Campbell River Project Water Use Plan

Flow-Habitat Analysis of Lower Campbell River

Implementation Year 2

Reference: JHTMON-6 Component 3

Year 2 Annual Monitoring Report

Study Period: April 1, 2021 to December 31, 2022

Laich-Kwil-Tach Environmental Assessment Ltd. Partnership and Ecofish Research Ltd.

June 15, 2023

JHTMON-6 Component 3: Flow-Habitat Analysis of Lower Campbell River

Year 2 Annual Monitoring Report

Prepared for:

BC Hydro Water License Requirements
6911 Southpoint Drive, 11th Floor
Burnaby, BC, V3N 4X8

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Prepared by:

Laich-Kwil-Tach Environmental Assessment Ltd. Partnership

Ecofish Research Ltd.

Laich-Kwil-Tach
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Title page photographs – top left: looking upstream at the John Hart Generating Station tailrace from above First Island (September 3, 2021); top right: Lower Campbell River looking downstream from the lower end of Second Island (September 3, 2021); bottom left: radio-controlled boat equipped with ADCP and RTK GPS and accompanying crew raft (September 10, 2021); bottom right: water level logger installation and surveying at a stranding sensitive monitoring site (June 22, 2021).

For enquiries contact: Technical Lead documentcontrol@ecofishresearch.com 250-334-3042

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Senior Reviewers:

Jonathan Abell, PhD., E.P., R.P.Bio. No. 4537

Environmental Scientist, