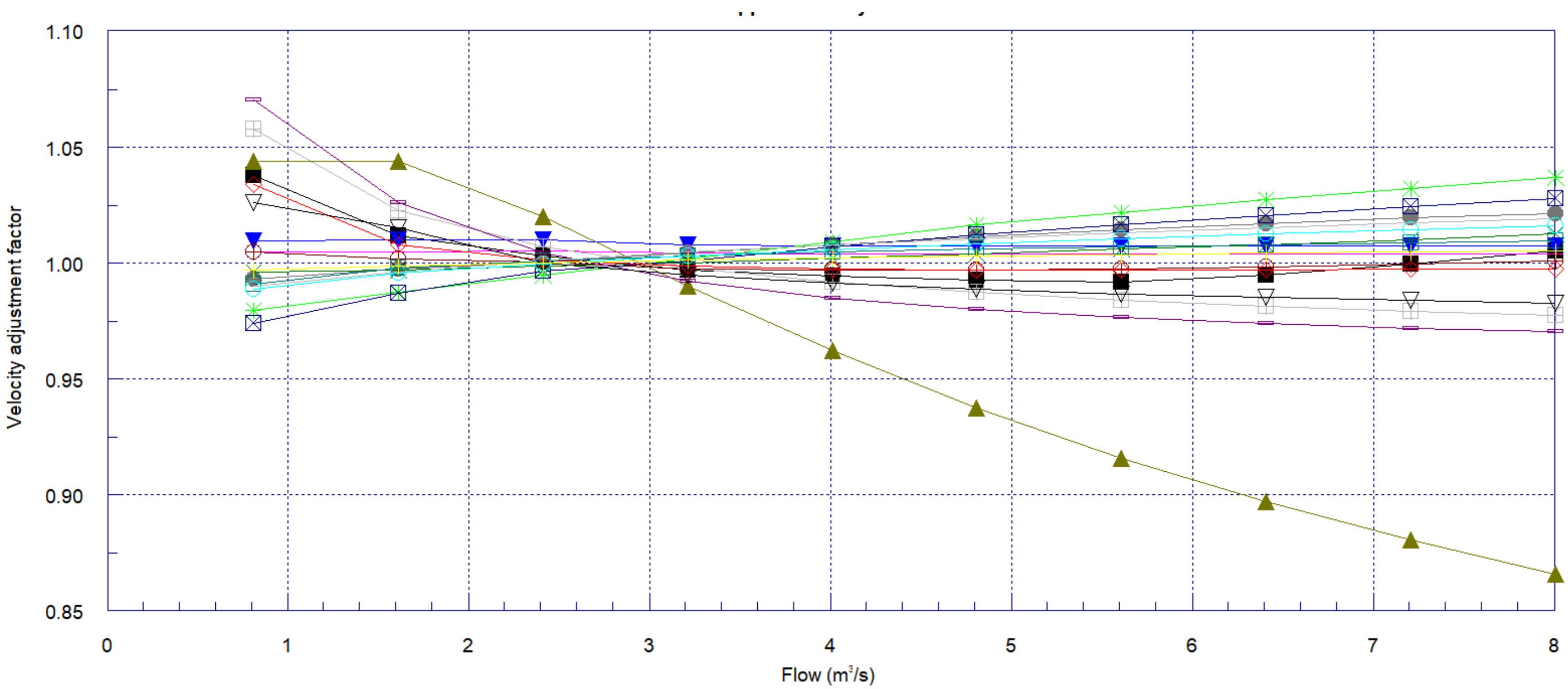
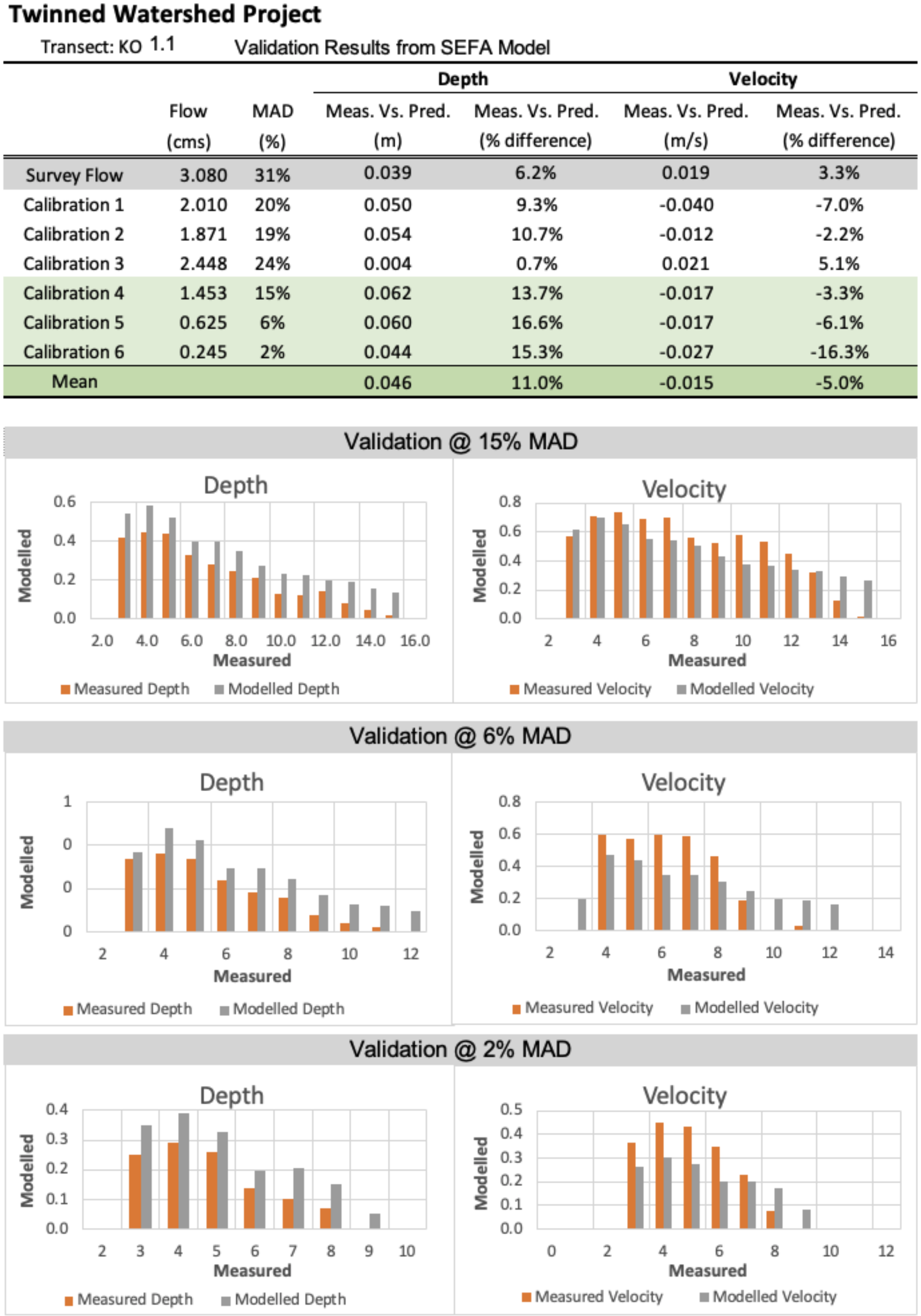


Figure 4-11. Koksilah River EFA, Calibration of Ratings. Figure shows velocity adjustment factors across the range of calibration flows.

Appendix 4B: SEFA Model Validation

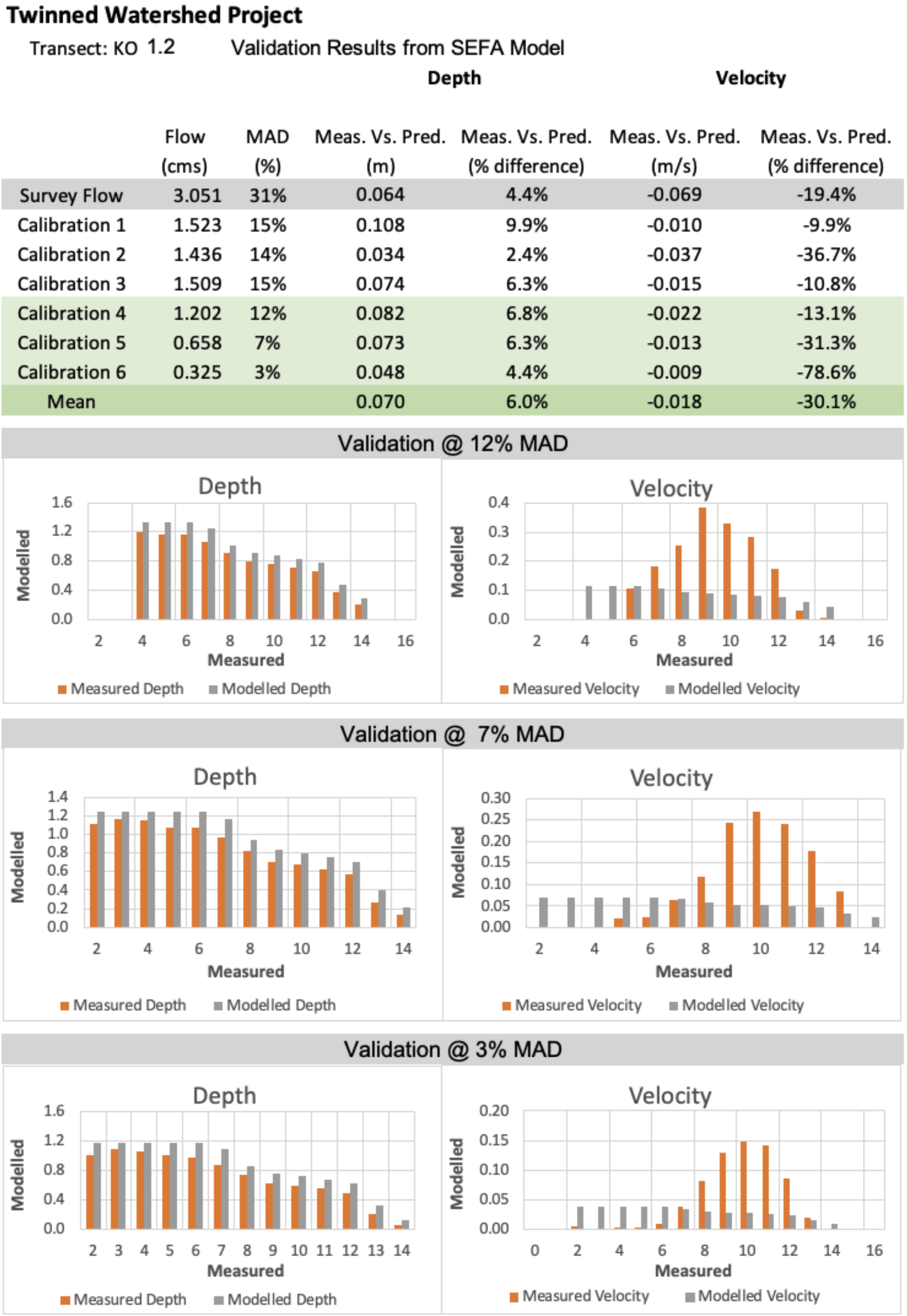


Twinned Watershed Project

Transcript: KO 1.1 Validation Results from SEFA Model

	Flow (cms)	MAD (%)	Depth Meas. Vs. Pred. (m)	Depth Meas. Vs. Pred. (% difference)	Velocity Meas. Vs. Pred. (m/s)	Velocity Meas. Vs. Pred. (% difference)
Survey Flow	3.080	31%	0.039	6.2%	0.019	3.3%
Calibration 1	2.010	20%	0.050	9.3%	-0.040	-7.0%
Calibration 2	1.871	19%	0.054	10.7%	-0.012	-2.2%
Calibration 3	2.448	24%	0.004	0.7%	0.021	5.1%
Calibration 4	1.453	15%	0.062	13.7%	-0.017	-3.3%
Calibration 5	0.625	6%	0.060	16.6%	-0.017	-6.1%
Calibration 6	0.245	2%	0.044	15.3%	-0.027	-16.3%
Mean			0.046	11.0%	-0.015	-5.0%

Figure 4-12. Koksilah River EFA, Validation of SEFA Model Results for Transect 1.1.



Twinned Watershed Project

Transcect: KO 1.2 Validation Results from SEFA Model

	Flow (cms)	MAD (%)	Depth Meas. Vs. Pred. (m)	Depth Meas. Vs. Pred. (% difference)	Velocity Meas. Vs. Pred. (m/s)	Velocity Meas. Vs. Pred. (% difference)
Survey Flow	3.051	31%	0.064	4.4%	-0.069	-19.4%
Calibration 1	1.523	15%	0.108	9.9%	-0.010	-9.9%
Calibration 2	1.436	14%	0.034	2.4%	-0.037	-36.7%
Calibration 3	1.509	15%	0.074	6.3%	-0.015	-10.8%
Calibration 4	1.202	12%	0.082	6.8%	-0.022	-13.1%
Calibration 5	0.658	7%	0.073	6.3%	-0.013	-31.3%
Calibration 6	0.325	3%	0.048	4.4%	-0.009	-78.6%
Mean			0.070	6.0%	-0.018	-30.1%

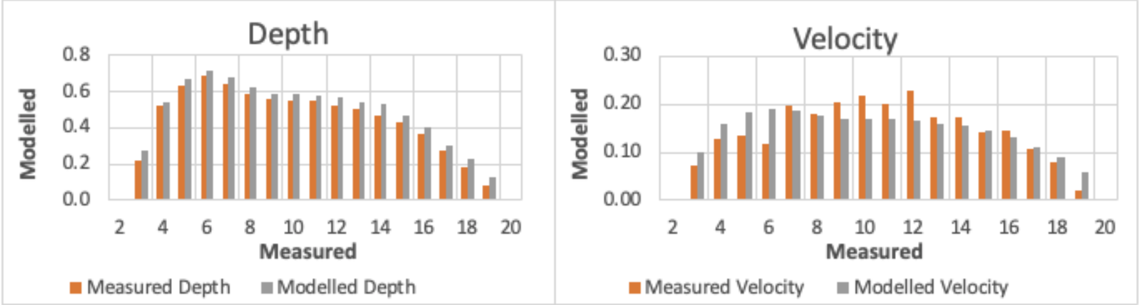
Figure 4-13. Koksilah River EFA, Validation of SEFA Model Results for Transect 1.2.

Twinned Watershed Project

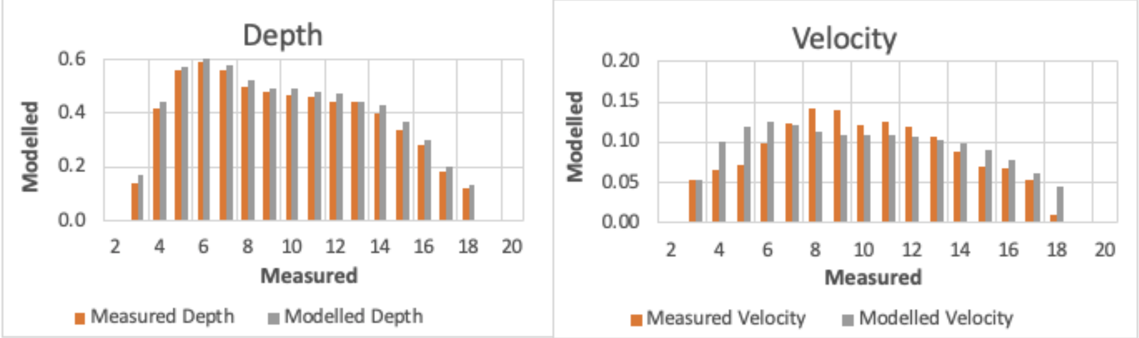
Transcript: KO 1.3 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.367	24%	0.027	3.3%	0.019	10.4%
Calibration 1	1.350	14%	0.029	4.2%	0.007	5.6%
Calibration 2	1.430	14%	0.033	4.7%	0.010	7.5%
Calibration 3	1.113	11%	0.027	3.9%	0.007	5.5%
Calibration 4	0.576	6%	0.017	2.9%	0.007	10.0%
Calibration 5	0.257	3%	0.008	1.6%	0.004	10.0%
Mean			0.023	3.5%	0.007	7.7%

Validation @ 11% MAD



Validation @ 6% MAD



Validation @ 3% MAD

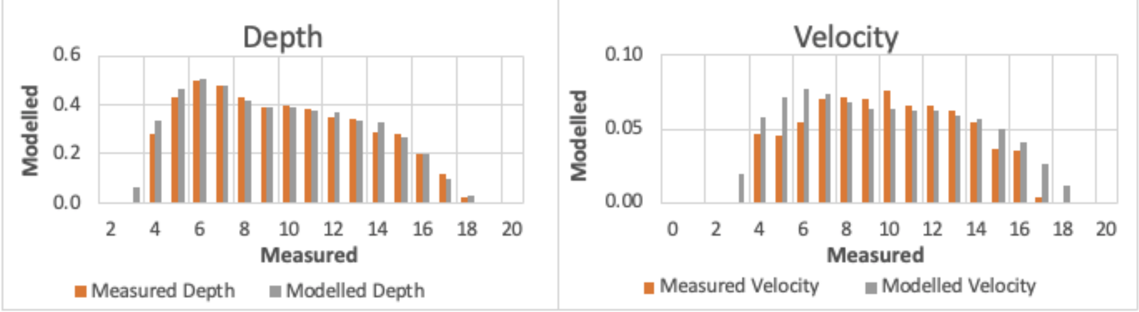
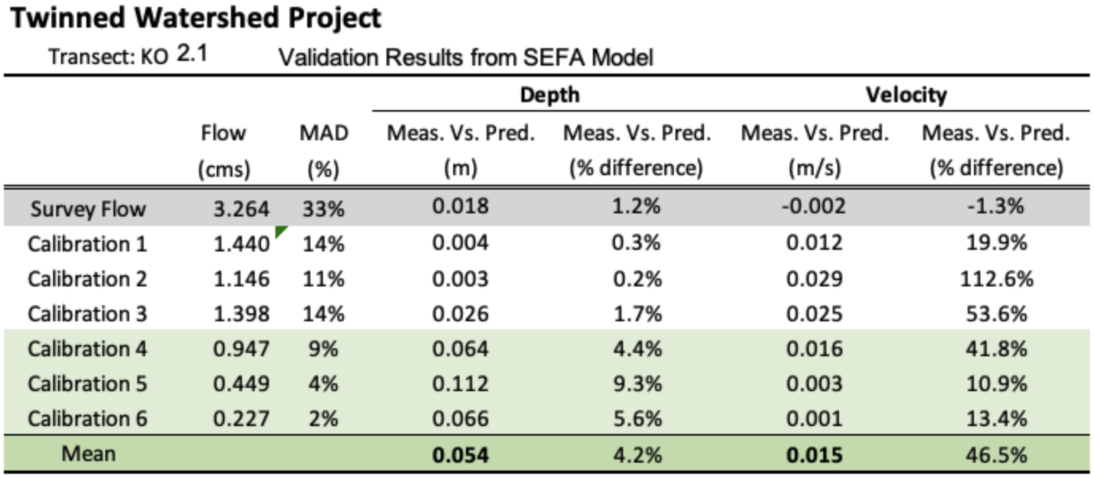


Figure 4-14 Koksilah River EFA, Validation of SEFA Model Results for Transect 1.3.



Twinned Watershed Project

Transcect: KO 2.1 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	3.264	33%	0.018	1.2%	-0.002	-1.3%
Calibration 1	1.440	14%	0.004	0.3%	0.012	19.9%
Calibration 2	1.146	11%	0.003	0.2%	0.029	112.6%
Calibration 3	1.398	14%	0.026	1.7%	0.025	53.6%
Calibration 4	0.947	9%	0.064	4.4%	0.016	41.8%
Calibration 5	0.449	4%	0.112	9.3%	0.003	10.9%
Calibration 6	0.227	2%	0.066	5.6%	0.001	13.4%
Mean			**0.054**	4.2%	**0.015**	46.5%

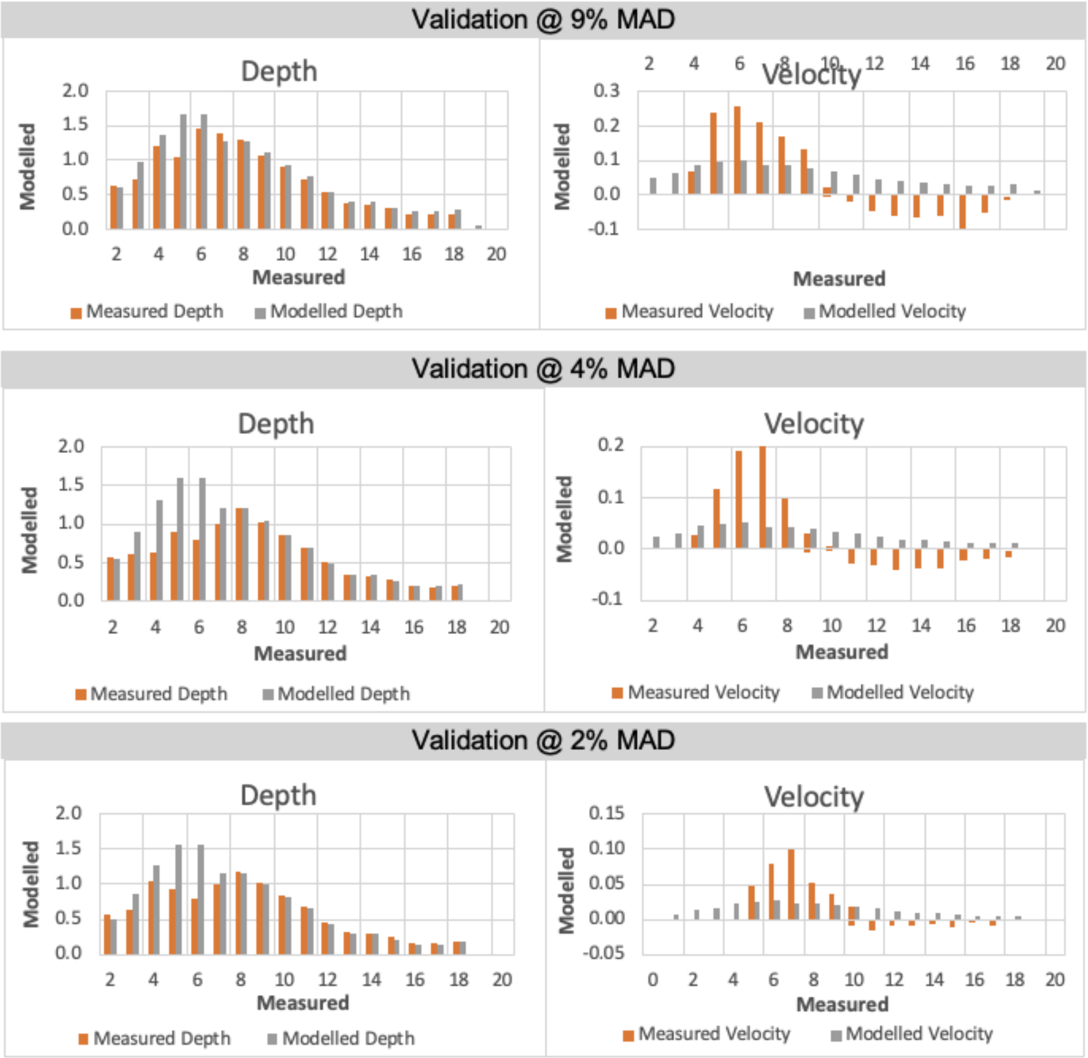
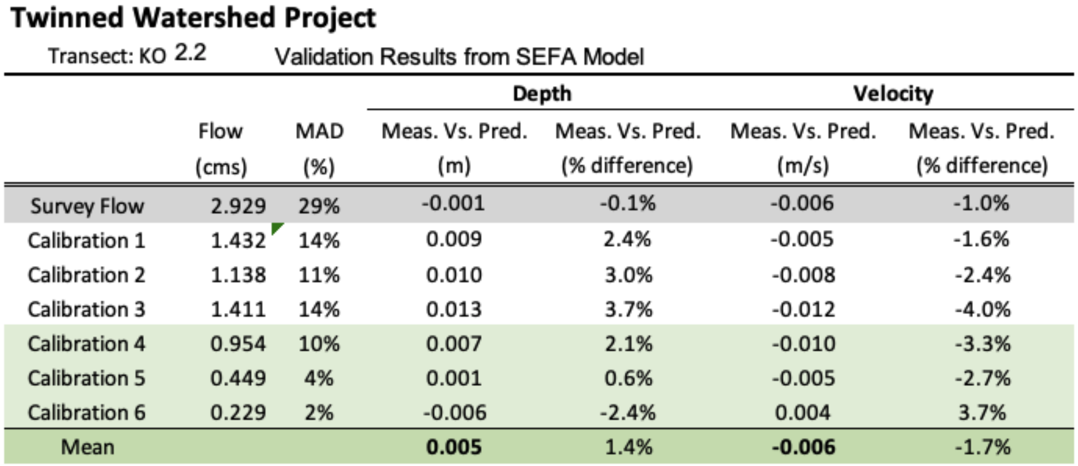


Figure 4-15. Koksilah River EFA, Validation of SEFA Model Results for Transect 2.1.



Twinned Watershed Project

Transcript: KO 2.2 Validation Results from SEFA Model

	Flow (cms)	MAD (%)	Depth Meas. Vs. Pred. (m)	Depth Meas. Vs. Pred. (% difference)	Velocity Meas. Vs. Pred. (m/s)	Velocity Meas. Vs. Pred. (% difference)
Survey Flow	2.929	29%	-0.001	-0.1%	-0.006	-1.0%
Calibration 1	1.432	14%	0.009	2.4%	-0.005	-1.6%
Calibration 2	1.138	11%	0.010	3.0%	-0.008	-2.4%
Calibration 3	1.411	14%	0.013	3.7%	-0.012	-4.0%
Calibration 4	0.954	10%	0.007	2.1%	-0.010	-3.3%
Calibration 5	0.449	4%	0.001	0.6%	-0.005	-2.7%
Calibration 6	0.229	2%	-0.006	-2.4%	0.004	3.7%
Mean			**0.005**	1.4%	**-0.006**	-1.7%

Figure 4-16. Koksilah River EFA, Validation of SEFA Model Results for Transect 2.2.

Twinned Watershed Project

Transect: KO 2.3 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.498	25%	-0.360	-100.0%	-1.307	-100.0%
Calibration 1	1.544	15%	-0.015	-5.3%	-0.108	-13.3%
Calibration 2	1.364	14%	-0.002	-0.7%	-0.049	-6.8%
Calibration 3	1.540	15%	-0.007	-2.3%	-0.032	-4.5%
Calibration 4	0.932	9%	-0.016	-6.2%	-0.005	-0.9%
Calibration 5	0.520	5%	-0.013	-6.2%	-0.032	-8.0%
Calibration 6	0.253	3%	-0.003	-1.7%	-0.004	-1.9%
Mean			**-0.008**	-3.4%	**-0.024**	-4.4%

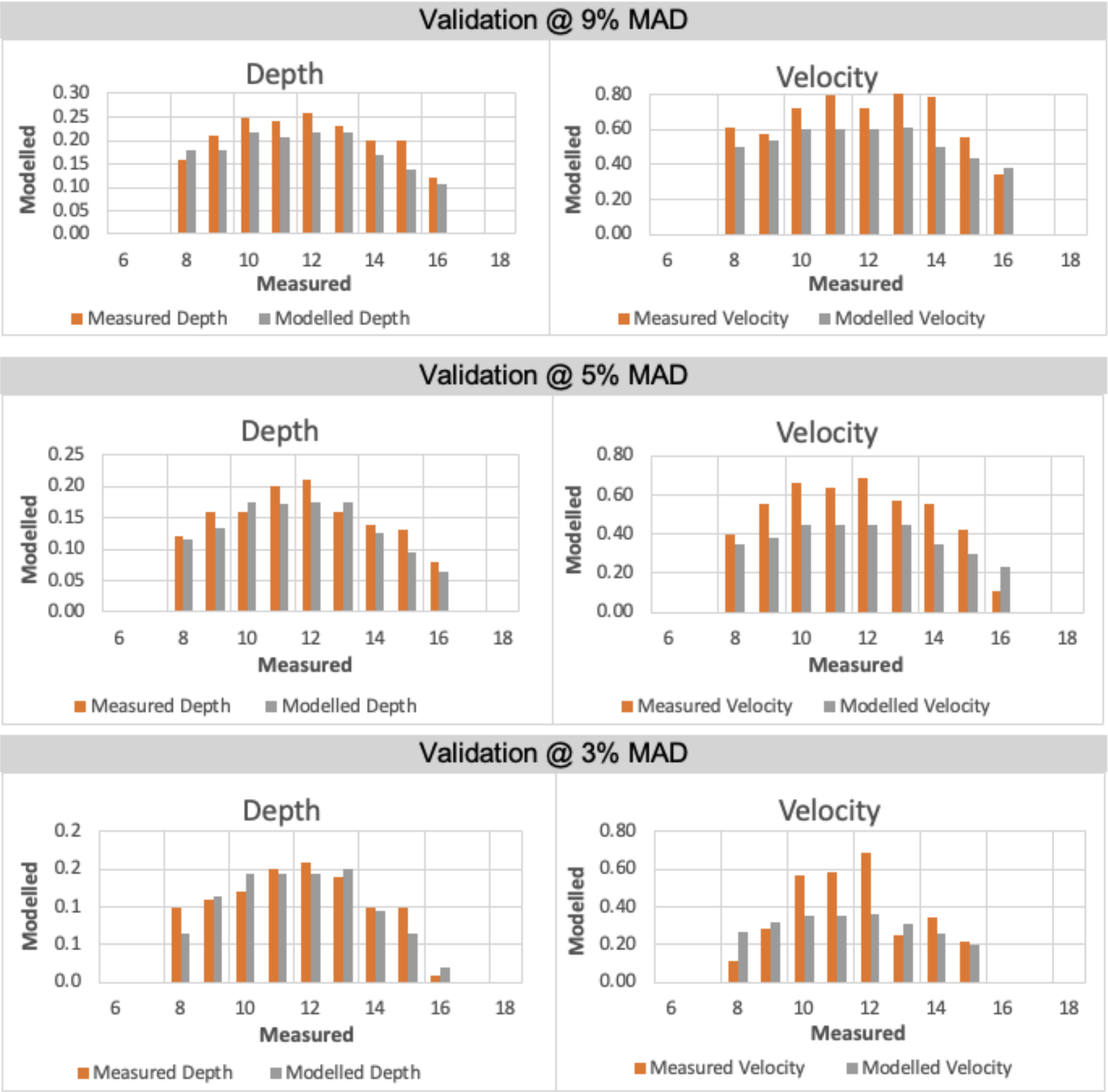
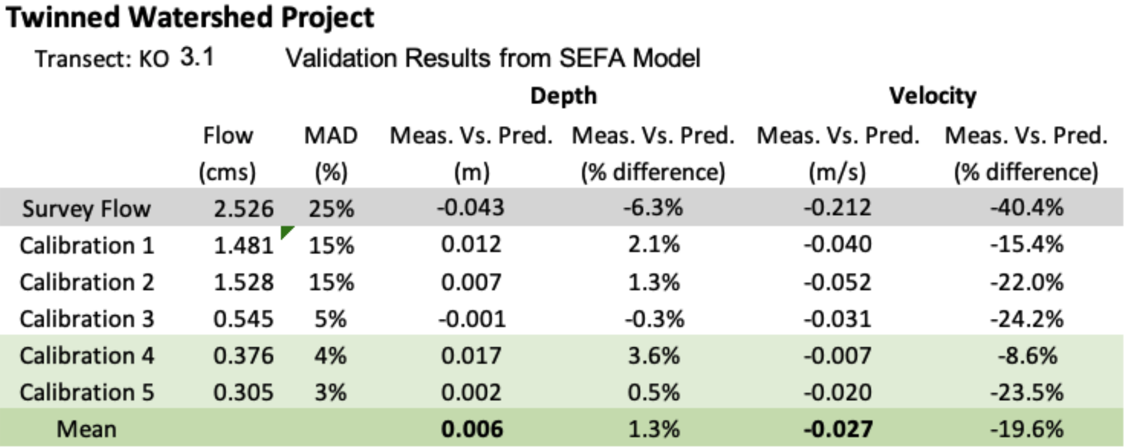


Figure 4-17. Koksilah River EFA, Validation of SEFA Model Results for Transect 2.3.



Twinned Watershed Project

Transect: KO 3.1 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.526	25%	-0.043	-6.3%	-0.212	-40.4%
Calibration 1	1.481	15%	0.012	2.1%	-0.040	-15.4%
Calibration 2	1.528	15%	0.007	1.3%	-0.052	-22.0%
Calibration 3	0.545	5%	-0.001	-0.3%	-0.031	-24.2%
Calibration 4	0.376	4%	0.017	3.6%	-0.007	-8.6%
Calibration 5	0.305	3%	0.002	0.5%	-0.020	-23.5%
Mean			**0.006**	1.3%	**-0.027**	-19.6%

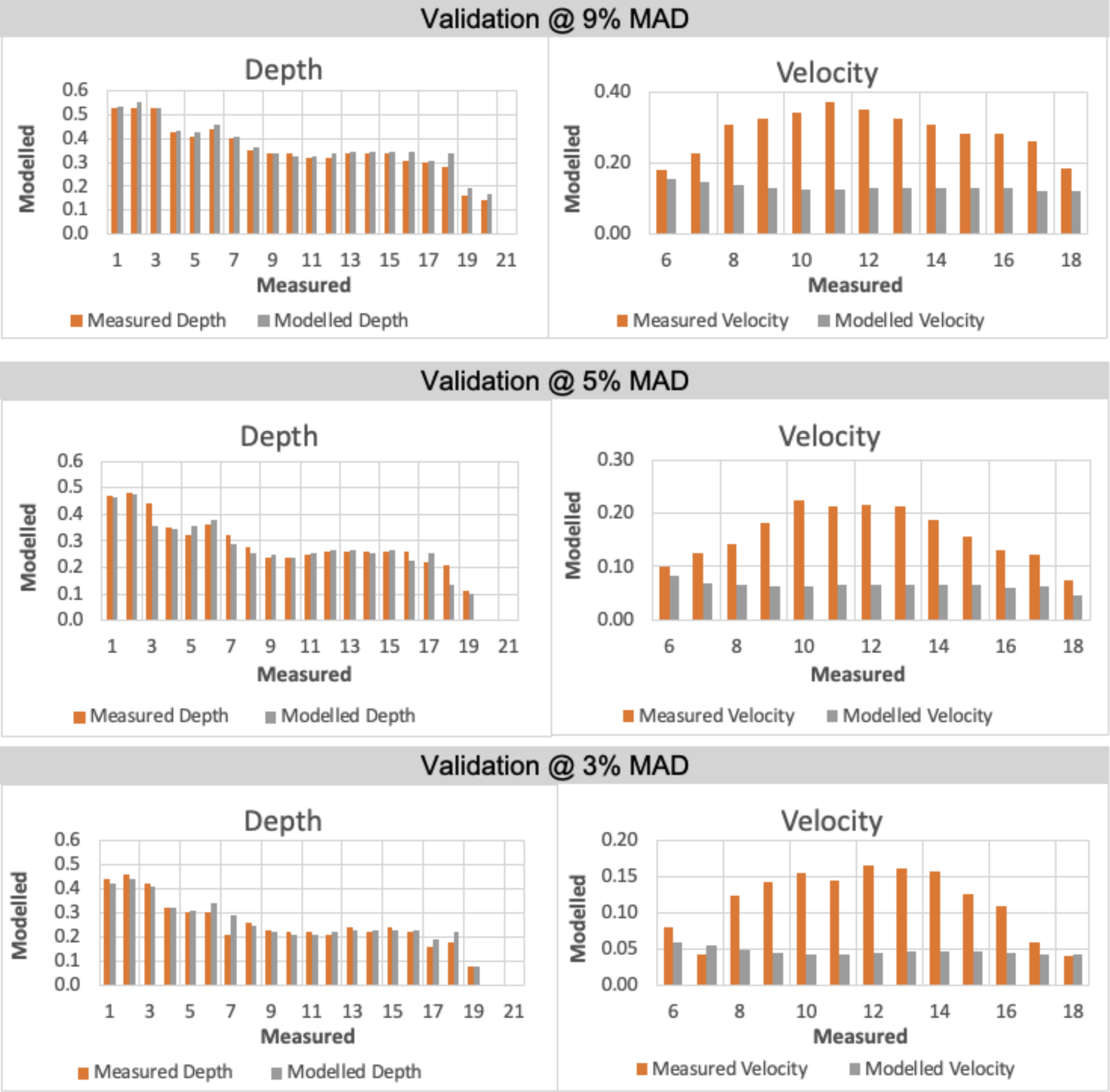
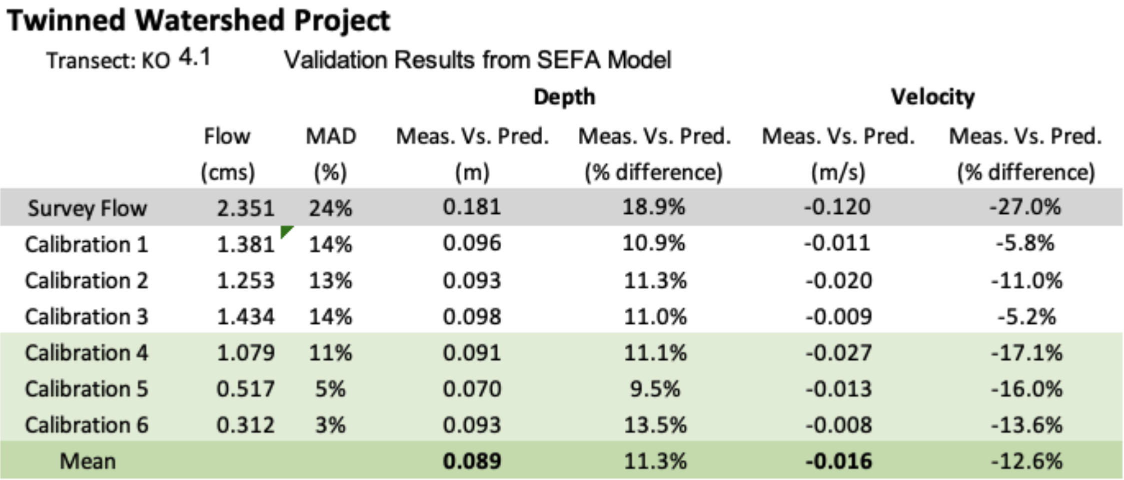


Figure 4-18. Koksilah River EFA, Validation of SEFA Model Results for Transect 3.1.



Twinned Watershed Project

Transcript: KO 4.1 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.351	24%	0.181	18.9%	-0.120	-27.0%
Calibration 1	1.381	14%	0.096	10.9%	-0.011	-5.8%
Calibration 2	1.253	13%	0.093	11.3%	-0.020	-11.0%
Calibration 3	1.434	14%	0.098	11.0%	-0.009	-5.2%
Calibration 4	1.079	11%	0.091	11.1%	-0.027	-17.1%
Calibration 5	0.517	5%	0.070	9.5%	-0.013	-16.0%
Calibration 6	0.312	3%	0.093	13.5%	-0.008	-13.6%
Mean			**0.089**	11.3%	**-0.016**	-12.6%

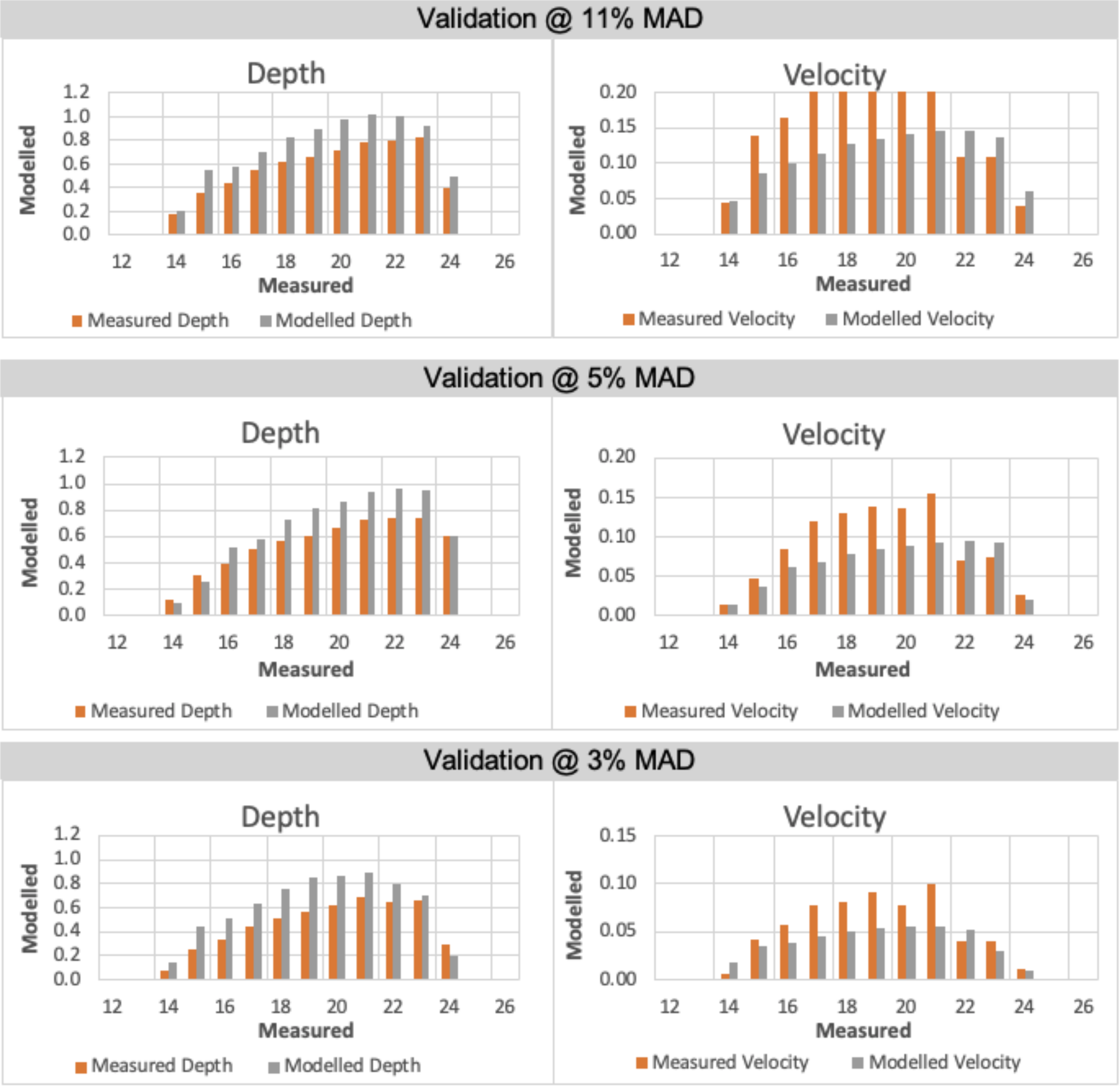


Figure 4-19. Koksilah River EFA, Validation of SEFA Model Results for Transect 4.1.

Twinned Watershed Project

Transect: KO 4.2 Validation Results from SEFA Model

	Flow	MAD	Depth		Velocity	
	(cms)	(%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.387	24%	0.003	0.3%	0.007	2.3%
Calibration 1	1.268	13%	0.017	2.1%	-0.002	-1.0%
Calibration 2	1.034	10%	0.015	1.8%	-0.001	-0.8%
Calibration 3	1.305	13%	0.022	2.7%	0.002	0.7%
Calibration 4	0.826	8%	-0.040	-5.1%	-0.018	-11.1%
Calibration 5	0.482	5%	0.022	3.2%	-0.008	-8.5%
Calibration 6	0.262	3%	0.006	0.9%	-0.002	-3.3%
Mean			**0.005**	0.7%	**-0.006**	-4.6%

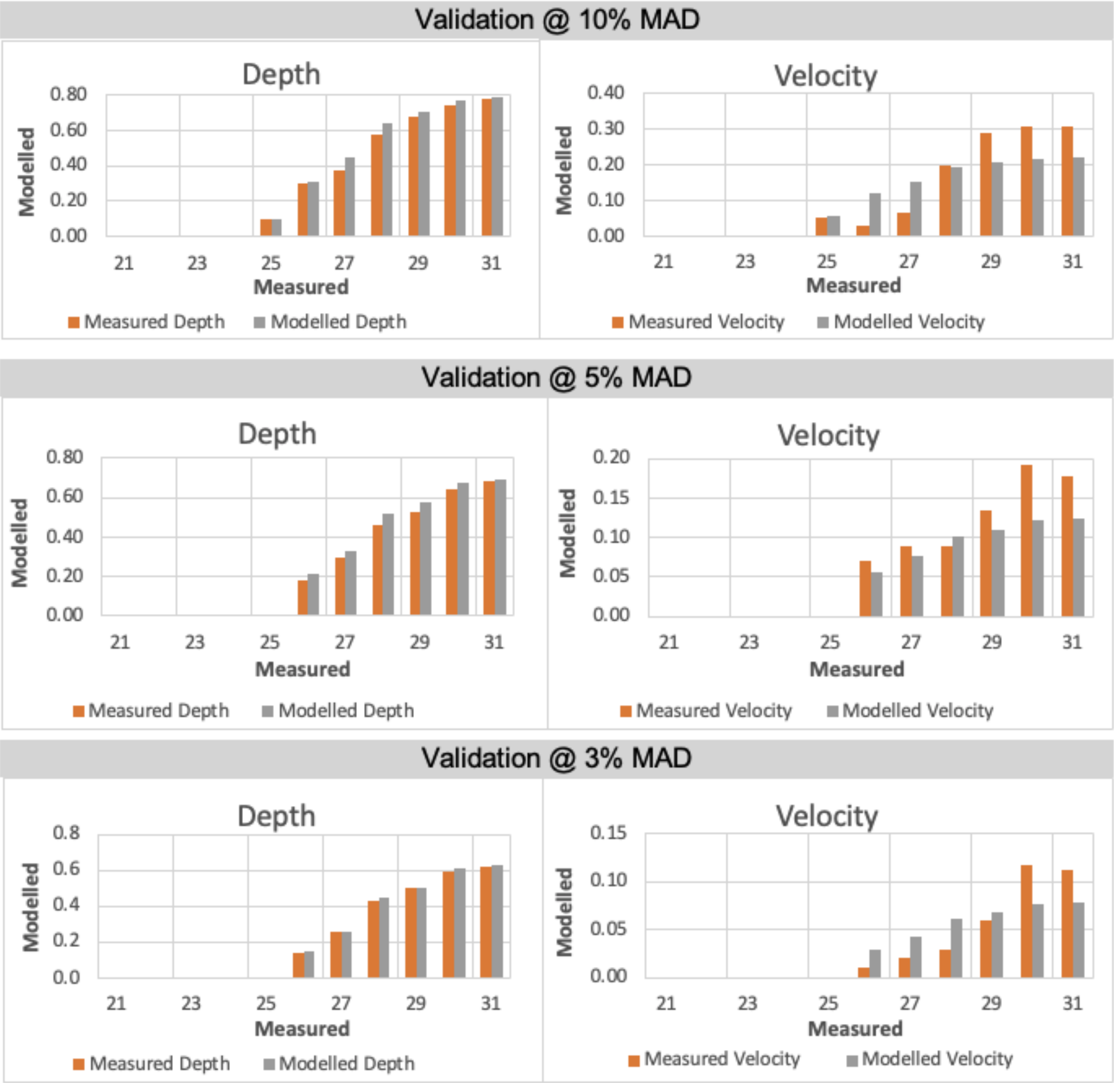


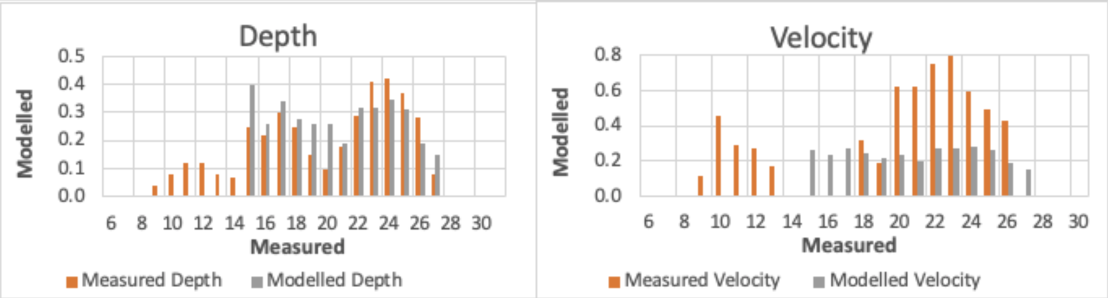
Figure 4-20. Koksilah River EFA, Validation of SEFA Model Results for Transect 4.3.

Twinned Watershed Project

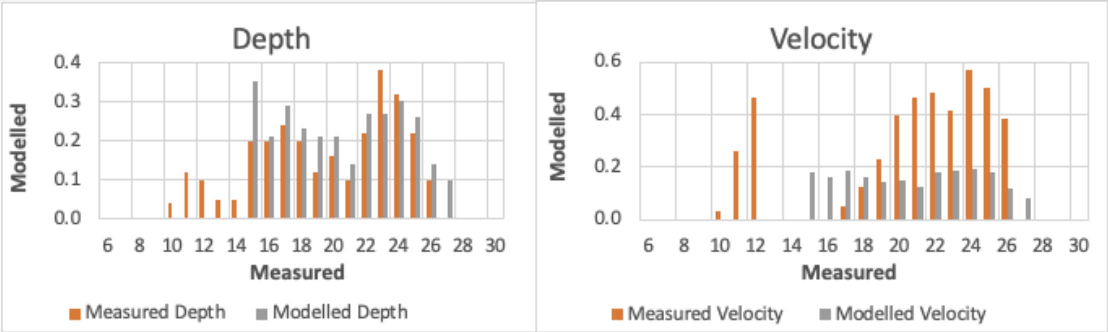
Transect: KO 5.1 Validation Results from SEFA Model

	Flow (cms)	MAD (%)	Depth Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Velocity Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.131	21%	-0.026	-4.9%	-0.004	-1.0%
Calibration 1	1.660	17%	-0.024	-6.2%	-0.141	-35.0%
Calibration 2	1.415	14%	-0.015	-3.5%	-0.120	-37.5%
Calibration 3	1.472	15%	-0.046	-8.3%	-0.081	-30.3%
Calibration 4	1.171	12%	-0.004	-1.0%	-0.087	-37.5%
Calibration 5	1.121	11%	-0.004	-0.9%	-0.088	-31.2%
Calibration 6	0.611	6%	0.006	1.6%	-0.057	-27.5%
Calibration 7	0.385	4%	0.015	4.8%	-0.043	-15.0%
Mean			**-0.008**	-1.2%	**-0.079**	-29.8%

Validation @ 11% MAD



Validation @ 6% MAD



Validation @ 4% MAD

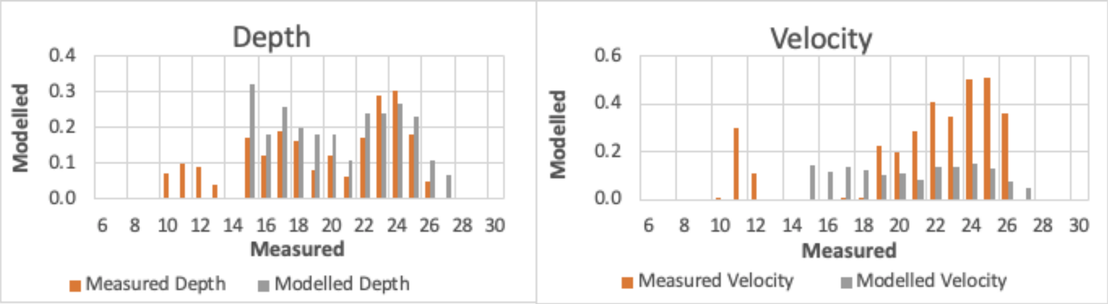


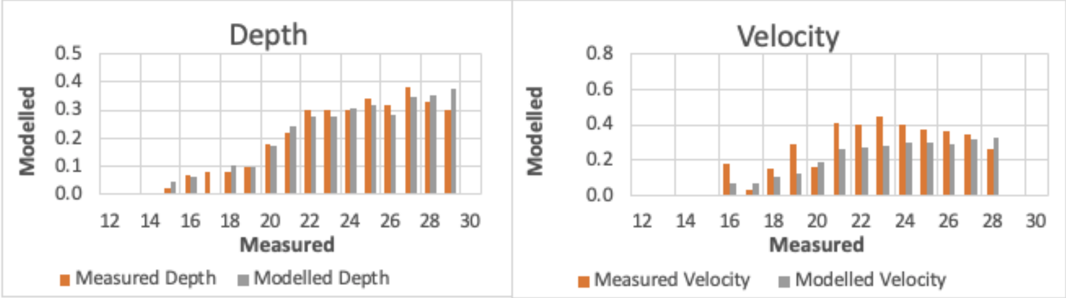
Figure 4-21. Koksilah River EFA, Validation of SEFA Model Results for Transect 5.1.

Twinned Watershed Project

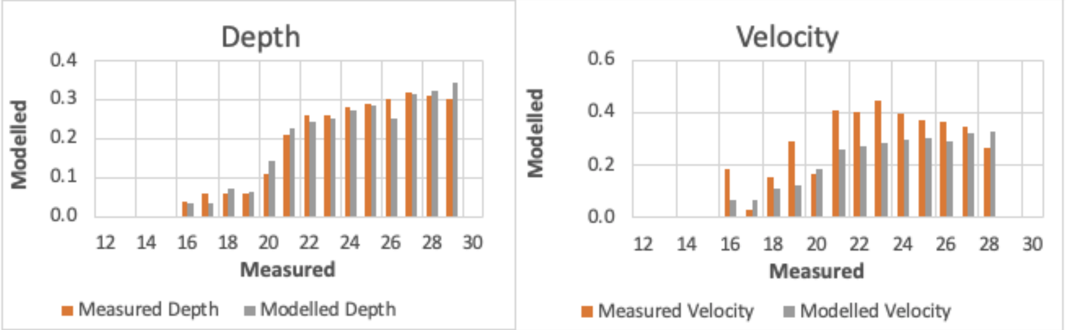
Transect: KO 5.2 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.279	23%	-0.007	-1.7%	-0.035	-7.1%
Calibration 1	1.384	14%	0.002	0.6%	-0.049	-12.4%
Calibration 2	1.082	11%	-0.005	-1.3%	-0.015	-4.9%
Calibration 3	1.748	17%	-0.004	-0.9%	-0.044	-10.1%
Calibration 4	1.095	11%	-0.002	-0.5%	-0.023	-7.1%
Calibration 5	0.762	8%	-0.001	-0.3%	-0.026	-8.8%
Calibration 6	0.462	5%	0.005	2.0%	-0.027	-10.6%
Calibration 7	0.272	3%	-0.001	-0.4%	-0.012	-6.7%
Mean			**-0.001**	-0.2%	**-0.024**	-8.0%

Validation @ 8% MAD



Validation @ 5% MAD



Validation @ 3% MAD

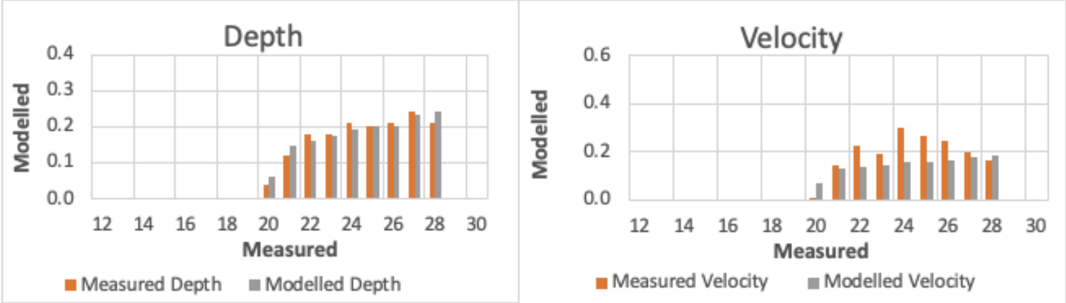


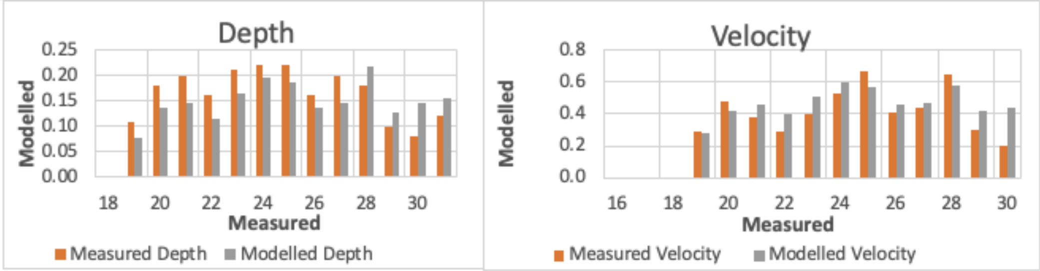
Figure 4-22. Koksilah River EFA, Validation of SEFA Model Results for Transect 5.2.

Twinned Watershed Project

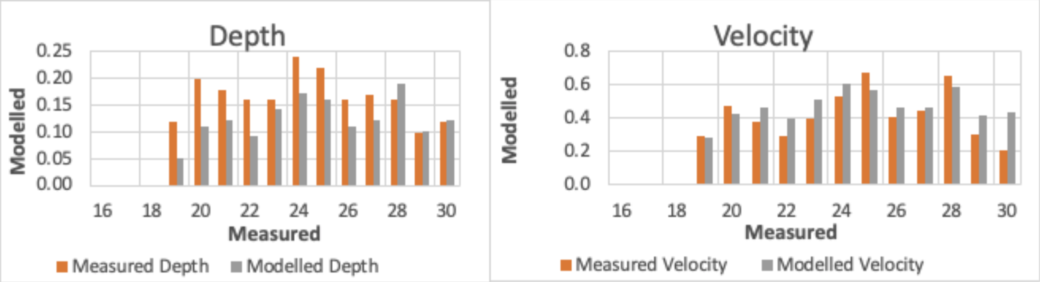
Transect: KO 5.3 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.425	24%	-0.007	-1.7%	-0.035	-7.1%
Calibration 1	1.503	17%	0.002	0.6%	-0.049	-12.4%
Calibration 2	1.283	15%	-0.005	-1.3%	-0.015	-4.9%
Calibration 3	1.852	19%	-0.004	-0.9%	-0.044	-10.1%
Calibration 4	1.178	12%	-0.002	-0.5%	-0.023	-7.1%
Calibration 5	0.942	9%	-0.001	-0.3%	-0.026	-8.8%
Calibration 6	0.572	6%	0.005	2.0%	-0.027	-10.6%
Calibration 7	0.463	5%	-0.001	-0.4%	-0.012	-6.7%
Mean			**-0.001**	-0.2%	**-0.024**	-8.0%

Validation @ 9% MAD



Validation @ 6% MAD



Validation @ 5% MAD

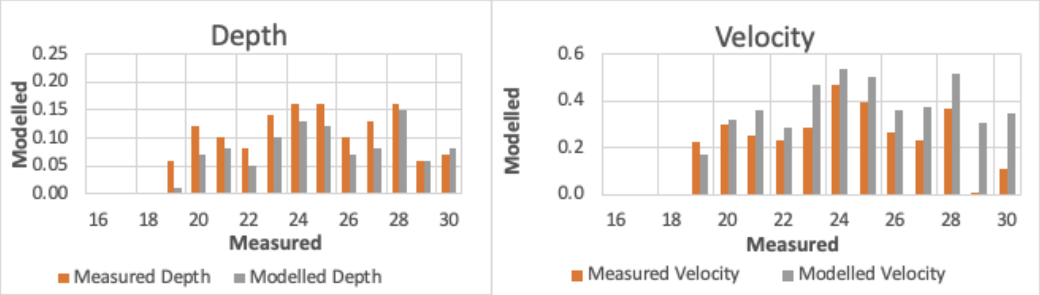


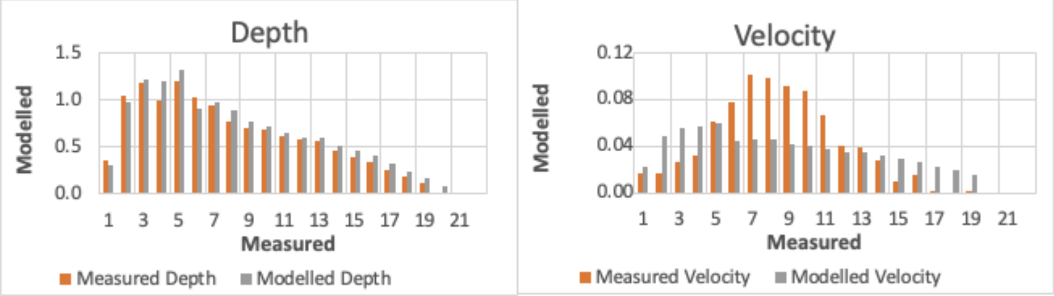
Figure 4-23. Koksilah River EFA, Validation of SEFA Model Results for Transect 5.3.

Twinned Watershed Project

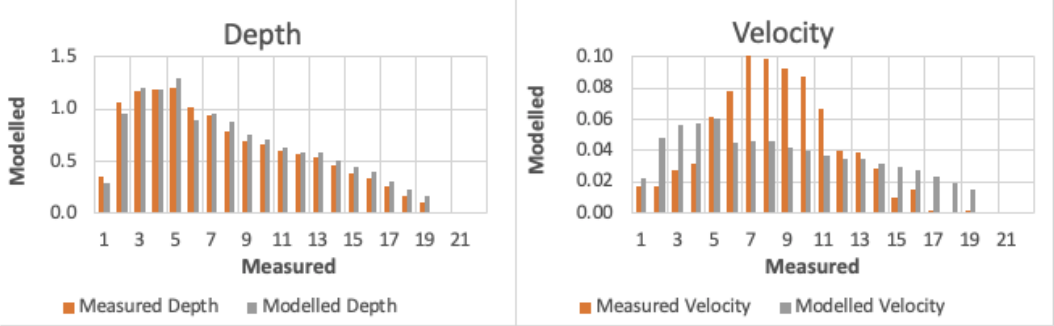
Transect: KO 5.35 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.123	21%	0.009	0.7%	0.002	3.9%
Calibration 1	1.535	15%	-0.024	-1.7%	0.002	3.6%
Calibration 2	1.327	13%	0.045	2.1%	-0.002	-3.6%
Calibration 3	1.285	13%	0.028	2.1%	0.000	-0.2%
Calibration 4	0.939	9%	0.037	2.8%	-0.002	-2.6%
Calibration 5	0.760	8%	0.020	1.6%	-0.002	-8.8%
Calibration 6	0.610	6%	0.020	1.6%	-0.002	-8.8%
Calibration 7	0.221	2%	0.024	2.1%	0.001	3.6%
Mean			**0.029**	2.1%	**-0.001**	-3.4%

Validation @ 8% MAD



Validation @ 5% MAD



Validation @ 3% MAD

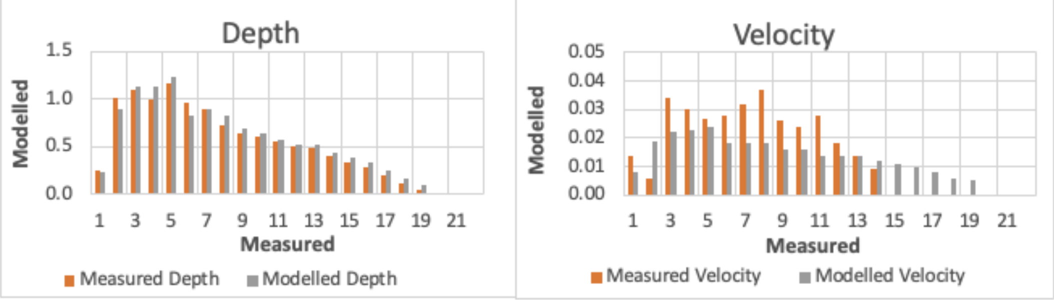


Figure 4-24. Koksilah River EFA, Validation of SEFA Model Results for Transect 5.35.

Twinned Watershed Project

Transect: KO 5.4 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.106	21.1%	-0.015	-2.5%	0.001	0.5%
Calibration 1	1.424	14.2%	0.011	2.7%	-0.014	-7.2%
Calibration 2	1.319	13.2%	0.021	5.3%	-0.018	-8.6%
Calibration 3	1.162	11.6%	0.019	5.3%	-0.014	-8.0%
Calibration 4	0.983	9.8%	0.020	7.2%	-0.017	-9.4%
Calibration 5	0.814	8.1%	0.026	8.8%	-0.014	-10.0%
Calibration 6	0.661	6.6%	0.026	8.8%	-0.014	-10.0%
Calibration 7	0.455	4.5%	0.023	8.9%	-0.013	-13.3%
Calibration 8	0.264	2.6%	0.020	7.9%	-0.005	-8.9%
Mean			**0.022**	7.4%	**-0.014**	-9.7%

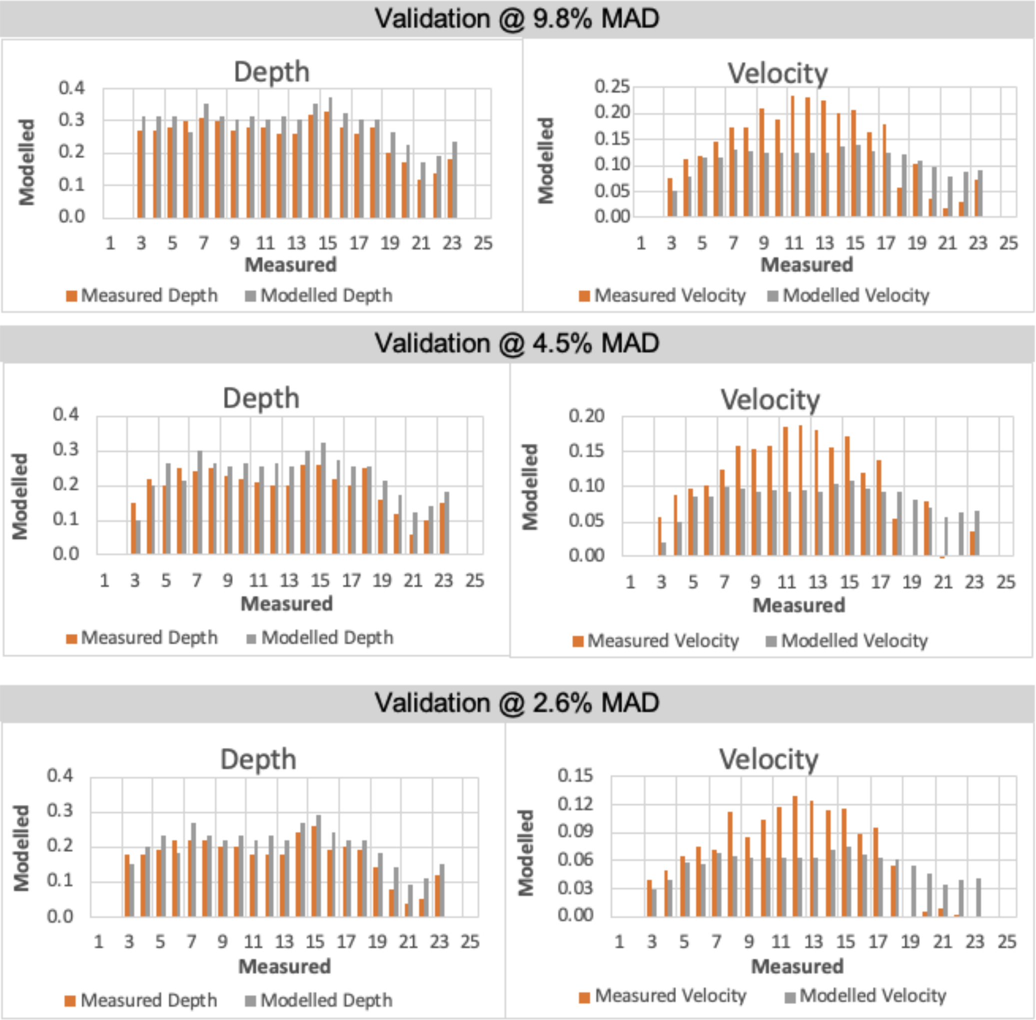


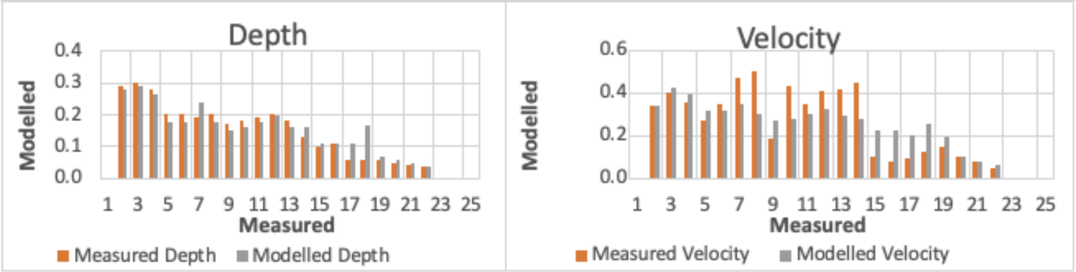
Figure 4-25. Koksilah River EFA, Validation of SEFA Model Results for Transect 5.4.

Twinned Watershed Project

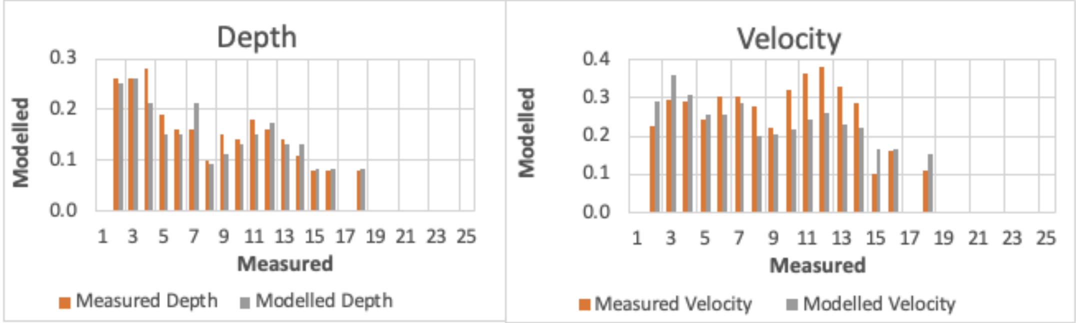
Transect: KO 5.5 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.042	20.4%	0.008	2.3%	-0.021	-4.3%
Calibration 1	1.571	15.7%	-0.005	-1.4%	-0.003	-0.8%
Calibration 2	1.353	13.5%	0.001	0.4%	-0.016	-3.9%
Calibration 3	1.138	11.4%	-0.005	-1.6%	0.002	0.7%
Calibration 4	2.122	21.2%	-0.001	-35.2%	-0.168	-48.0%
Calibration 5	0.877	8.8%	0.000	-0.3%	0.002	0.9%
Calibration 6	0.000		0.000		0.000	
Calibration 7	0.576	5.8%	-0.005	-1.7%	0.005	2.3%
Calibration 8	0.342	3.4%	-0.005	-2.0%	0.008	4.3%
Mean			**-0.002**	-6.7%	**-0.024**	-7.3%

Validation @ 8.8% MAD



Validation @ 5.8% MAD



Validation @ 3.4% MAD

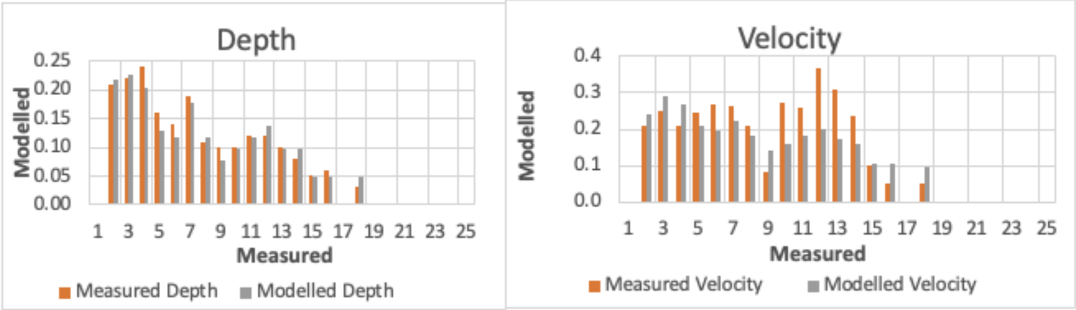


Figure 4-26. Koksilah River EFA, Validation of SEFA Model Results for Transect 5.5.

Twinned Watershed Project

Transect: KO 5.6 Validation Results from SEFA Model

			Depth		Velocity	
	Flow (cms)	MAD (%)	Meas. Vs. Pred. (m)	Meas. Vs. Pred. (% difference)	Meas. Vs. Pred. (m/s)	Meas. Vs. Pred. (% difference)
Survey Flow	2.130	21.3%	0.001	0.1%	-0.009	-5.5%
Calibration 1	1.623	16.2%	-0.033	-2.5%	-0.001	-1.1%
Calibration 2	1.357	13.6%	-0.002	-0.2%	-0.005	-4.8%
Calibration 3	1.234	12.3%	-0.023	-2.0%	-0.003	-3.0%
Calibration 4	1.118	11.2%	-0.043	-3.6%	0.000	-0.5%
Calibration 8	0.338	3.4%	-0.151	-12.8%	0.002	10.0%
Mean			**-0.055**	-4.6%	**-0.001**	0.4%

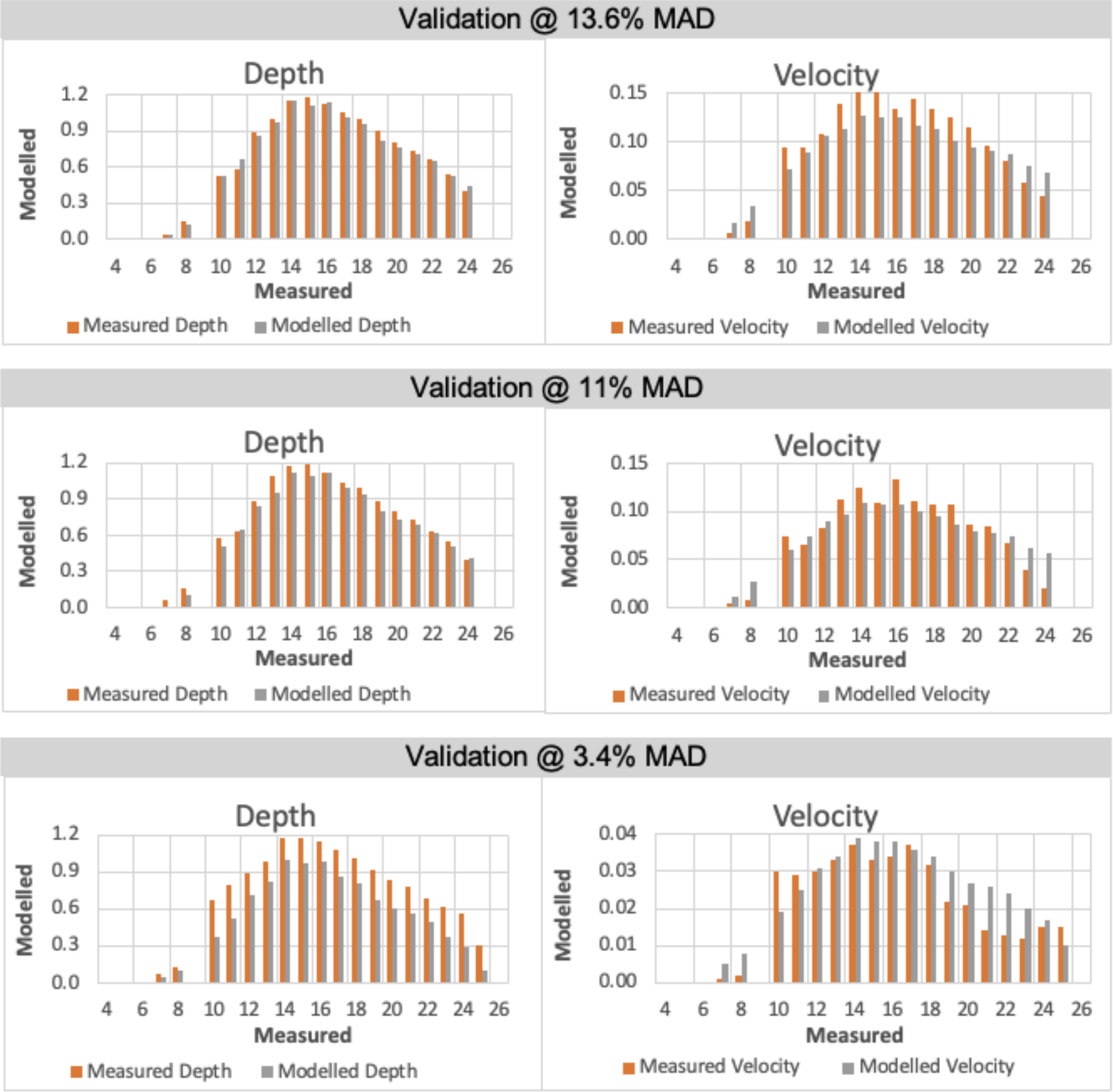


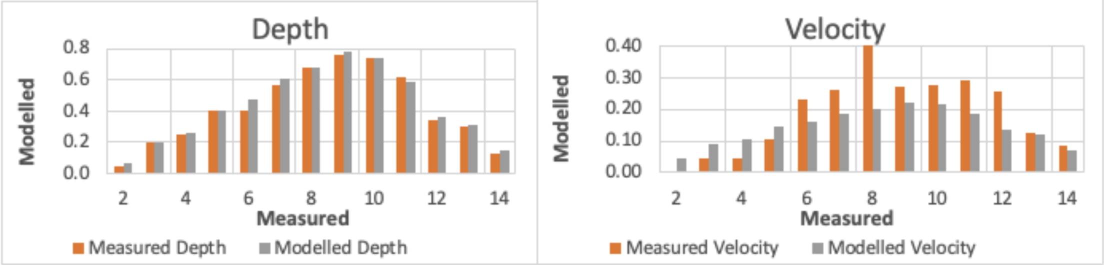
Figure 4-27. Koksilah River EFA, Validation of SEFA Model Results for Transect 5.6.

Twinned Watershed Project

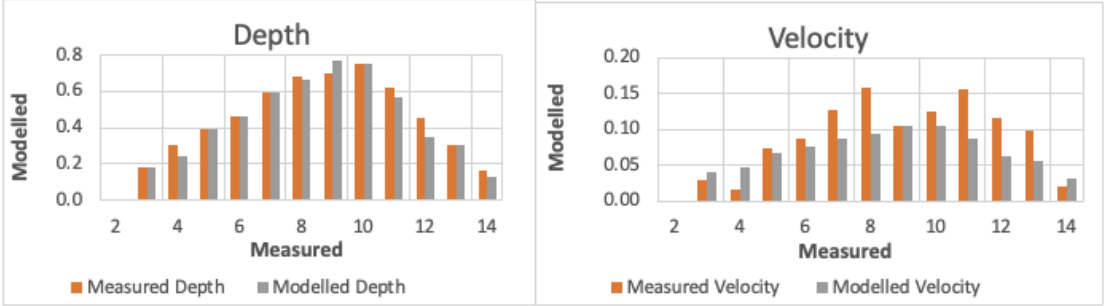
Transect: KO 5.7 Validation Results from SEFA Model

	Flow (cms)	MAD (%)	Depth Meas. Vs. Pred. (m)	Depth Meas. Vs. Pred. (% difference)	Velocity Meas. Vs. Pred. (m/s)	Velocity Meas. Vs. Pred. (% difference)
Survey Flow	2.106	19.7%	-0.278	-34.3%	0.001	0.5%
Calibration 1	1.333	13.3%	-0.002	-0.2%	-0.014	-7.2%
Calibration 2	1.260	12.6%	0.012	1.3%	-0.018	-8.6%
Calibration 3	1.057	10.6%	0.010	1.3%	-0.014	-8.0%
Calibration 4	1.430	14.3%	0.000	-0.8%	-0.017	-9.4%
Calibration 5	n/a	n/a	n/a	n/a	n/a	n/a
Calibration 6	n/a	n/a	n/a	n/a	n/a	n/a
Calibration 7	0.493	4.9%	-0.009	-1.3%	-0.007	-7.7%
Calibration 8	0.263	2.6%	0.000	0.0%	-0.002	-4.5%
Mean			**0.003**	0.1%	**-0.012**	-7.6%

Validation @ 10.6% MAD



Validation @ 4.9% MAD



Validation @ 2.6% MAD

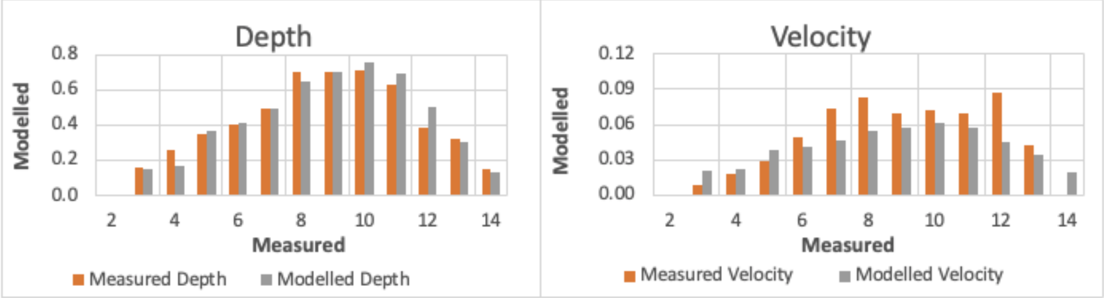


Figure 4-28. Koksilah River EFA, Validation of SEFA Model Results for Transect 5.7.

Appendix 4C: Habitat Suitability Curves

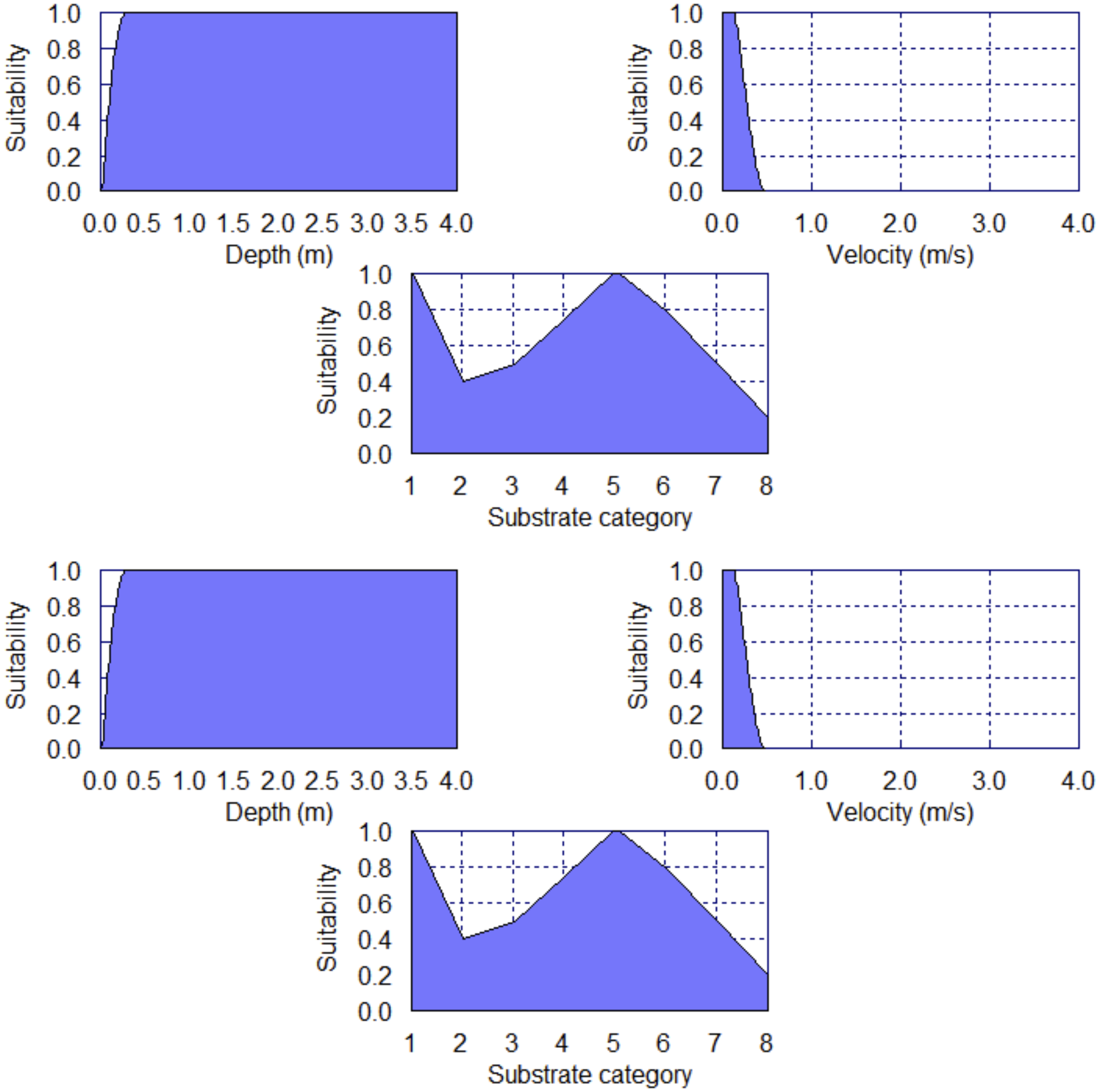


Figure 4-29. Koksilah River EFA. Habitat Suitability Curves for Coho fry (summer).

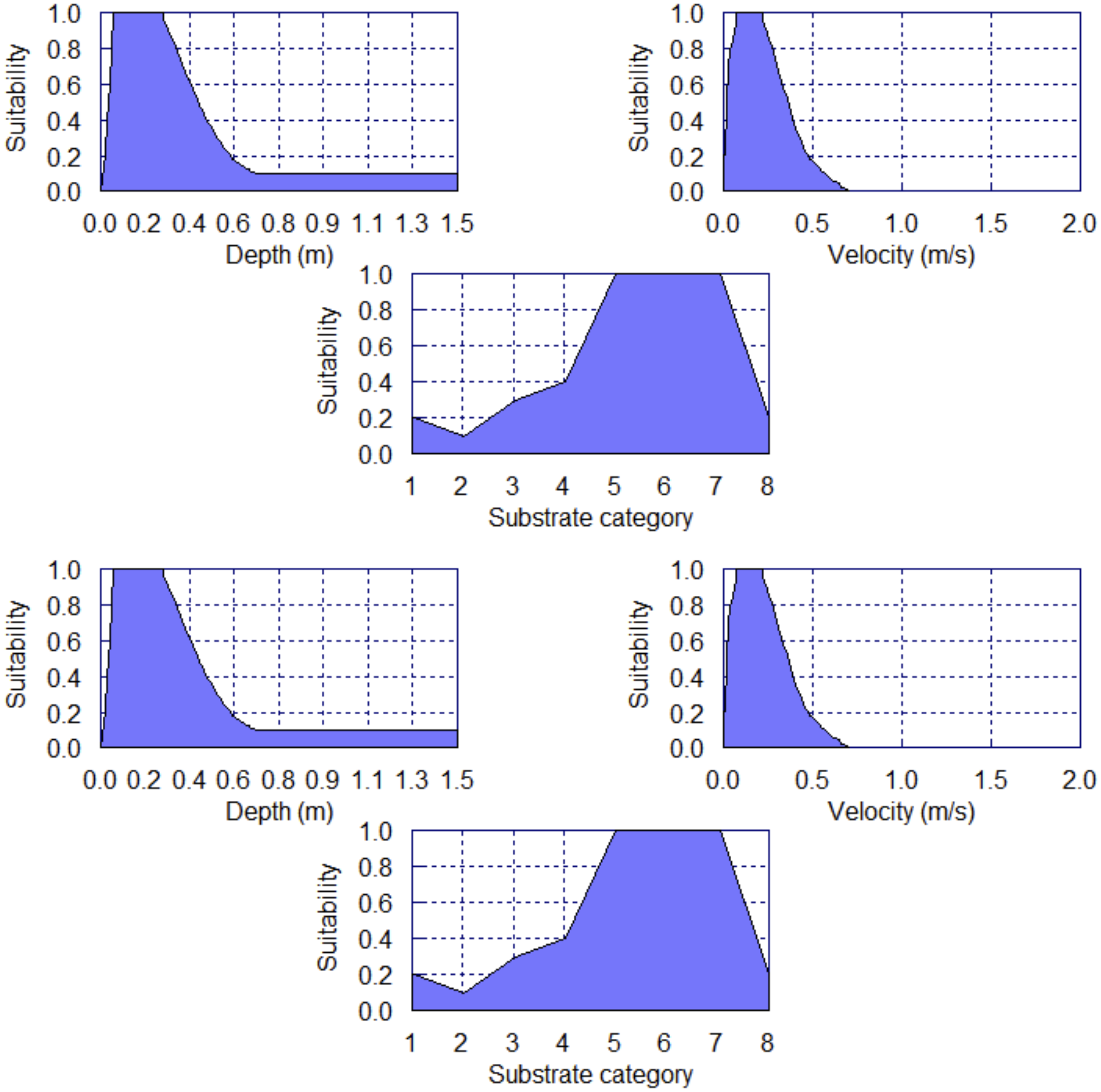


Figure 4-30. Koksilah River EFA. Habitat Suitability Curves for Steelhead fry (summer)

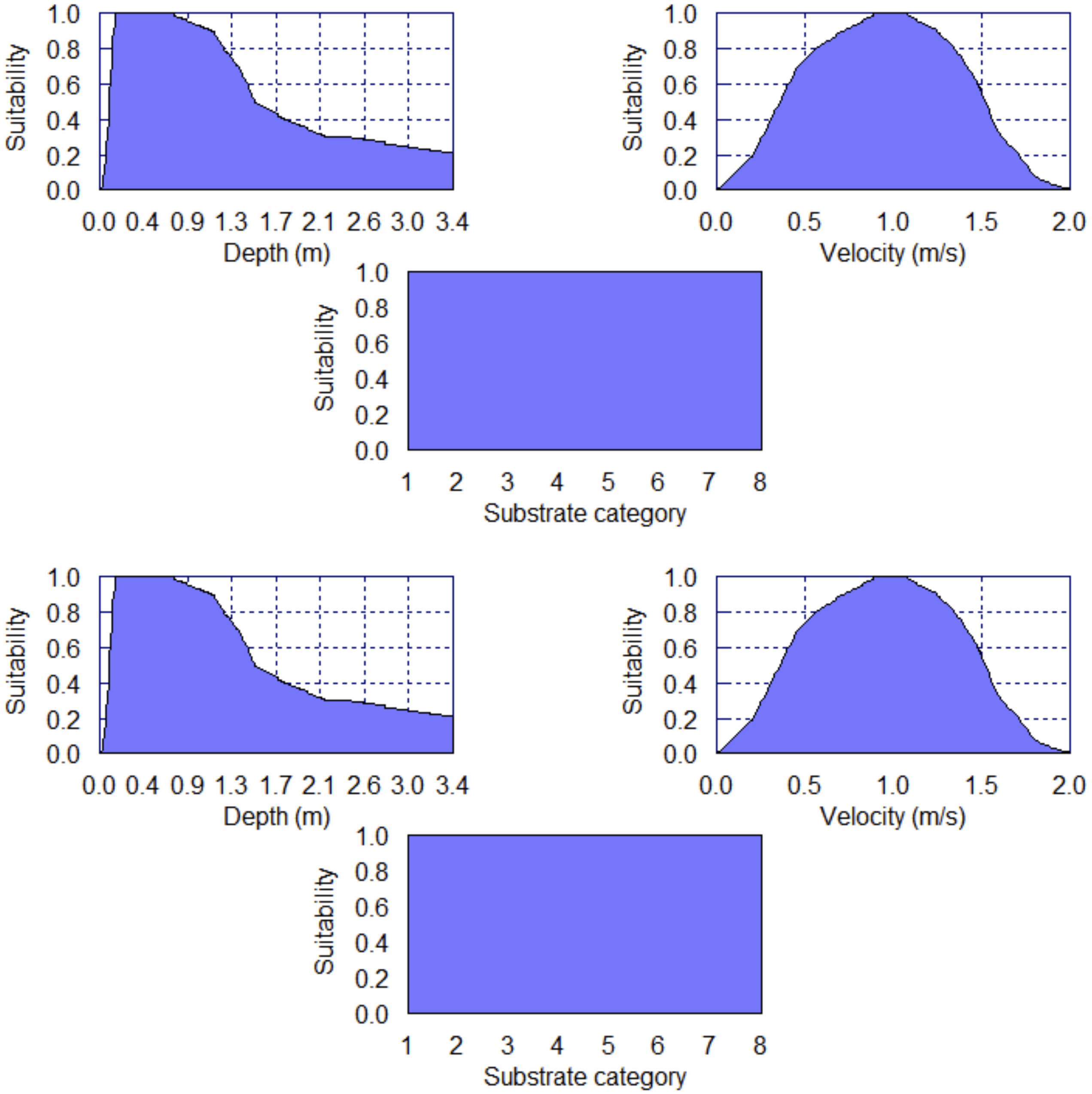


Figure 4-31. Koksilah River EFA. Habitat Suitability Curves Insect.

