BC Hydro

Campbell River Water Use Plan

Monitoring Program Terms of Reference

- **JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**

Revision 1

January 25, 2018

JHTMON-6 – Campbell Watershed Riverine Fish Production Assessment
Monitoring Program Terms of Reference
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REVISION RATIONALE

The purpose of JHTMON-6 is to resolve uncertainties of habitat-flow relationships for Quinsam and Salmon Rivers. The scope of JHTMON-6 assessment includes: a) flow-habitat relationship derived for Miller Creek and Salmon River; b) fish passage assessments for Quinsam River and Salmon River; and c) a comparative flow-habitat methodology assessment on the Campbell River downstream of John Hart Generating Station. The study area consists of Quinsam and Salmon Rivers in areas downstream of each diversion structure.

The Salmon River diversion was out of service in 2010 due to dam safety deficiency concerns. These concerns were temporarily addressed and Salmon River diversion was in operation for Year 1 (March 2015 to April 2016; Component 1, Wright et al. 2016; Component 2, Marriner et al. 2016) of the monitoring program. However, long term dam safety concerns persisted as well as issues regarding obstruction to upstream migration of adult salmon spawners and the effectiveness of a fish screen in the diversion canal to return entrained out-migrating salmon smolts to the Salmon River preventing diversion into the Campbell River (see JHTWORKS-6). Given the estimated costs associated with addressing these issues, decommissioning of the Salmon Diversion Dam was the preferred alternative for improving fish passage and eliminating dam safety concerns. Additionally, removal of the dam will restore the Salmon River to the natural river channel with no incremental impact to the environment resulting in a substantial reduction in BC Hydro's environmental footprint. With the support and approval by First Nations and regulators (including approval from the BC Utilities Commission to decommission the dam), BC Hydro started the deconstruction of the Salmon Diversion Dam on July 1st, 2017. As stated in Section 2.5 of thisTerms of Reference (TOR), in the absence of diversion, there is no diversion related Water Use Plan (WUP) impacts to be monitored for the Salmon River section of this monitor. Therefore all aspects of monitoring related to the Salmon River have been removed in this TOR Revision and all Salmon River monitoring will cease upon approval of this TOR revision by the Comptroller of Water Rights. A summary of the proposed Monitor changes are provided in Table 1 below.

Table 1: Key changes to the JHTMON-6 TOR and rationale for their inclusion.

Section	Change	Rationale
1.1 Background	• Removed Salmon River components and update cited references	• No diversion related WUP impacts to be monitored with decommissioning of Salmon River Diversion Dam
1.2 Management Questions	• Removed Salmon River components	• No diversion related WUP impacts to be monitored with decommissioning of Salmon River Diversion Dam
1.3 Summary of Hypotheses	• Removed Salmon River components	• No diversion related WUP impacts to be monitored with decommissioning of Salmon River Diversion Dam
1.4 Key Water Use Decision	• Minor text edits	• Improved clarity and consistency
2.1 Objective and Scope	• Removed Salmon River components • Edits to Table 2 to remove all Salmon River components • Edits to Table 3 to remove all Salmon River components	• No diversion related WUP impacts to be monitored with decommissioning of Salmon River Diversion Dam
2.2.1 Flow Habitat Relationships in Diversion Streams	• Removed Salmon River components • Updated text to include the use of 1D model	• No diversion related WUP impacts to be monitored with the decommissioning of Salmon River Diversion Dam • Year 1 report proposed the use of a 1D model in place up updating the existing model (Wright et al. 2016).
2.3.1.1 Review of Existing Information	• Replaced originally proposed work with reference of completed work.	• Specifying work has been completed
2.3.1.2 Data Captured and Model Development	• Removed Salmon River components • Updated proposed work to reflect recommendations included in Year 1 report (Wright et al. 2016) • Included reference of completed work	• No diversion related WUP impacts to be monitored with the decommissioning of Salmon River Diversion Dam • Recommendations developed as an outcome of the literature review completed in Year 1 (Wright et al. 2016) • Specifying work has been completed
2.3.1.3 Data Analysis	• Minor text edits • Included reference of completed work	• Improved clarity and consistency • Specifying work has been completed
2.3.1.4 Reporting	• Included reference of completed work	• Specifying work has been completed

2.3.2.1 Review of Existing Information	• Minor text edits • Included reference of completed work	• Improved clarity and consistency
2.3.2.2 Data Capture and Model Development	• Minor text edits • Included reference of completed work	• Improved clarity and consistency
2.3.2.3 Data Analysis	• Minor text edits	• Improved clarity and consistency
2.3.2.4 Reporting	• Included reference of completed work	• Specifying work has been completed
2.4.1 Flow-Habitat Relationship in the Diversion Stream	• Minor text edits	• Improved clarity and consistency
2.4.2 Fish Passage Prescription for Diversion River	• Minor text edits	• Improved clarity and consistency
2.5 Schedule	• Included reference of completed work • Removed Salmon River components	• Improved clarity and consistency; no diversion related WUP impacts to be monitored with the decommissioning of Salmon River Diversion Dam
3 References	• References added for Year 1 studies	• Improved clarity and consistency

1.0 Program Rationale

1.1 Background

A clear understanding of habitat-flow relationships is a key component of instream flow assessment and the decision-making processes associated with Water Use Plan (WUP) development. It allows for the development of performance measures that quantify, at least in relative terms, expected gains and losses of habitat quantity and/or quality that can be compared to the performance measures of other values in water resource trade-off matrix. This approach was used in the Campbell River WUP, but the fish technical committee (FTC) encountered several difficulties in its implementation, largely due to the lack of information created by incomplete studies and uncertainty in some of the methods used to quantify habitat. These difficulties in turn created considerable uncertainty in the decision making process, including uncertainty in the WUP's outcome as it relates to fish benefits. Furthermore, they could not be resolved within the time frame and budget constraints of the WUP.

To overcome these difficulties and allow the WUP to proceed, the habitat study work originally planned for the WUP was abandoned and a new, less data intensive approach was adopted to predict the outcome of flow changes. This new approach relied on the meta-analysis of other instream flow studies in the Pacific Northwest to predict flow-habitat relationships based on simple, easily obtained input variables (Hatfield and Bruce 2000, and Bruce and Hatfield, *in progress*). This approach however was new and untested. As a result, its acceptance by the FTC was conditional on the resolution of three critical areas of uncertainty:

1) Habitat-flow relationships in the diversion donor stream.

   Several difficulties arose during data collection and analysis of flow transects for Quinsam River, which prevented completion of analysis within the timeframe of the WUP. To proceed with the WUP, flow assessment of the diversion stream had to rely on regional data, meta-analysis modeling (Bruce and Hatfield, in progress) and professional judgment rather than site-specific information. Given that the modeling exercise was unproven, there was considerable uncertainty expressed by the FTC in its predictions.

2) Physical barriers to upstream migration in the diversion donor stream.

   During development of the fish passage performance measure (PM), the FTC identified the ability of fish to pass specific barriers at different flows as a key data gap. To proceed with the PM, the FTC used professional opinion to set critical passage flows. However, when doing so, considerable uncertainty was expressed by the FTC during the decision making process. The barriers of greatest interest to the FTC were falls and cascades on the Quinsam River.

3) Conflicting 1D (transect based) and R2D (triangular grid based) modeling results in the Lower Campbell River.

   As part of the data collection efforts of the Campbell River WUP, BC Hydro undertook two-dimensional hydraulic modeling of the lower Campbell River to quantify local, river hydraulics at different flows. Prior to the WUP a similar *one-dimensional model was developed on behalf of BC Hydro (see Burt and Burns 1995), but at a smaller scale. Part of the model verification process was to compare the two models, which uncovered conflicting results (e.g., the amount of spawning habitat and the shape of habitat-flow curves). These differences could not be resolved within the time constraints of the WUP and an alternative flow assessment method was used, which involved use of the meta-analysis models of Bruce and Hatfield (in progress). As noted above, reliability of the model was unproven and therefore, the FTC expressed considerable uncertainty about its results.*

The FTC recommended that a monitoring program be implemented to address each of these uncertainties so that the information can be used to confirm/validate the meta-analysis based decisions, as well as remove them as barriers to future WUP review decision making.

1.2 Management Questions

The three areas of uncertainty identified by the FTC lead to the following WUP related management questions:

1) What is the relationship between habitat and flow in the Quinsam River diversion route through Miller Creek for all salmonid species during their fry, juvenile, and spawning life stages?

   The scope of the flow-habitat study work presented here is different from that of the WUP work; it is more in line with WUP objectives and is directly related to performance measure needs (see below for more details on the scope change).

2) Are these empirical flow-habitat relationships consistent with meta-analysis results?

   A strong correlation between the two sets of results will add confidence in the WUP results. Conversely, a poor correlation will cause one to suspect the likelihood of observing the expected fish related benefits, and could in turn be the cause of a negative result in the fish abundance monitor (Monitor 8).

3) At what range of flows do migrating fish successfully navigate site-specific barriers on the Quinsam River, and is its frequency/duration sufficient to ensure successful migration?

4) What are the key differences between one- and two-dimensional hydraulic modeling approaches to habitat assessment of the stream? What are their strengths and weaknesses and what method should be used to model hydraulic/habitat conditions in lower Campbell River?

1.3 Summary of Hypothesis

The monitor is designed to address the Management Questions of Section 1.2 through the test of six null hypotheses. The first three hypotheses relate to issues surrounding the habitat – flow relationship and how they compare to the meta-analysis predictions used during the WUP process (Management Questions 1 and 2). These hypotheses can be grouped in to a single component of the monitor where the first two are direct investigations of the habitat flow relationship itself. The third hypothesis is concerned more with the causal link between the flow habitat relationship and fish production and is considered a compliance monitor (i.e., are the expected gains in habitat being realized, and do they result in greater fish abundance?).

$H_0$1: Over the range controlled by the diversion, flow does not affect the quantity and quality of fish habitat.

Hypothesis $H_0$1 will have to be tested for each species and life stage known to occur there. Although it is likely that the hypothesis will be rejected, its statement is still necessary as it sets up the study's design to collect the data necessary to assess and describe the relationship in either a General Linear Model (GLM, which includes ANOVA) or non-linear regression framework. This analysis will lead to predictive relationship of habitat area versus flow.

$H_0$2: The empirically derived flow-habitat relationship does not differ significantly from the predictions made by the Bruce and Hatfield (*in progress*) meta-analysis model.

Test of this hypothesis will determine whether the meta-analysis based flow habitat relationships used in the WUP are comparable to that empirically derived as part of $H_0$1 and is designed to address the uncertainty expressed by the Consultative Committee (CC) associated with its use. As in $H_0$1, hypothesis $H_0$2 will have to be tested for each species and life stage of resident salmonids.

$H_0$3: The frequency and duration of flow events outside the range considered to be optimal or near optimal for maximum habitat availability are not sufficient to cause measurable long term population impacts as indicated by fish abundance assessments.

Test of this hypothesis is a corollary to the hypotheses and management questions addressed in Monitor 8 that investigates the impact of flow variability on habitat utility and corresponding effects on fish behaviour. As in $H_0$1, hypothesis $H_0$3 will have to be tested for each species and life stage known to utilize them. Test of the hypothesis will rely on the salmonid population and/or stock assessment data collected in Monitor 8 as an indicator of population success.

The next hypotheses relate to Management Question 3 of Section 1.2. The fourth hypothesis is mainly concerned with the flow-passage relationship while the fifth hypothesis addresses uncertainty in the causal link between passage flow conditions and successful population migration.

$H_0$4: Over the range influenced by the impoundment/diversion structure, successful passage of upstream migrants in the diversion donor stream is unrelated to flow.

Given the anecdotal information collected to date, Hypothesis $H_0$4 will most likely be rejected. However, collecting the data to test the hypothesis sets up the study to provide the information necessary to identify the range of flows that allow successful passage. The hypothesis will have to be tested for each migrating species.

$H_0$5: The frequency and duration of flow events outside the range considered to be optimal or near optimal for successful passage (to be defined in consultation with federal and provincial fisheries agencies) are not sufficient to severely impede successful migration of the population.

As in $H_0$4, hypothesis $H_0$5 will have to be tested for each migratory species. A corollary of hypothesis $H_0$4 would be to determine whether the hydrological events that lead to unsuccessful migration are within the realm of control of the associated impoundment structure.

The final impact hypothesis is a direct test of the differences between two flow-habitat assessment methods, and is designed to address Management Question 3 of Section 1.2. The comparative assessment of Bruce (2004) will serve as the theoretical backdrop of the monitor.

$H_0$6: Habitat-flow relationships derived from hydraulic data collected through 1D (i.e., transect based) and R2D (triangular grid based) are not significantly different.

If $H_0$6 is rejected, then a series of follow up, analytical investigations will have to be carried out to clearly define the reasons why, and in turn identify the advantages of each method and conditions for their use in data collection.

1.4 Key Water Use Decision

For a variety of reasons, the flow-habitat studies designed to provide the information necessary for WUP decision making could not be completed within the time frame of the WUP process (Anon 2004), requiring that an office based modeling exercise, vetted by a professional opinion, be used to guide much of the necessary flow habitat assessments and decision-making processes. Because the meta-analysis modeling exercise was largely an unproven technology, this created considerable uncertainty among FTC members, as well as CC members, about the expected fish benefits of the consensus WUP. In light of this uncertainty, the CC recommended that a monitoring program include studies that will complete the WUP studies initiated during the data collection phase of the process. Such a monitor would serve two main purposes; 1) provide confirmation that the decisions made during the WUP process in the absence of site specific data were appropriate and that they did not create unforeseen impacts; and 2) provide reliable, site specific assessment tools to better evaluate future operational changes.

Results of the monitor would also be used in concert with the fish population monitoring at the diversion stream and the lower Campbell River mainstem (Monitor 8) to verify that the expected fish benefits resulting from implementation of the WUP is indeed being realized. It will also provide the necessary diagnostic information to determine the cause if not. Collectively, results of this monitor will further improve the knowledge base from which future WUP-related decisions will be made.

2.0 Program Proposal

2.1 Objective and Scope

The objective of this Monitor is to address the Management Questions presented in Section 1.2 by collecting data necessary to test the impact hypotheses outlined in Section 1.3. The following aspects define the scope of the study:

1) Study areas will be limited to those areas below BC Hydro diversion facility within the area of operational influence. For each study component, the study areas are as follows:
   - Flow-habitat relationships are to be derived for Miller Creek from the diversion dam to the confluence of Lower Campbell Lake reservoir;
   - Fish passage assessments will be carried out in Quinsam River from the diversion dam to the confluence of Lower Campbell River; and
   - The comparative flow-habitat methodology assessment will be carried out in the non-tidal portion of Campbell River, between the John Hart Generating Station (JHT GS) tailrace and the Highway 19 south-bound bridge.
2) Each component will be completed over a three-year period, but their timing need not overlap. The entire program should be completed before the next WUP review period 10 years following implementation of the WUP. For planning purposes, it is assumed that the three studies will be carried out in sequence, starting with the fish passage component, followed by the development flow habitat relationships, and ending with the flow habitat model comparison in Lower Campbell River.
3) The species and life stages of interest are as indicated in Tables 2 and 3, which include the periodicity of each life stage. It should be noted that the species and life history timing indicated in Tables 2 and 3 were derived during the Campbell River Water Use Plan though technical discussions among FTC members (Anon 2004).

Table 2: Passage timing for defining salmon and steelhead passage prescriptions for Quinsam River

Spawning Migration Timing of Passage Suitability Analysis		
	MAD (cms): 2.96	
	Start	End
Chinook	21-Sep	31-Oct
Coho	21-Sep	31-Oct
Pink	01-Aug	14-Oct
Winter Steelhead	15-Oct	14-May
Summer Steelhead	Not Applicable	

Table 3: Life history timing used to derive salmon and steelhead flow requirements for the Quinsam and Lower Campbell Rivers.

Habitat Use Timing for Rearing and Spawning Salmonids					
		Quinsam River		Lower Campbell River	
		Start	End	Start	End
Spawning	Chinook	01-Oct	30-Nov	07-Oct	23-Nov
	Coho	15-Oct	15-Dec	15-Oct	15-Dec
	Pink				
	Rainbow	01-Feb	30-Apr	01-Oct	15-Dec
	Winter Steelhead	01-Aug	14-Oct	01-Mar	15-Apr
	Summer Steelhead	Not Applicable		Not Applicable	
Rearing	Chinook Fry	07-May	23-Jul	07-Mar	23-Jul
	Coho Juveniles	15-May	31-Oct	15-May	31-Oct
	Pink Juveniles				
	Steelhead Fry	23-Jun	31-Oct	23-Jun	31-Oct
	Steelhead Parr	15-May	31-Oct	15-May	31-Oct

1) All field sampling will be carried out in a standardized manner and follow a specified schedule to ensure consistency among years in data quality and collection procedures.
2) A data report will be prepared annually, summarizing the year's findings. All data will be archived in a format to be developed in consultation with BC Hydro staff.
3) A final report will be prepared at the end of the Monitor that summarizes the results of the entire Monitor, discusses inferences that can be drawn pertaining to the impacts of the WUP over time, and presents conclusions concerning the management question in Section 1.2 and the impact hypotheses in Section 1.3.

2.2 Approach

This monitor will be carried out as a series of three independent studies, each corresponding to one of the critical uncertainties identified by the CC in Section 1.1. This TOR provides a description of the studies as they are presently conceived, but contractors are encouraged to suggest improvements, provided that they do not alter the monitors' scope and continue to satisfy the studies' objectives as described above. In general the approach recommended for each study component is as follows:

2.2.1 Flow-Habitat Relationships in Diversion Stream

This will be a three-year study that combines the development and calibration of a transect-based flow-habitat model with physical surveys at key transects at the Quinsam River study location. This monitor will require completion of a 1D physical habitat model to simulate velocity and depth characteristics for a range of flows (Wright et al. 2016), calibration of the model, and verification of model results in relation to meta-analysis predictions. Results of the study will be used to develop species and life stage specific flow-habitat relationships for each system and to compare them with the theoretical curves used in the WUP.

2.2.2 Fish Passage Prescriptions for Diversion Rivers

This will be a three-year study that will combine a literature review of salmonid passage requirements with a field survey at known locations below the diversion structures. Passage success will be based on the presence of migrating fish above known barriers established through repeated snorkel observations following specific flow events. The study will be primarily opportunistic in nature, though some experimental trials are encouraged should the conditions allow. Results of the study will be used to define the passage flow requirements of adult salmon migrating upstream of each system.

2.2.3 Flow-Habitat Analysis of Lower Campbell River

This will be a three-year study that will combine the refinement of an existing two-dimensional (2D) habitat model developed for the Campbell River WUP with a thorough review of existing habitat use information of key Campbell River rearing and spawning sites. The same data used in the 2D model will be used to construct similar relationships using the 1D (transect based) approach. The results will be compared to identify the advantages and disadvantages of each approach, and ultimately lead to a selection of the best methodology based on geomorphology of the Campbell River, the quality of data that each approach develops, and the type of data that best addresses the impact hypotheses and management questions of interest.

2.3 Methods

The methods described below are designed to satisfy the objectives of the studies as defined by the CC during the WUP process, and to assess the hypotheses as stated in this TOR. All proposed changes must meet the objectives and information requirements set out in this TOR and must not add to scope of this monitor.

Each component of the monitor will involve the following activities:

1) Review of existing information:

   A review of WUP study requirements, data collection procedures, and the extent of study completion will be requikred to a) finalize the scope of work needed to bring each of the tasks to completion; b) establish familiarity with the underlying assumptions and rationale for the WUP work; and c) finalize the work plan details for data collection, model development and impact hypothesis testing.

   This has been completed for flow-habitat relationships (Wright et al. 2016) and fish passage (Marriner et al. 2016).

2) Data Capture and Model Development:

   Based on the work plan established from the information review process, data will be collected as required to complete the development/calibration of models and/or to address impact hypotheses.

3) Data Analysis:

   Flow-based analyses will be carried out to establish species and life history specific flow-habitat requirements for each site. These will be based on the flow habitat relationships developed in the preceding work, the nature of which will be different for each of the study components.

4) Reporting:

   In general, reporting will consist of semi-annual updates, a work plan to be completed in Year 1 of the monitor, and a final report due at the conclusion of each monitor. A separate series of reports will be prepared for each component of the monitor.

2.3.1 Flow-Habitat Relationship in the Diversion Stream

2.3.1.1 Review of Existing Information

The literature review was completed in Year 1 of the Flow-Habitat Relationship Component (Wright et al. 2016). The Year 1 report provides a work plan specifying methods for required data collection, analyses and hydraulic modeling to be undertaken over the remaining two years of the study.

2.3.1.2 Data Capture and Model Development

All literature review and work plan development has been completed and provided in the Year 1 report (Wright et al. 2016). Field work is expected to commence in late summer or fall when flows in the stream will be at their lowest. Data collection at higher flows will occur throughout the winter and spring of the following year. Model calibration and analysis is to start in the summer of second year and should be completed by the third year of study. To ensure that the time line is met, and refinements to the transect model should be completed prior to the calibration work. Some sampling effort will be set aside during the second year and third year for additional data collection should the need become apparent during the modeling work.

Study Design

Flow habitat relationships will be developed at Miller Creek from the Quinsam Diversion dam to its outlet into Lower Campbell Lake Reservoir. Fifteen transects will be completed to adequately characterize a flow habitat relationship.

Transect placement within the study location should follow a stratified random sampling regime where the total number of transects will be distributed among the specified reaches in proportion to their length (each reach is considered to be a stratum). Within each reach, transects are to be placed roughly in the center of either riffle or glide habitats in relative proportion to their availability (pool data are excluded because hydraulic changes as a function of discharge are much less pronounced than other unit types). The riffle and glide habitat units are to be selected at random from a database of units, but with the constraint that they must be easily accessible and can be safely sampled (i.e., if the habitat unit selected is deemed unsafe to access or sample, another will be randomly selected).

A database of habitat units will be required in order to set up the study design. A fish habitat database for Miller Creek (AMEC Earth and Environmental, 2004) has been constructed using provincial Fish Habitat Assessment Procedures (FHAP) (Johnston and Slaney 1996). Where possible, the location of each habitat unit should be marked on air photos for later reference. This will simplify the assessment of whether a chosen site is accessible and safe to sample, as well as aid in relocating the unit if selected for transect placement.

In the field, transect locations will be marked by survey pins on either side of the study stream above the high water mark. The pins can be installed to bedrock with a hammer-drill and used as elevation benchmarks for comparing water surface elevation. The pin locations will be recorded using corrected GPS data, as well as relative to one another using compass bearings and distance measurements (this will simplify relocation of the second pin once the first one has been found). Photographs of each transect should also be taken from both upstream and downstream perspectives.

Procedures used for water velocity and cross-sectional area measurement as well as discharge calculation at selected transects should follow the methods described in Gore (1996) or USGS (2005).

The scope of the present work is considerably smaller than what was originally conceived during the WUP. Much of the WUP work was based on a set of study requirements established well in advance of stakeholder discussions on fish habitat issues and their corresponding water management objectives. This fast-tracking was done to ensure that the information would be available in time for use during the WUP project. To ensure that all possible issues could be dealt with, the scope of the WUP work was such that all areas were investigated. In addition to the location listed above, this included Crest Creek below the Heber diversion outlet to the confluence of Elk River, the Elk River from the Crest Creek confluence to the outlet into Upper Campbell Lake reservoir, the Quinsam River mainstem downstream of the Quinsam Diversion Dam, and the Salmon River diversion route from the outlet of the diversion canal into Fry Creek to the Fry Creek outlet into Lower Campbell Lake reservoir. The reasons for excluding this work from the present monitor are as follows:

Crest Creek – The Crest Creek diversion structure is considered to be outside the scope of WUP as it does not have any infrastructure to control flow. As well, the concept of a minimum flow release to Crest Creek was considered to be contradictory to the First Nations concerns regarding the inter-basin transfer of water.

Salmon River Diversion – No minimum flow requirements were established during the WUP that would require confirmation. A habitat assessment found the system was generally of poor quality with little potential to sustain large populations of fish. Though fish were caught throughout the system, their numbers were very low. Some of the catch was believed to be strays from the Salmon River mainstem. Though the system could benefit from increased minimum flows, this would be at the expense of Salmon River flow requirements that are already considered to be critically low during periods in the winter and the summer. Further, the decommissioning of the Salmon River Diversion resulted in no diversion related WUP impacts to be monitored.

Quinsam River Mainstem – The Quinsam river mainstem downstream of the diversion structure was the only flow-habitat study that was successfully completed during the WUP process. Results of the work are more than adequate to meet the needs of future WUP reviews.

Data Requirements

In general, field work will consist primarily of hydraulic surveys of transects that are located based on a stratified random sampling design of habitat units in the study area. The surveys are to be carried out at several flows leading towards the development of a flow-habitat relationship. See Wright et al. (2016) for data requirements at each transect.

Survey Methods

There will be two aspects to the transect survey. The first will consist of hydraulic surveys across each transect with the goal of developing a model to simulate depth and velocity over a range of flows. The second aspect will be the collection of independent discharge and stage height measurements at each transect, including other hydraulic parameters such as energy slope and relative roughness (using Hicks and Mason (1991) as a reference for comparison). These data will serve as the primary inputs to the transect model to estimate habitat suitability at flows other than those observed during the transect profile survey.

The hydraulic surveys should, as a minimum, consist of the following data to be consistent with previous work:

1) Date and time, crew, water and air temperature;
2) System, reach number, and habitat unit type (pool, glide, riffle, cascade);
3) Unique transect name or other identifier;
4) Tag identifiers for left and right pins marking the location and orientation of the transect relative to the channel's bank-full state;
5) Identification of control features upstream of the transect (a hand drawn map is best, backed up with photographs), including large woody debris, large boulders, shoals or gravel bars;
6) While facing downstream, measure water surface elevation (WSE) relative to the left bank pin elevation at both left and right banks of the transect line and 15 to 30 m upstream (preferably within the habitat unit); and
7) At a minimum of 15 stations (at 0.5 to 1 m intervals) across the transect line, measure;
    a) water depth (m);
    b) average column velocity (measure velocity at two-thirds of the water depth when depth is less than 60 cm, otherwise measure at one-fifth and four-fifths of the water depth);
    c) substrate type as dominant/subdominant using boulders, cobbles, gravel, fines and vegetation as key substrate categories (Johnston and Slaney 1996); and

d) Available cover as a percentage of the station interval width and cover type (using Johnston and Slaney 1996 definitions).

All data should be collected in a standardized way and entered into a database format consistent with the transect model's input requirements. The database format should be developed in consultation with BC Hydro staff to ensure consistency across all Monitors.

Transect Flow Model

The flow model will be a stand-alone predictive tool that will integrate physical parameters collected at the transects of interest with relationships governing hydraulic response to changes in flow level (water surface elevation), transect profile, and slope (physical and energy slopes), as defined in Chiu et al. (1976). Hydraulic response equations will be refined according to calibrations conducted at each transect, such that transect hydraulics under different conditions (high/low energy, confined/un-confined, etc.) can be modeled without further calibration. The flow model will have the following attributes:

1) Be programmed in Visual Basic (VB) and set-up as a Windows executable file;
2) Contain a graphical user interface and a data import tool for entering transect data specific to direct hydraulic predictions and calibration data. Data will be spatially defined and stored in a Microsoft Access database;
3) Provide two-dimensional hydraulic predictions for each transect flow and provide additional data import functions to incorporate habitat use indices (defined outside of these study terms), such that hydraulic response can be reported in terms of habitat response for fish species life histories of interest (see Table 3); and
4) Provide reporting functions according to the level of information provided, such that users with incomplete information can identify data gaps to focus on, and users with complete information can summarize the habitat response for the flow range of interest at each site.

Much of the VB programming has already been done (by J. Bruce and A. Leake of BC Hydro), including set up of a graphical interface. This work however is still incomplete. The area requiring the greatest work is in establishing a robust optimization routine to solve for two unknown variables that are used in three equations. Another possible issue is one of compatibility with newer versions of the VB programming language; the current program was written in VB 5.0 which has since become obsolete. The contractor will be expected to work with BC Hydro staff to finalize the programming work done to date and create a standalone product that can be used in future Campbell River flow-habitat studies, as well as in other BC Hydro systems where flow-habitat data are to be collected.

2.3.1.3 Data Analysis

All data will be entered into a database developed in consultation with BC Hydro for subsequent analysis. This will ensure that data collected over the years are compatible and can be extracted and compared without concern regarding differences in file format. BC Hydro will provide direction on data entry and file formats. Some refinements may be required to the presentation formats and analyses suggested below, following collection and review of data. Contractors and BC Hydro are expected to make the adjustments necessary to ensure that the best methods are used throughout the analytical process.

It should be stressed that the analyses described below are to be repeated for each species and life stage of interest. In addition, where applicable, the assumptions of homoscedasticity, normality and independence are to be evaluated to the extent possible. Where required, either an appropriate transformation algorithm is applied to the data set or an alternative equivalent, non-parametric statistic should be used. For full details, see Wright et al. (2016).

Data analysis will consist of several steps, beginning with the derivation of species and life stage specific flow habitat relationships using the newly calibrated transect-based habitat model. Using the standardized habitat suitability curves selected by the Campbell River FTC (one for each species and life stage), the depth and discharge data generated by the transect model for each test flow will be converted to a measure of Weighted Usable Area (WUA) using the methods of Bovee (1982). A WUA measure will be derived for each of the three test flows where basic survey data are available, as well as beyond the measured range (by no more than 1.5 times the highest measured flow) using extrapolation techniques. Interpolation techniques will be used to obtain WUA data in between the three test flows. Both interpolation and extrapolation will be done on Chiu et.al. (1976) critical hydraulic variables rather than on the WUA data themselves. This will ensure that the interpolated WUA values are consistent with the channel's shape and local hydraulic nuances captured in Chiu et.al. (1976) variables. Through interpolation and extrapolation, a flow-WUA curve can be derived that spans the full range of flows that are of interest, with individual WUA estimates available across a set interval of modeled flows (e.g., every 0.5 m^3/s starting at 1 m^3/s).

Flow-WUA curves will be derived separately for each transect. Each species and life stage-specific WUA curve at a given transect site will be considered a single observation. Calculation of an average WUA curve for a given species or life stage will be done by averaging all WUA estimates for a given discharge across all modeled discharges in the range of interest. If some transects are considered more important or valuable than others, a weighted averaging scheme can be used where a weighting value is assigned to each transect that reflects its relative importance.

Estimates of standard error will be calculated using bootstrapping techniques. WUA curves will be randomly selected with replacement from the set curves derived for each transect and averaged as described above. This process is repeated for at least 1000 times. The 5^{th} and 95^{th} percentile values of WUA at each of the modeled discharges will form the 95% confidence interval of the flow-WUA curve. These calculations will form the basis of addressing hypothesis H_01.

To test H_02, the average WUA curve derived above will be compared to the meta-analysis curve used in the WUP using both regression analysis and subjective assessment. The WUA / %Maximum Habitat values of both curves will be rescaled so that the respective maximum values are both equal to an index value of 1. Then for each discharge, the index values will be plotted against each other for regression analysis with an intercept fixed *a priori* at 0. Subjective assessment will simply be based on a direct comparison of the regression shape of indexed values vs. discharge. Among the key items to consider includes the discharge of peak habitat area, the broadness of the curve near the peak, rate at which habitat increases with discharge as it approaches the peak, and the rate of habitat change as discharge moves away from the peak. Depending on the degree and nature of similarity the contractor may, and indeed is encouraged to employ other more rigorous methods of comparison.

The final component of data analysis is to examine the relationship of habitat availability each year with the various measures of annual fish productivity (Monitor 8). Assuming that there will be sufficient annual variability in the population abundance measurements and habitat availability, a correlation analysis should be carried out to determine if there is a link between the two measures. If the comparison of the flow habitat relationships above finds that the two methods of derivation yield different results, a correlation analysis with the population abundance data may shed light as to which method provides a more accurate measure of habitat availability in relation to prevailing discharge. The corollary of the analysis is that, should a dramatic change in population abundance be observed, a significant correlation would indicate that habitat availability, driven by prevailing discharge, may be the main cause (Monitor 8).

2.3.1.4 Reporting

Over the three years of study, annual reporting will be as follows:

1) Year 1 annual data report has been completed (Wright et al. 2016). The report summarized the work completed during the WUP, identified data needs, described the chosen transect locations and rationale for selection, and presented a fully functional transect-based habitat modeling software. It also included a draft version of a user manual.
2) Year 2 annual data report will summarize the data collected at each transect site, the modeling results, and present the model derived flow habitat relationship prepared to date. The report will also identify all outstanding data needs for collection in the following year. Though it may be possible to collect all flow data at all transects in one year, work done to date has shown that there is a high likelihood that the full range of test flows may not be available in one year. One or more hydraulic years may be required. For planning purposes it is assumed that a second year of data collection is required.
3) The Year 3 final report will summarize all data collected to date, including a description of all derived flow habitat relationships. This final report will report on the test of all hypotheses above, and provide a flow habitat analysis framework for use in future WUP review processes.

In general, the annual data reports will summarize the year’s findings and include a short discussion of how the year’s data compare to that collected in previous years. It will include a brief description of methods, present the data collected that year, and report on the results of all analyses.

At the conclusion of the Monitor in Year 3, a final comprehensive report will be prepared from all of the data and/or annual reports written to date that:

1) Re-iterates the objective and scope of the Monitor;
2) Presents the methods of data collection and analysis;

3) Describes the compiled data set and presents the results of all analyses;
4) Presents the result of all impact hypothesis testing and their consequence in terms of addressing the Management Questions in Section 1.2; and
5) Discusses the consequences of these results as they pertain to the current BC Hydro operations.

The final report should also include a detailed user manual for the transect model, along with a robust (error free) standalone version of the model. Each report will be due in spring of the year following the data collection period.

2.3.2 Fish Passage Prescriptions for Diversion Rivers

2.3.2.1 Review of Existing Information

The monitor began with a comprehensive literature review of existing information on the threshold attributes of streams that hinder passage for each of the fish species of interest, including all of the information held by the Fisheries and Oceans Canada (DFO) and Ministry of Environment (MOE) concerning fish passage issues on the Quinsam and Salmon diversion streams (Marriner et al. 2016). Included in the review process was a collation of all relevant transect information and flow analyses (stage and velocity-discharge relationships) done in the past, including the work being carried out in Section 2.3.1.

The key outcomes of the literature review include:

1) Clear definition of fish passage thresholds/criterion;
2) Stream specific migration periodicity of all species of interest;
3) Identification of known fish barriers in each of the diversion streams, including a chronological listing of all experimental and/or anecdotal observations of fish passage issues;
4) Collation of the necessary hydraulic information that would allow calculation of discharge and other local stream hydraulic conditions at each site of interest based on easily obtained field observations;
5) An office based assessment of whether a given barrier can become passable should an appropriate flow be provided. Such an assessment will allow ranking of sites where flow would have the greatest impact on passage, as well as eliminate sites from the study that lie above barriers that are impassable regardless of discharge; and
6) Estimates of habitat gains or losses should each potential barrier issue be resolved.

2.3.2.2 Data Capture and Model Development

The general approach to the study will be to carry out regular inspections of all known barriers in the system with the intent of collecting local, barrier-specific hydraulic data (stage height and wetted width) at various flows, as well as noting the presence or absence of migrating fish upstream the given barrier under investigation. The intent of these frequent inspections is to identify those times that fish have made it past a particular barrier, and to note the discharge during which it occurred. For the most part, the study will rely on the natural variability of flows within study stream to provide a range of test flows, though it is recognized that it may be necessary to arrange specific releases with BC Hydro. Such requests will only be considered by BC Hydro on an individual basis as it may not always be possible or practical to provide such releases.

It should be noted that the present study is concerned primarily with passage issues that are related to low flow conditions. Passage issues associated with high flows are assumed to be periodic in nature, generally of short duration, and tend not to be sensitive to operational changes. In situations where field evidence suggests otherwise, the circumstance will be identified, but further study will be carried out as it is considered outside the scope of the present monitor.

Study Sites

Critical fish passage barriers have been identified from the literature review and discussions with local fisheries agency staff (see Marriner et al. 2016). These have been located in the field by reconnaissance survey. The physical characteristics of each index site has been described in detail, including the type of barrier (e.g., log jam, falls, shallow riffle), height or length of barrier, water depth and flow characteristics at time of survey, along with photo-documentation of the site from established reference points at, above and below the barrier. The reference site photographs will be repeated throughout the survey period. UTM coordinates have been obtained by GPS for each site as well. Included in this initial reconnaissance survey was identification of potential holding areas and spawning habitats most likely to be used by in-migrating fish should they be able to get past the barrier of interest. Regular visits to these sites will be the primary means of establishing the presence/absence of fish and if possible, relative abundance.