Appendix 4D: SEFA Model Results

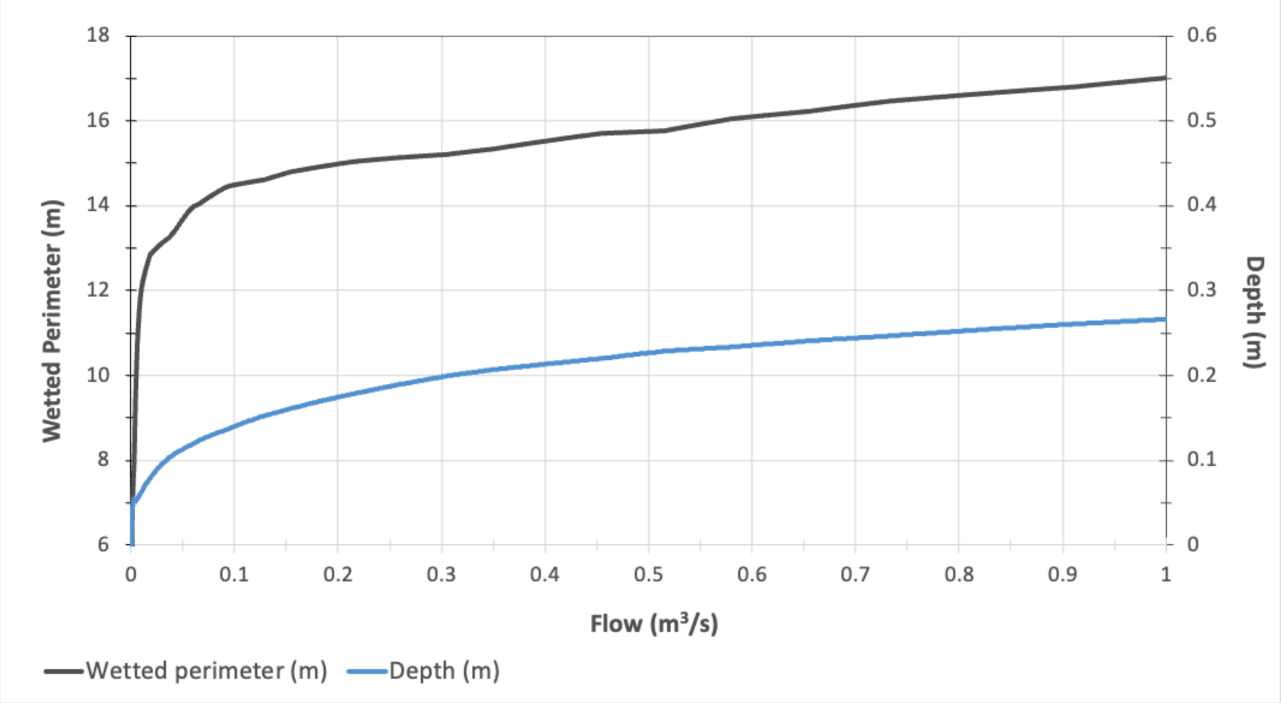


Figure 4-32. Koksilah River EFA, Shallow Glide Flow-Width and Flow-Depth Relationships.

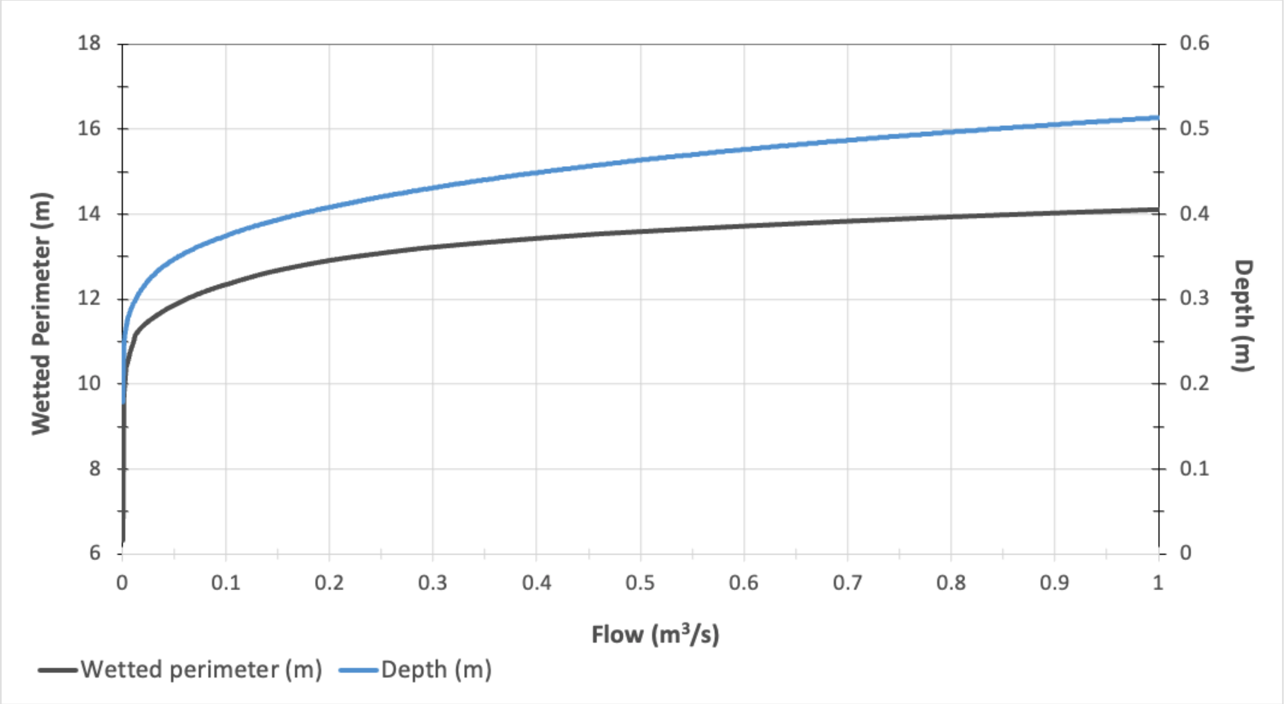
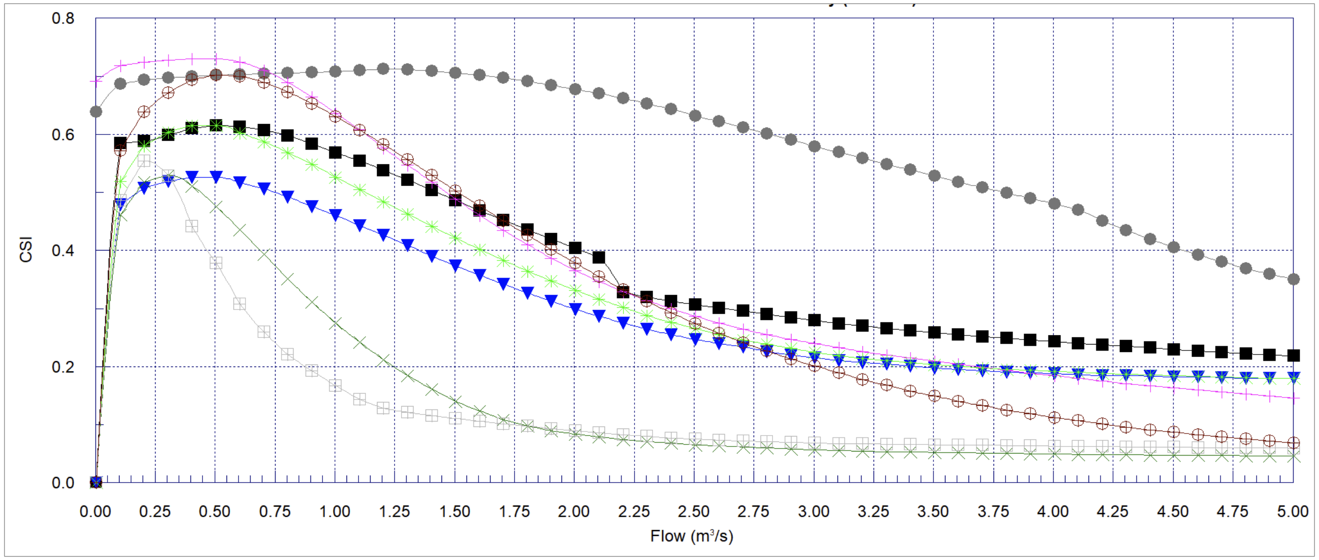


Figure 4-33. Koksilah River EFA, Deep Glide Flow-Width and Flow-Depth Relationships.



Shallow. Glides
2.2, 3.1, 5.2, 5.4

Deep Glides
1.3, 4.2, 5.6, 5.7

Figure 4-34. Koksilah River EFA, Habitat-Flow Relationships for Coho fry. Top Figure shows the Area Weighted Suitability (Quality). Bottom Figure shows the Combined Suitability (Quality).

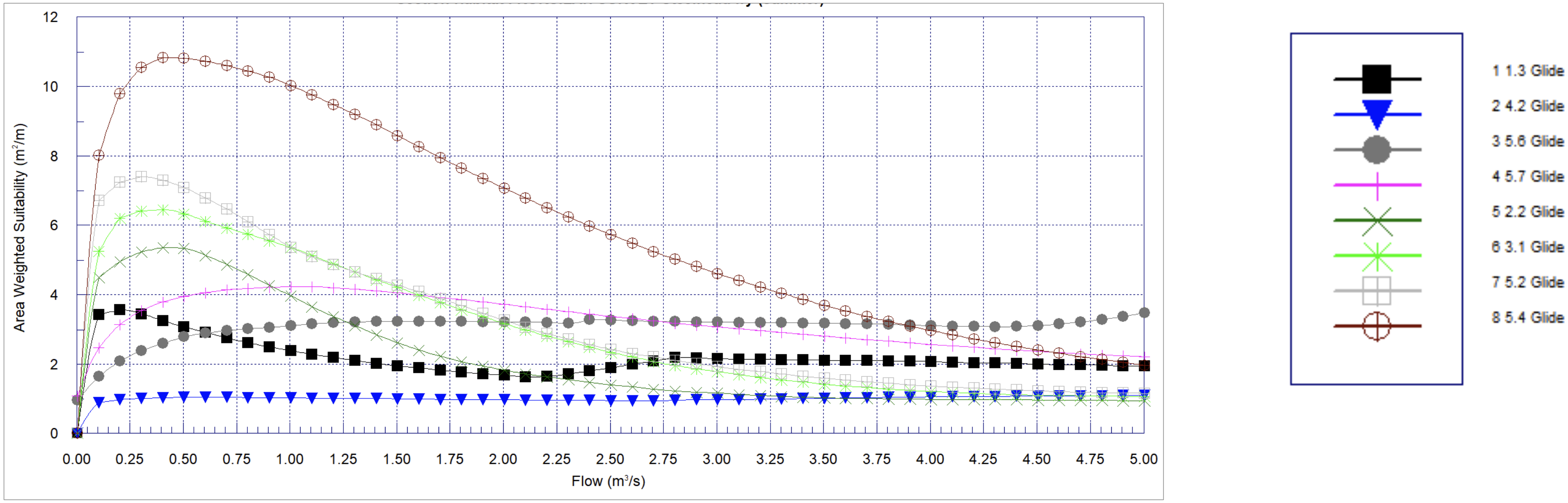


Figure 4-35 . Koksilah River EFA, Habitat-Flow Relationships for Steelhead fry. Top Figure shows the Area Weighted Suitability (Quality). Bottom Figure shows the Combined Suitability (Quality).

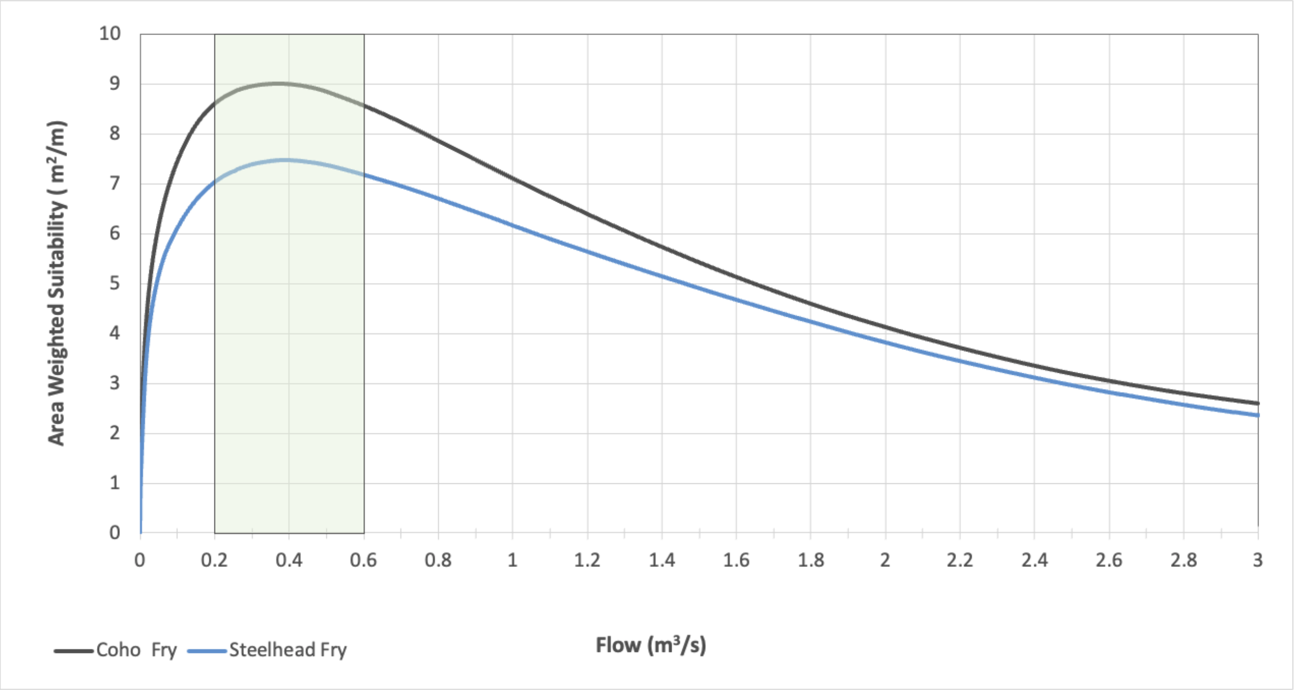


Figure 4-36. Koksilah River EFA, Area Weighted Suitability for Shallow Glides.

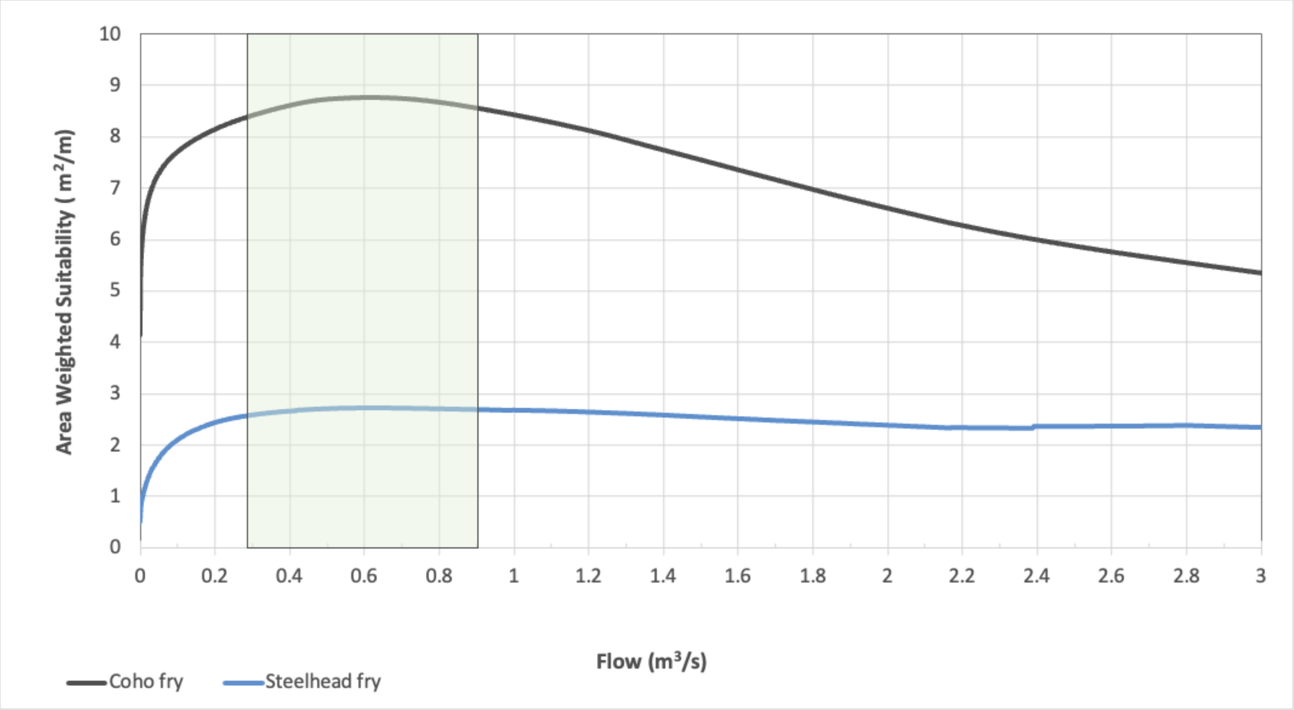


Figure 4-37. Koksilah River EFA, Area Weighted Suitability for Deep Glides.

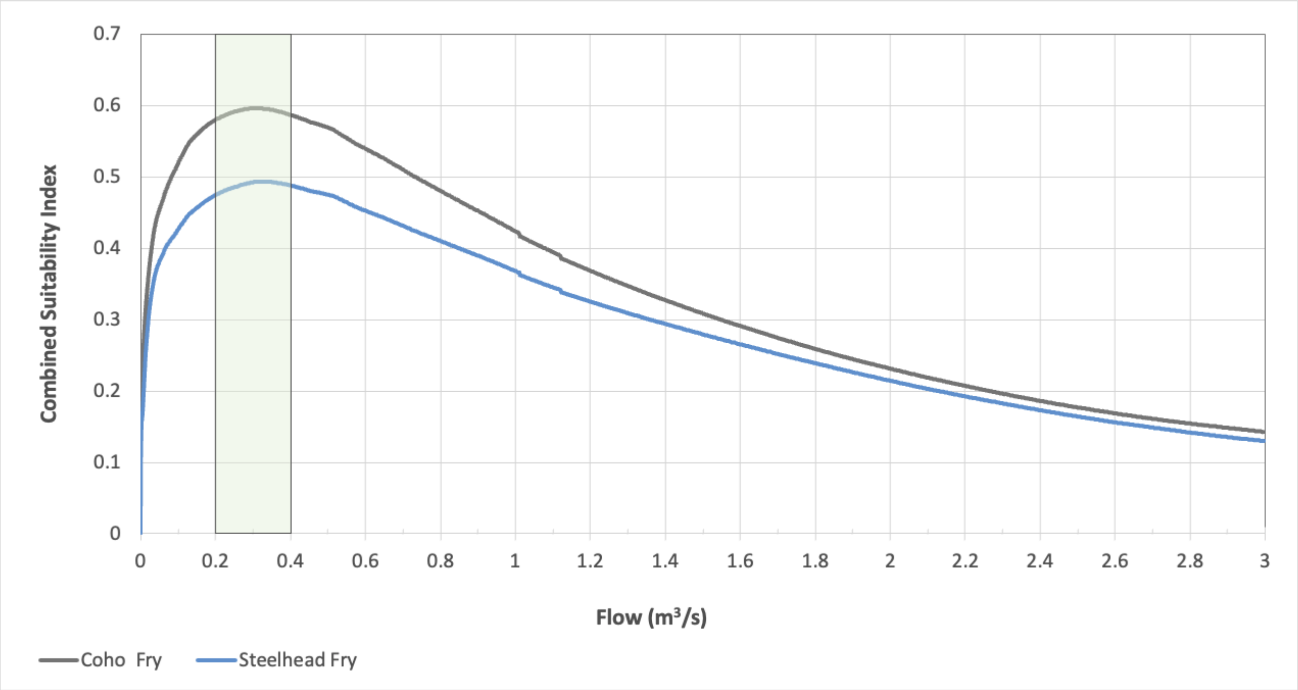


Figure 4-38. Koksilah River EFA, Area Combined Suitability Index for Shallow Glides.

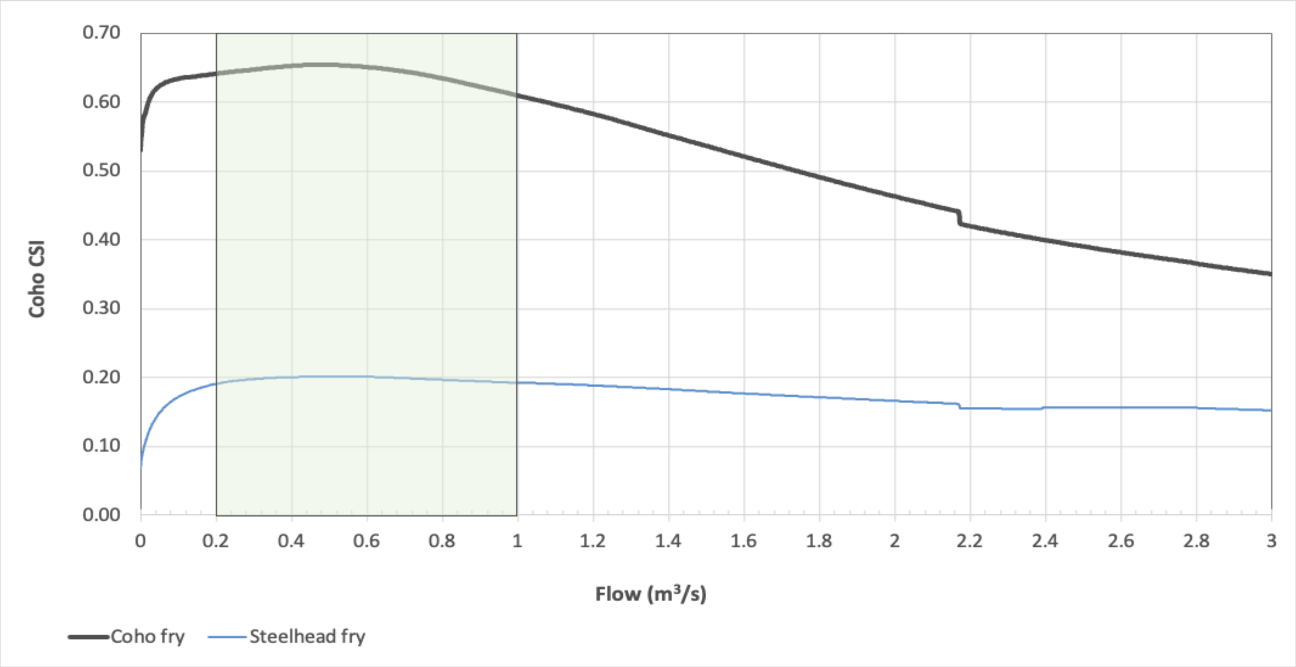


Figure 4-39. Koksilah River EFA, Combined Suitability Index for Deep Glides.

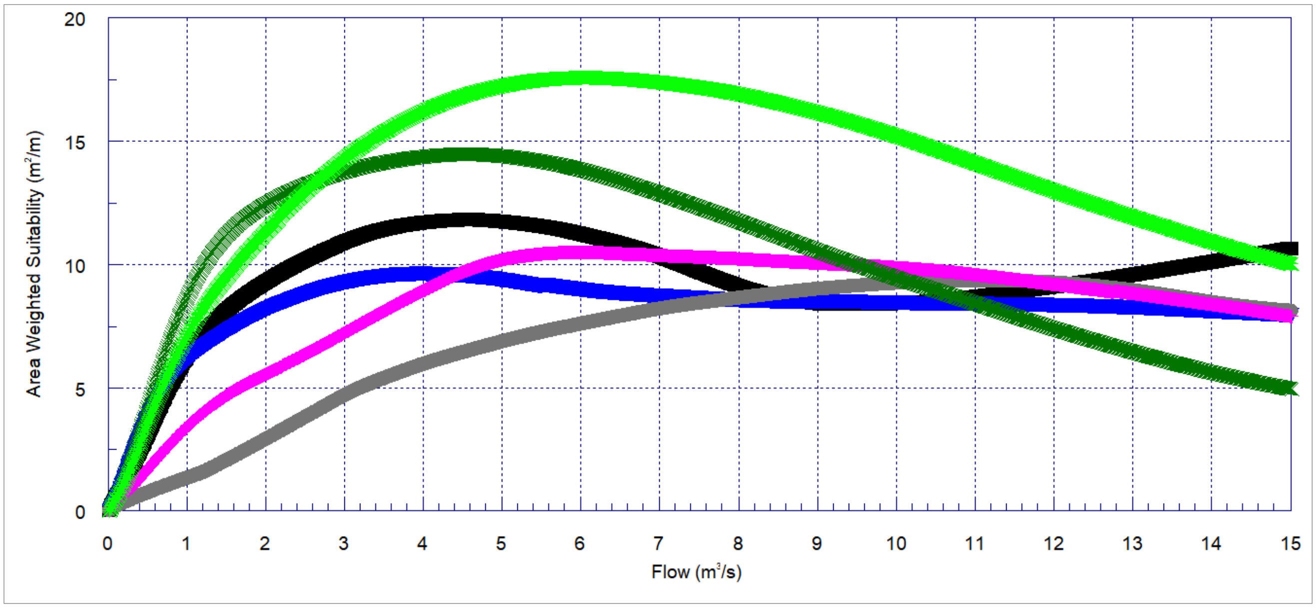


Figure 4-40. Koksilah River EFA, Area Weighted Suitability for Insects in Riffles.

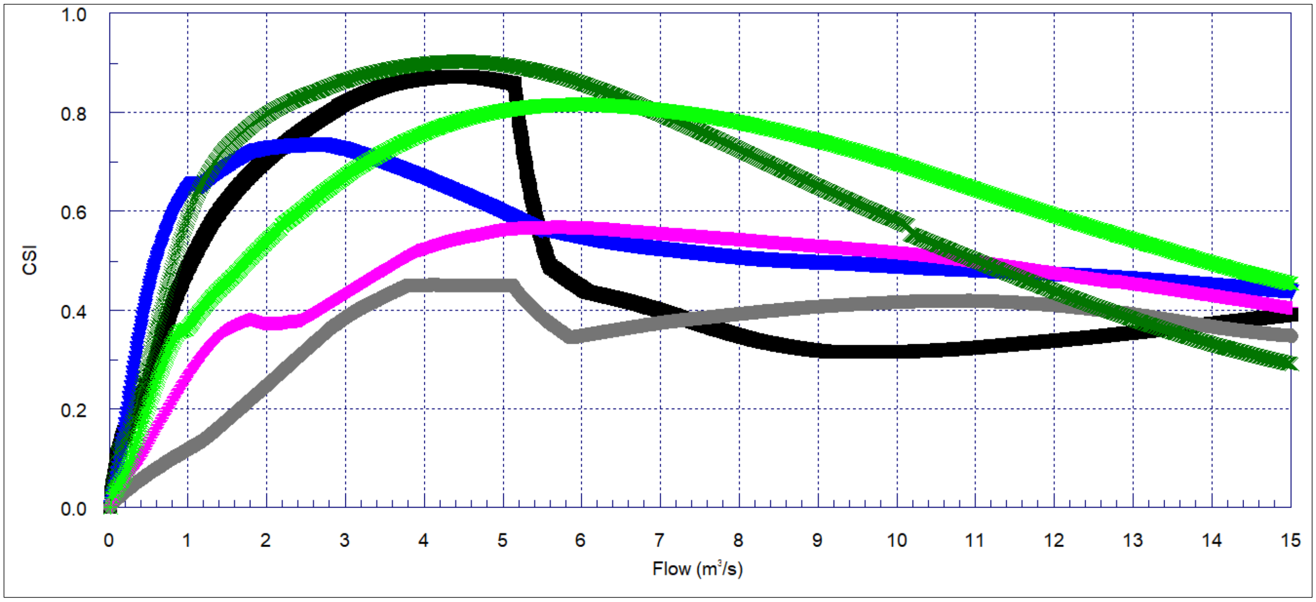


Figure 4-41. Koksilah River EFA, Combined Suitability Index for Insects in Riffles.

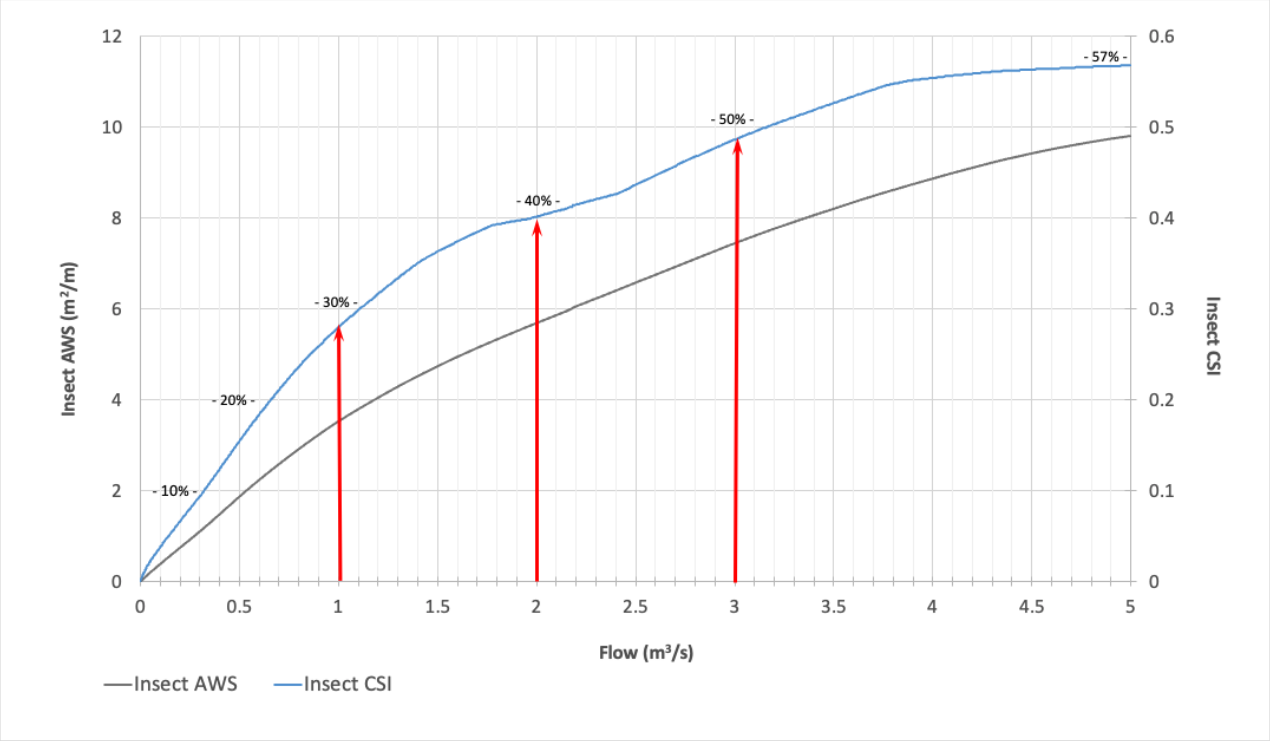


Figure 4-42. Koksilah River EFA, showing both Area Weighted Suitability and Combined Suitability Index for Insects. Figure shows (red arrows) that 30% CSI corresponds to 1 m^3/s, while 40% CSI corresponds with 2 m^3/s, and 50% CSI corresponds to 3 m^3/s

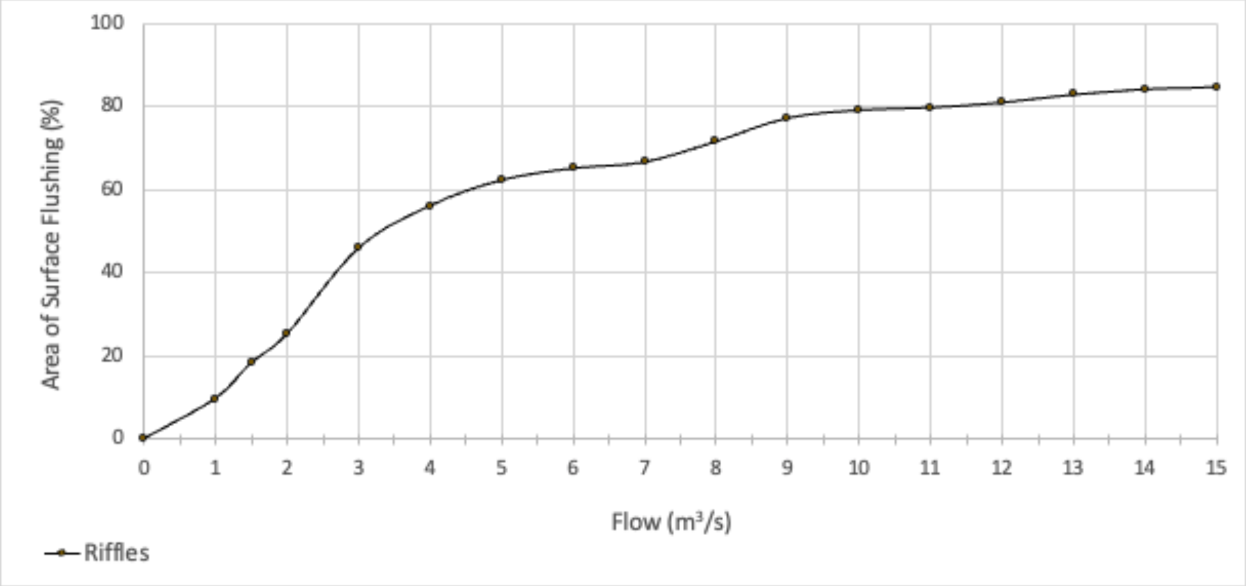


Figure 4-43. Koksilah River EFA, Surface Sediment Flushing. Figure shows that at 1 m^3/s there is 10% of the streambed that is actively flushing / transporting sediments. And at 4 m^3/s, roughly 60% of the streambed is active.