Also during the initial reconnaissance survey, a temporary staff gauge was installed upstream of the barrier to track river stage through time with each site visit. The stage data was related to estimated river discharge (done by watershed analysis using existing water survey gauging stations as well as relevant flow data from other monitoring study work, such as the habitat study in section 2.3.1) in order to establish a percent mean annual discharge (%MAD) criterion for successful passage where warranted.

Data Collection

Data collection at the study site will be carried out over the fall and spring months in accordance to the migration periodicity of species of interest. At a minimum, data will be collected on a weekly basis, but the frequency of visits can be increased to daily intervals to capture passage events during period of fluctuating flows. For planning purposes, it will be assumed that spawning occurs over a six week period both during the fall and spring, and that site visits would have to be made every third day (i.e., 14 survey days per season). To ensure optimal distribution of survey time relative to a system's prevailing hydrology, the survey team will have to constantly be aware of prevailing flow conditions, as well as be aware of the potential for change in the very near future given upcoming weather conditions and operations. The contractor is encouraged to maintain daily contact with BC Hydro staff for information pertaining to short-term forecasts of stream flow. It should be noted here that precise forecasts are not necessary and crew deployment strategies can be established based only on general patterns of flow change (e.g., whether there will be a rapid or gradual increase or decrease in flows over the next few days based on the likelihood of incoming rains and current BC Hydro operating practice).

All data will be collected by a two person crew, which may require the use of snorkel gear depending on site accessibility. The data to be collected during each survey visit include:

- River stage at the time of the survey (discharge will have to be estimated as well, but can be done later in the office);
- Photographs from each reference location using the same camera settings (magnification, focal length, etc.) to create a series of directly comparable photos linked to river stage (and in turn discharge);
- Fish presence/absence immediately downstream of the barrier of interest (relative abundance data should be collected if possible); and
- Fish presence/absence upstream in the holding and spawning areas upstream of the barrier identified during the reconnaissance survey (relative abundance data should be collected if possible).

In addition to the field survey data above, the following data will be tracked:

1) Daily weather conditions, including average level of precipitation for the area,
2) Daily discharge estimate (based on Water Survey Canada gauging data and watershed analysis), and
3) The year’s run timing for salmonids in adjacent areas in order to confirm periodicity (based primarily on casual interviews of local and regional biologists that work in the area, including Quinsam Hatchery staff)

Survey data can be collected for up to three years to ensure that all reasonable flow conditions have been adequately explored (i.e., the 14 survey days per season can be dispersed as required over the three period). For planning purposes, it is assumed that much of the work will be done in Year 2 of the monitor, but that need not be the case. During the last year of the monitor, should there be critical missing information at a particular discharge, the contractor may submit a request to BC Hydro to deliver a specific flow. It should be noted however, that the capacity to regulate flows at each of the diversion structures is limited as there is no upstream storage except for Wokas Lake Dam. As a result, it may not be feasible or practical to satisfy the flow request.

2.3.2.3 Data Analysis

All data will be entered into a common database in a BC Hydro standard format for subsequent analysis. This will ensure that data collected over the years are compatible and can be extracted and compared without concern regarding differences in file format. BC Hydro will provide direction on data entry and file formats. Some refinements may be required to the presentation formats and analyses suggested below, following collection and review of data. Contractors and BC Hydro are expected to make the adjustments necessary to ensure that the best methods are used throughout the analytical process.

It should be stressed that the analyses described below are to be repeated for each species of interest. In addition, where applicable, the assumptions of homoscedasticity, normality and independence are to be evaluated to the extent possible. Where required, either an appropriate transformation algorithm is applied to the data set or an alternative equivalent, non-parametric statistic should be used.

Data analysis will consist of several steps, starting with the conversion of the stage elevation observations collected in the field to discharge measurements based on estimates of prevailing flow at each site (derived through watershed analysis). The relationship will in turn be used to validate, and if need be calibrate, the analytic methods used to estimate discharge at the site. With this relationship in hand, a daily time series of discharge can be derived for the site for use in subsequent analyses.

The next step of the analytical procedure will be to collate the photographs into a sequence of increasing discharge in order to better appreciate the hydraulic conditions at a given barrier site relative to prevailing discharge. This photo-document will provide invaluable information when trying to corroborate anecdotal or experimental results, as well as aid in draw inferences and conclusions from the data.

At a minimum, the presence/absence data will be plotted as a time sequence to be compared with the daily discharge. The temporal relationship between the first observation where fish presence has been noted above a particular barrier and the day's (or previous day's) discharge will give the first indication of a threshold discharge for passage. Calculation of this threshold value in subsequent years will add greater confidence as to what the range of passage flows should be using one or more of the meta-analysis techniques available to collectively analyse the data (e.g., averaging the annual threshold data, or establishing a range).

In cases where relative abundance data could be collected, similar comparative plots should be prepared, but the analysis will be focused on all those observations where a significant jump in upstream fish numbers occurs. The day's (or previous day's) average discharge where each of the jumps in upstream spawner abundance increase will be selected as the key discharge data that will be used to define the fish passage criterion. As with the threshold data above, each year of assessment would add greater confidence in this passage flow criterion using one or more of the meta-analysis techniques available to collectively analyze the data (e.g., the group of data collected each year can be collated for calculation of simple descriptive statistics, or Bayesian techniques can be used to gradually refine the estimate of optimum passage discharge – here assumed to be the annual mean).

The contractor is encouraged to explore other aspects of the relationship between the presence/absence and relative abundance data where appropriate, especially the interrelationship between the frequency of occurrence of passage flows, and the likelihood of movement during such condition as different times of the migration period. The analysis above should collectively provide the data necessary to address hypothesis $H_0 4$ in Section 1.3. In each case, the occurrence of fish upstream of a given barrier that appears to happen only when followed by a specific flow condition will serve as evidence to reject the hypothesis. The consistency with which this result occurs can be used as a measure of confidence and statistical inference (i.e., 1 acceptance of H_04 out of 10 trials is equivalent to a $P_{acceptance}$ of 0.10).

The final step in the analysis would be to take all of the species and stream specific passage flow criterion developed in the preceding analyses and compare them to the historical time series of stream flows for the period of record (pre-dam), as well as that predicted following implementation of WUP operations, and with flows that would have occurred should the diversion dam not be there. This will provide an indication of the frequency with which these desirable flows occurred under historical (pre-dam) conditions (number of events per year in the fall and again in the spring), how this may or may have not improved with WUP implementation, and how both states compare had the diversion structure not be there. This information will in turn be used to address hypothesis H_05 in Section 1.3.

As a simple follow up, the passage criterion data will be related to mean annual discharge (MAD) in order to present it as a proportion of MAD. This can then be compared to BC Ministry of Environment flow standards commonly used to establish passage flows.

2.3.2.4 Reporting

Over the three years of study, annual reporting will be as follows:

1) Year 1 annual data report has been completed (see Marriner et al. 2016). The report summarized the information review and index site locations were chosen. It also included a summary of initial data collected at each critical barrier site and associated analytical results;
2) Year 2 annual data report will summarize the observations at each critical barrier site collected to date, associated analytical results, and identify data need that remain outstanding. The latter will form the basis of any flow requests to be made to BC Hydro; and
3) The Year 3 final report will summarize all data collected to date, including the presentation of passage flow criterion for each site in % MAD. This final report will report on the test of hypotheses 4 and 5 above, and provide recommendations specific to the implementation of flow recommendations over the review period or in WUP reviews for the watershed.