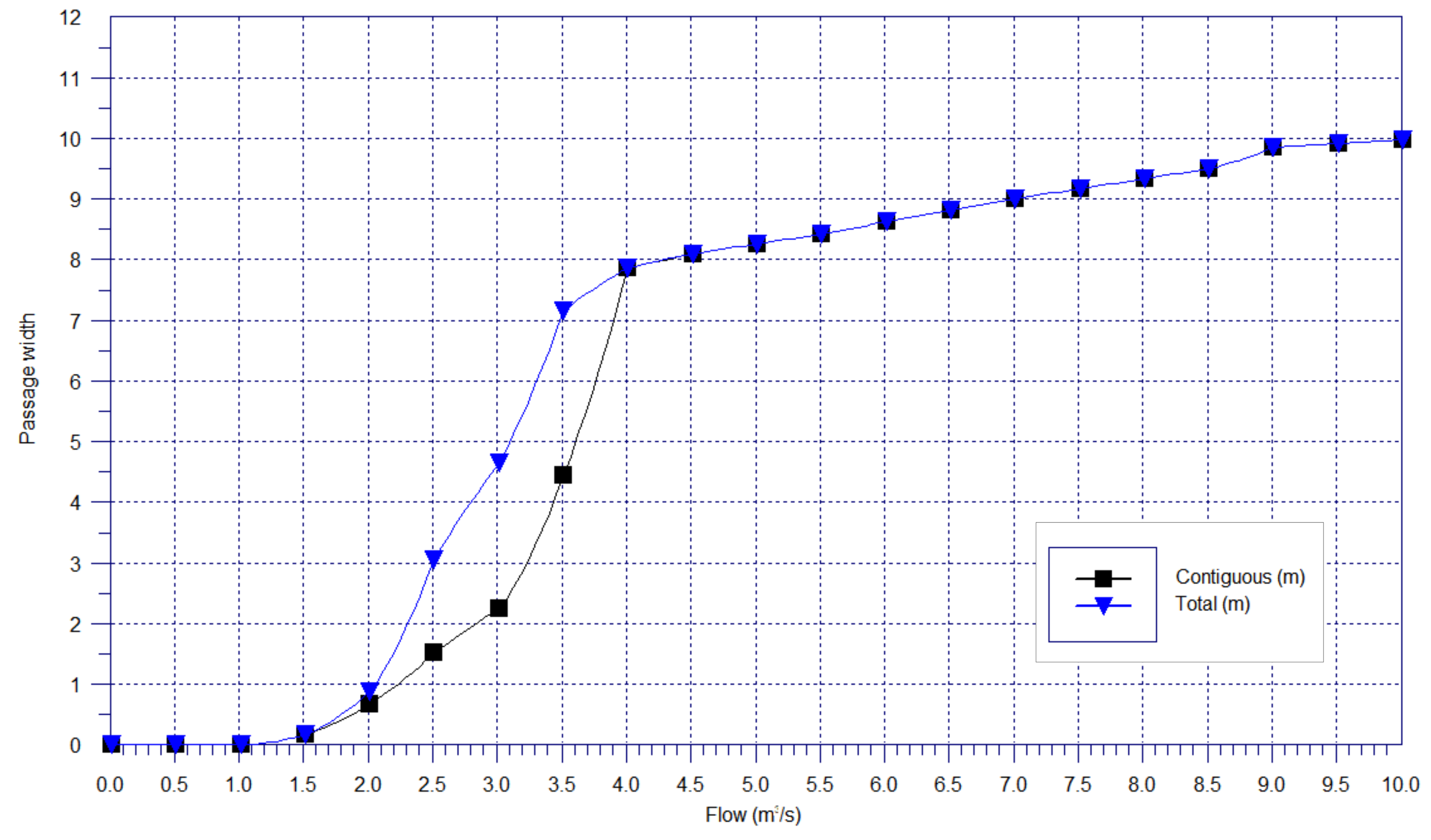


Figure 4-44. Koksilah River EFA, Adult Chinook Passage of Riffles. Passage criteria of >0.24 m depth and <2.54 m/s were used. Figure shows that, for the combined results of all six riffles in the EFA, migration of adult Chinook through riffles initiates between 1.0 to 1.5 m³/s. A continuous passage width of 1.0 m is realized at a flow of approximately 2.2 m³/s.

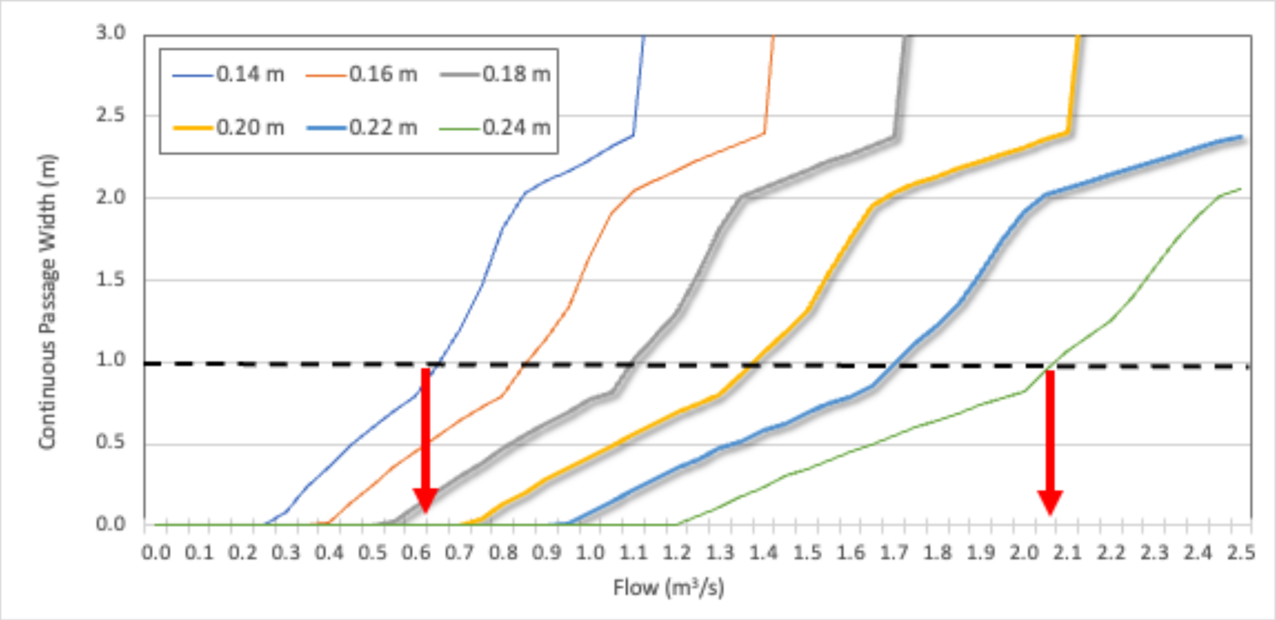


Figure 4-45. Koksilah River EFA, Upstream migration for adult Chinook salmon showing passage criteria, spanning depths of 0.14 m to 0.24 m to represent a broad range of body sizes. Figure shows that to <u>maintain 1.0 m of continuous passable channel width</u> flows of 0.6 m^3/s to 2.1 m^3/s would be required (red arrows).

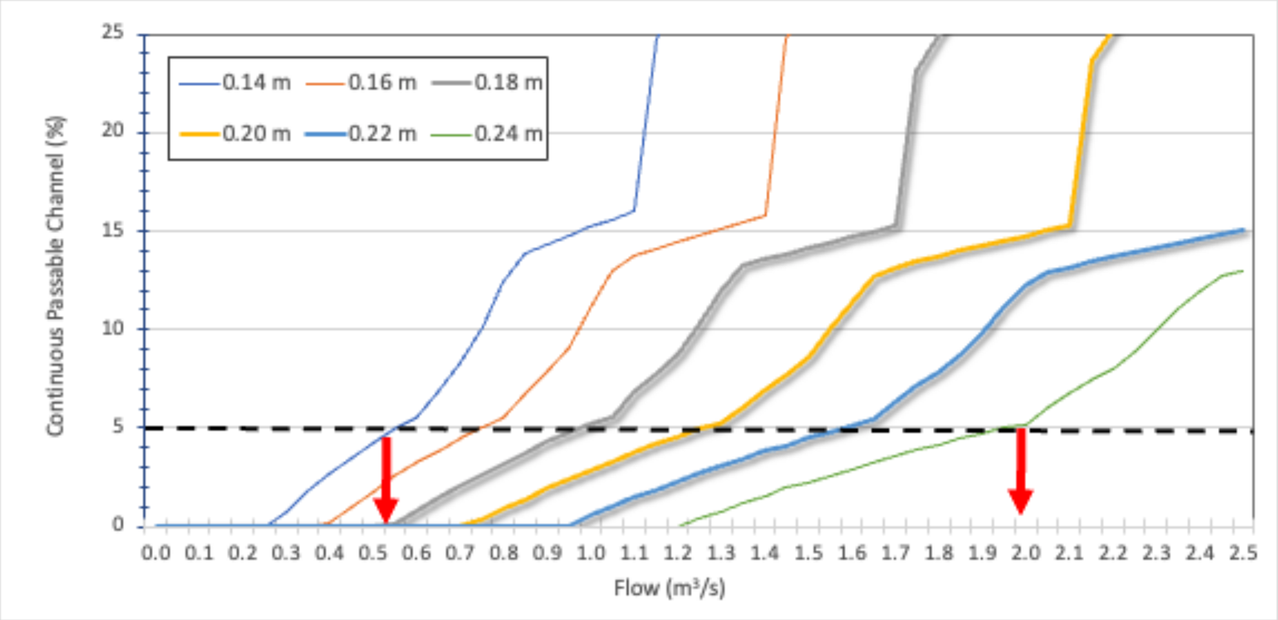


Figure 4-46. Koksilah River EFA, Upstream migration for adult Chinook salmon showing a broad range of passage depth criteria from 0.14 m to 0.24 m. Figure shows that to <u>maintain 5% of continuous passable channel width</u> flows of 0.5 m^3/s to 2.01 m^3/s would be required (red arrows).

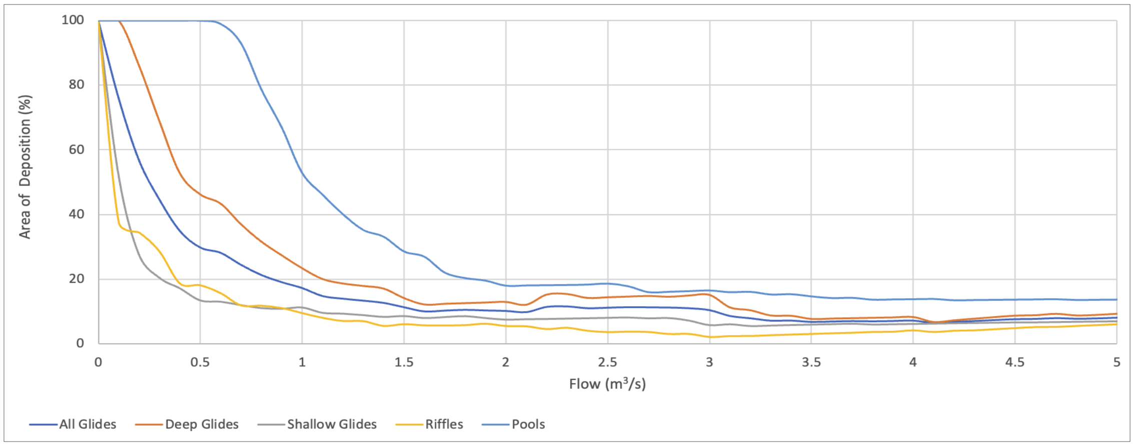


Figure 4-47. Koksilah River EFA, Silt Deposition for all Meso-Habitats.

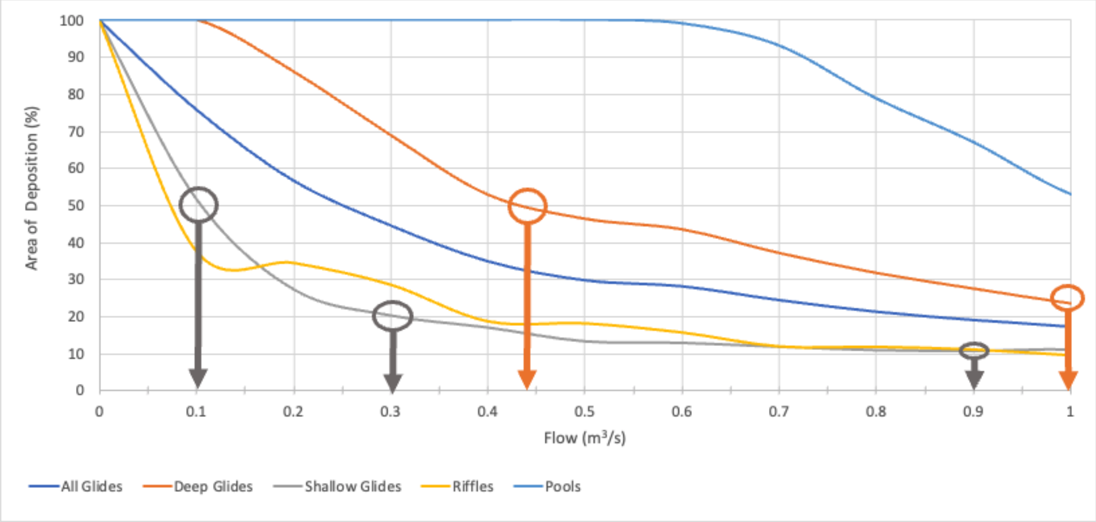


Figure 4-48. Koksilah River EFA, Silt Deposition for all Meso-Habitats. Figure showing the flow that corresponds to 10% and 50% Area of Deposition for Deep and Shallow Glides.

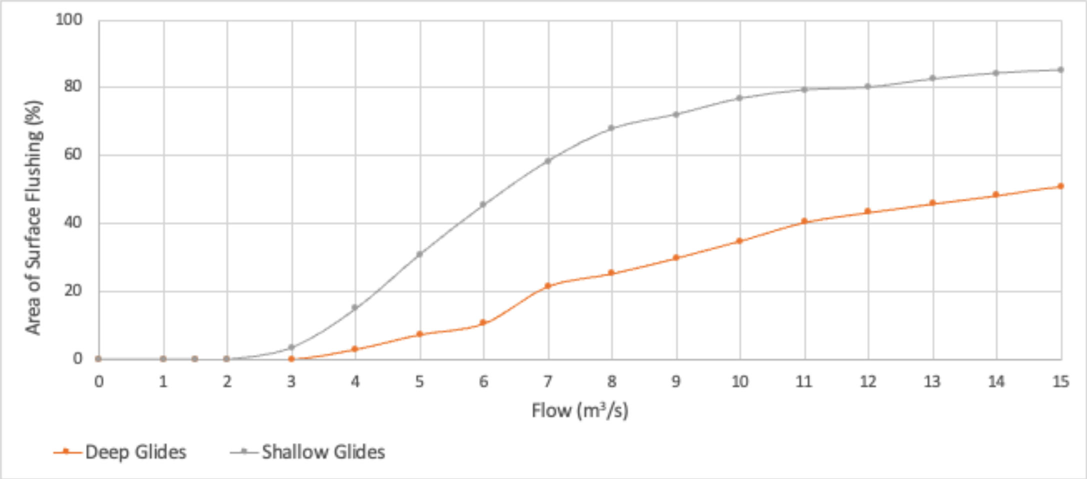


Figure 4-49. Koksilah River EFA, Surface Flushing for Deep and Shallow Glides.

Appendix 4E: Transect Photos

Photo 4-2. Transect 1.1 Looking Across the Stream

Photo 4-3. Transect 1.2 Looking Downstream

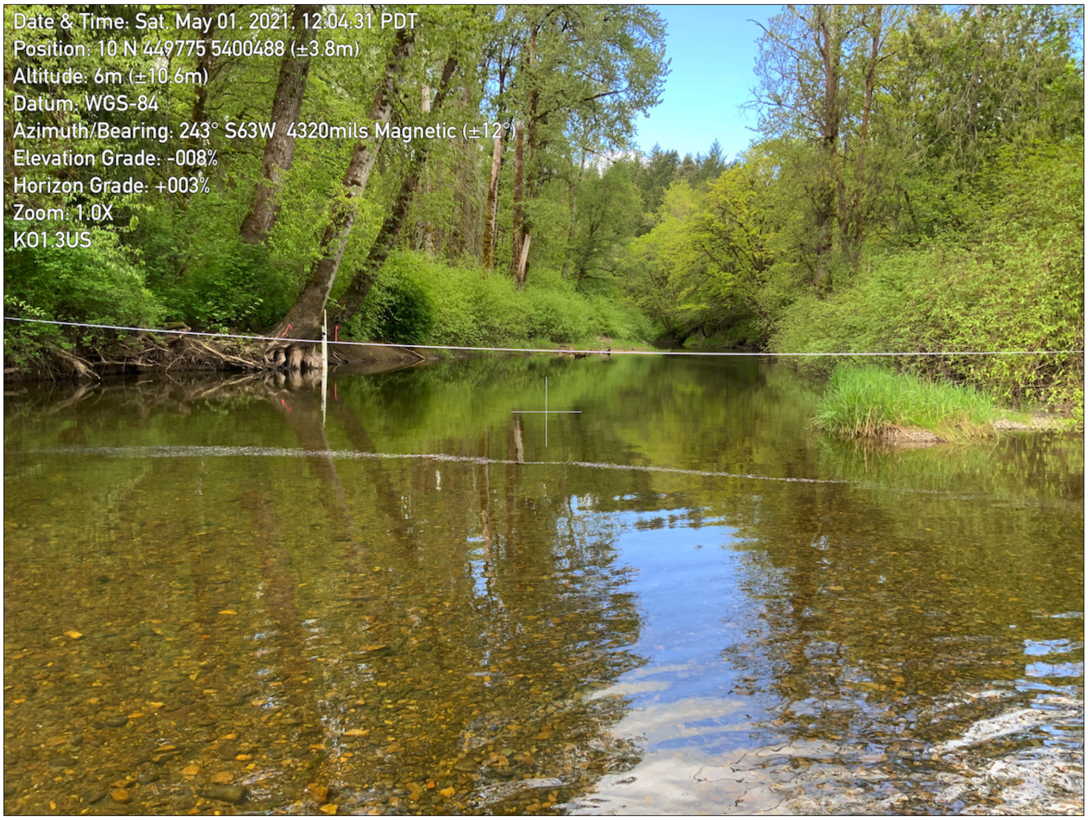


Photo 4-4. Transect 1.3 Looking Upstream

Photo 4-5. Transect 2.1 Looking Downstream

Photo 4-6. Transect 2.2 Looking Upstream

Photo 4-7. Transect 4.1 Looking Upstream

Photo 4-8. Transect 4.2 Looking Upstream

Photo 4-9. Transect 2.3 Looking Downstream

Photo 4-10. Transect 3.1 Looking Downstream

Photo 4-11. Transect 5.1 Looking Upstream

Photo 4-12. Transect 5.2 Looking Upstream

Photo 4-13. Transect 5.3 Looking Downstream

Photo 4-14. Transect 5.35 Looking Upstream

Photo 4-15. Transect 5.4 Looking Upstream

Photo 4-16. Transect 5.5 Looking Downstream

Photo 4-17. Transect 5.6 Looking Across Stream

Photo 4-18. Transect 5.7 Looking Upstream