In general, the annual data reports will summarize the year's findings and include a short discussion of how the year's data compare to that collected in previous years. It will include a brief description of methods, present the data collected that year, and report on the results of all analyses.

At the conclusion of the Monitor in Year 3, a final comprehensive report will be prepared from all of the data and/or annual reports written to date that:

1) Re-iterates the objective and scope of the Monitor,
2) Presents the methods of data collection and analysis,
3) Describes the compiled data set and presents the results of all analyses,
4) Presents the result of all impact hypothesis testing and their consequence in terms of addressing the management questions in Section 1.2, and

5) Discusses the consequences of these results as they pertain to the current BC Hydro operations, and the necessity and/or possibility for future change.

Each report will be due in spring of the year following the data collection period. All reports will be submitted to a Monitoring Advisory Committee for review and comment prior to being finalized for general release.

2.3.3 Flow-Habitat Analysis of Lower Campbell River

2.3.3.1 Review of Existing Information

Two studies were used during the WUP to quantify habitat availability as a function of flow. The first was prepared by Burt and Burns (1995) several years before the WUP. It used a transect-based technology that was considered at the time to be a state of the art assessment technique. Since that study however, a two dimensional terrain-based modeling technique (River 2D) has replaced the transect-based modeling approach as the most preferred method of flow habitat assessment. The River 2D is believed to overcome a number of modeling difficulties encountered in the transect approach. For this reason, the River 2D approach to habitat modeling was employed for the Lower Campbell River WUP studies (Leake 2004). However, because application of the River 2D methodology was still considered by some to be experimental in nature, the FTC recommended that the River 2D results be compared to the Burt and Burns (1995) results as a means of validating the modeling technique and confirm its applicability to the Lower Campbell River system. The work of Burt and Burns (1995) was considered to be accurate by many of the participants in the FTC, and was therefore used as reference for comparison. When the comparison was made however, dramatic differences in modeling results became apparent.

Bruce (2004) began to examine the reasons for the discrepancy, and was partially successful in highlighting how different methods of calculation could lead to different habitat assessment values. However, a more thorough analysis was thwarted by the fact that the River 2D (Leake 2004) and the Burt and Burns (1995) data did not overlap sufficiently to allow for more direct comparison. This monitoring study is designed to overcome this limitation so that a more comprehensive assessment of the two methods can be made, ultimately leading to the selection of a preferred methodology best suited to the lower Campbell River and its information needs.

For this component of the monitor, the literature review will be limited to the studies referred to above, as well as the supporting literature regarding the implementation of each modeling approach. The objective of the review will be to gain:

- A working knowledge of the Lower Campbell River River2D model, particularly the Reach 2 component (non-tidal reach);
- A clear understanding of the Burt and Burns (1995) approach to habitat modeling, including the location of all transects
- A common set of habitat suitability curves to be tested with each modeling method.

- A clear definition of data requirements needed to refine the River 2D model so that it incorporates transect-based data similar to that of Burt and Burns (1995)

2.3.3.2 Data Collection and Model Development

Data collection activities will follow the requirements identified in the literature review, which is expected to include some field survey work to build overlap between the River 2D and transect based models of Leake (2004) and Burt and Burns (2005), respectively. At selected locations (roughly corresponding to that established by Burt and Burns) water depth, and velocity data will be collect at 0.5 to 1 m intervals across a transect line perpendicular to the river's thalweg. All field data collection will take place during the summer when rivers flows are at their lowest (as prescribed in the WUP). The depth and velocity data will be collected by a water velocity meter mounted to wading rod, or from an Acoustic Doppler Current Profiler (ADCP) should the water be too deep or fast for safe wading while collecting data. All depth and velocity data will be tagged with a UTM coordinate derived from a survey total station mounted along the bank of the river at known survey locations (based on triangulation from established survey pins). A large prism will be mounted above the stream velocity meter that will mark the precise location of the instrument in the river.

The existing River2D model will be refined and re-calibrated by incorporating the new field data into the model terrain mesh (see Leake 2004 for an explanation of the model building and calibration process).

With the newly calibrated model, the model will be run at a discharge equal to that observed during the transect data collection period. Apparently, the newest version of the River 2D software has an algorithm that allows one to extract 'transect' slices of the river model to simulate transect data for direct comparison to the field transect data that was collected. These transect slices of the River 2D model will be one of the key outputs of the modeling process; each corresponding to a transect line measured in the field. The other is a measure of Weighted Usable Area (WUA) based on a set of standard habitat suitability curves (Developed by the FTC during the WUP process). The WUA estimates will be calculated for the River 2D model as a whole, the river 2D slices, and then be compared to the transect field measurements.

2.3.3.3 Data Analysis

All data will be entered into a database developed in consultation with BC Hydro staff for subsequent analysis. This will ensure that data collected over the years are compatible and can be extracted and compared without concern regarding differences in file format. BC Hydro may provide direction on data entry and file formats. Some refinements may be required to the presentation formats and analyses suggested below, following collection and review of data. Contractors and BC Hydro are expected to make the adjustments necessary to ensure that the best methods are used throughout the analytical process.

Data analysis will continue from where Bruce (2004) left off in his assessment of the two modeling approaches. For the first analysis, the modeled transect 'slices' will each be correlated with the corresponding measured field data using simple correlation analysis. To ensure that observations correspond to one another, interpolation techniques will be used where necessary. A strong correlation between both sets of depth and velocity data would indicate good correspondence between the two modeling approaches.

A comparison of WUA data derived directly from the River 2D data, that of the transect slices (the transect data will be summed as per Bovee 1982 to get a measure of WUA) and that using the field measurements (treated in the same way that the transect slices were) will provide the data necessary to address hypothesis $H_0$6. It should be stressed that this test is strictly comparative in nature and that statistical assessment is not possible (there are no measures of error).

From the result above, the contractor will be encouraged to explore the data set further to uncover reasons for any differences that are apparent, particularly in light of the issues raised by Bruce in his assessment (2004). The contractor should also attempt to differentiate the source of the difference, i.e., whether it is the result of measurement error, calculation technique, or simply a consequence of how each methodology is applied (e.g., transects tend to be highly localized in assessment, therefore inflating the importance of that area of interest relative to others in the river while river 2D tends to be ‘global’ and therefore tends to ‘dilute’ the relative importance of specific habitats that may be of interest).

A key outcome of the analysis would be a set of recommendations as to when to use either of the modeling approaches given the spatial scale of the analysis (habitat unit, reach, section, river wide etc.), the objective of the study and the type of assessment data need to resolve the instream flow needs issue at hand. This will help address the last management question in Section 1.2.

2.3.3.4 Reporting

This monitor is expected to take three years to complete, but it may not require a third year of data collection/modeling if the requirements are less than what it is assumed to be here. Based on the three year time line, the following reports are expected:

- Year 1 annual data report summarizing data gaps and work plan for Years 2 and 3 if applicable. Can also include a summary of data collected in that year;
- Year 2 annual data report summarizing data collection conducted and schedule for completion;
- Year 3 will provide the final report summarizing the work conducted in the information review, data collection and model refinements and the results of the comparison between habitat studies. The report will assess hypothesis $H_0$6 and recommend the most appropriate method of a flow-habitat assessment given the hydraulic conditions in the system as well as the species life history data requirements.

In general, the annual data reports will summarize the year’s findings and include a short discussion of how the year’s data compare to that collected in previous years. It will include a brief description of methods, present the data collected that year, and report on the results of all analyses.

At the conclusion of the Monitor in Year 3, a final comprehensive report will be prepared from all of the data and/or annual reports written to date that:

1) Re-iterates the objective and scope of the Monitor;
2) Presents the methods of data collection and analysis;
3) Describes the compiled data set and presents the results of all analyses;
4) Presents the result of all impact hypothesis testing and their consequence in terms of addressing the management questions in Section 1.2; and
5) Discusses the consequences of these results as they pertain to the current BC Hydro operations, and the necessity and/or possibility for future change.

Each report will be due in spring of the year following the data collection period.

2.3.4 Safety Concerns

A safety plan will be developed for all aspects of the study in accordance with Work Safe BC and BC Hydro procedures and guidelines. It is important to note that, because of the remoteness of some of the study areas and the large geographical area that must be covered, all field work must be carried out by a minimum two-person crew and that appropriate check-in and checkout procedures must be followed.

2.4 Interpretation of Results

2.4.1 Flow-Habitat Relationship in the Diversion Stream

Test of $H_0 1$ is geared towards the development of species and life stage specific flow habitat relationships for the study stream. These relationships are to be used in two ways. The first is as a validation technique of the meta-analysis predictions (Bruce and Hatfield, In progress) used in the WUP and corresponds to a test of $H_0 2$. Failure to reject $H_0 2$ for any of the species and life stage specific habitat curve comparisons would indicate that the two curves are similar and that in WUP decisions based on the meta-analysis data would not have been any different than if they were based on a more empirically derived relationship. Rejection of $H_0 2$ on the other hand would be indicative of a possible error, and would require that a decision be made on which of the two approaches, if any, is the most appropriate for WUP decision making.

One way to determine this would be to assess which more closely provides a habitat time series that matches that of fish production in the study stream. This is a test of $H_0 3$. The flow habitat that yields the best correlation would likely be the best candidate for WUP decision making. It is also possible that neither turn out to be significantly correlated with fish production indices. If that is the case, then either fish production in the study stream is independent of flow over the range that can be provided, or that some other factor is governing fish production that is not flow related, or that neither curve adequately describes the relationship of flow and habitat. The contractor, based on the patterns of data observed in the present monitor, as well as information gathered from other monitoring studies in the study area and past experience, will have to assess the likelihood of each outcome and make recommendations for consideration in future WUP review processes regarding data collection needs.

Failure to reject $H_0 1$ would suggest that habitat availability does not change over the range of flows tested. This is entirely possible if the range of flows is sufficiently narrow and is located in a part of the flow habitat relationship that is near its peak, or that the channel morphology is such that habitat area simply changes location rather increase in total area as flows increase beyond some 'optimum' discharge. Regardless of the mechanism, this outcome will hamper attempts to test H_02 and H_03. If neither of these hypotheses can be tested, then the contractor will have to decide using professional opinion which of the two approaches is best suited for future WUP decision making in the future, and recommend data collection needs for consideration at the next WUP review period.

2.4.2 Fish Passage Prescriptions for Diversion Rivers

There are two testable hypotheses associated with fish passage issues. The first is designed to test whether there is a relationship between successful fish passage and flow over the range controllable by each impoundment structure (H_04). The second hypothesis (H_05) is concerned with whether present flow conditions under the WUP are sufficient to meet the flow requirements identified in the test of H_04, and that it does so frequently enough to allow the migrating fish populations access to otherwise inaccessible upstream habitats. Test of H_05 is only meaningful if H_04 is rejected. Failure to reject H_04 would indicate that either fish can access all upstream habitats under present flow conditions, or that the system is impassable regardless of the discharge released form the diversion structure.

Failure to reject H_05 would suggest that present flow conditions are adequate to allow passage over what are deemed to be fish barriers outside the range of suitable flows, and that no further action is required. Rejection of H_05 however, would indicate that under the present WUP conditions, fish are being denied access to potentially usable habitat in upstream areas. If the restriction is considered to be a significant population constraint, fish agencies may consider requesting an immediate change in flow to remove the constraint. Otherwise the information should be presented for consideration at the next WUP review process.

2.4.3 Flow-Habitat Analysis of Lower Campbell River

Test of H_06 will determine if the two methods under consideration that are used to define flow- habitat relationships yield significantly different results. Failure to reject H_06 would suggest that there are no methodological differences, and that the differences noted during the WUP were more likely due to changes in the river over the time span that separates the two studies, and perhaps differences in study site locations. Conversely, rejection of H_06 would indicate methodological differences, and that a choice would have to be made in terms of which method is more suitable to resolve a given flow issue. If H_06 is indeed rejected, the contractor will be expected to identify those aspects that would lead to appropriate methodology selection so that they may be employed in future instream flow needs assessments and WUP decision making processes.

2.4.4 General

In all cases, failure to reject a hypothesis does suggest that the stated hypothesis is true. However, there is always a chance that this conclusion is in error and that the failure to reject the hypothesis has to do with some other factor related to study design. These may include such factors as;

1) There was only a minimal response to the range of treatments used;
2) The resolution of the Monitor was too low to detect a change (too small a sample size);
3) The change in flow treatment was too small to illicit a measurable ecological response (too small a treatment effect);
4) Measures of response are inappropriate;
5) There is some other limiting factor that either that masks the ecological response to operational changes; or
6) Some combination of the above.

These factors must always be taken into consideration when interpreting the outcome of a statistical test. When possible, statistical resolution of the Monitor can be determined through power analysis at the conclusion of the Monitor when estimates of sampling error can be made. Results of the analysis will indicate the limits of detection for a change in fish population or habitat response and will put the results of the Monitor into the proper statistical context. The contractor is expected to carry out such power analyses whenever the nature of data collection allow for a measure of sampling error.

2.5 Schedule

This TOR assumes that each study component of the monitor will require three years for completion. The first year is dedicated to literature review, model development and study design components of each study. This has been completed for the Flow-Habitat Relationship and Fish passage components (Marriner et al. 2016 and Wright et al. 2016, respectively). In absence of diversion, there is no diversion related WUP impacts to be monitored. Therefore, due to the 2017 decommissioning of the Salmon River Diversion Dam, no further work will be conducted on the Salmon River. This leads to the data collection and analysis phases of each study in the second year for only Quinsam River. If the hydrological/hydraulic conditions during this second year allow, no further data collection would be needed and a final report can be prepared at that time. However, experience in the system has shown this to be rarely the case. As a result, data collection was spread over a two-year period to increase the likelihood that appropriate hydrological/hydraulic conditions may occur. This effectively extends the timing of each study to three years. It should be noted that in each case, there is a risk that a third (or more) year of data collection may be needed. If that is the case, the contractor will spread the total level of field sampling effort out accordingly (i.e., adding another year of data collection does not add significantly to the cost of the study, rather effort not used in prior years will be shifted to cover the cost of data collection in additional years). Data analysis and reporting for additional years of data collection will be kept to a minimum so as to not add to the total cost of the program.

All three studies described in this TOR (fish passage, flow-habitat relationship, flow-habitat relationship) are independent of one another; they can but need not be carried out simultaneously or in a particular sequence. For planning purposes, the studies are carried out in sequence to spread the cost over time. Results of the fish passage study are assumed to have the greatest immediate importance and therefore this study is placed first in the sequence. This study is expected to be completed by the Year 5 interim monitoring review period. The flow-habitat relationship study is next in the sequence and is followed by the flow-habitat methodology comparison study, the results of which are only relevant to the WUP review period.

2.6 Budget

The work described above will be completed within the currently approved Comptroller of Water Rights budget. With the removal of work associated with the Salmon River Diversion Dam, BC Hydro expects to report a total budget underspend at the end of the project.

Total Program Cost: $728,550.

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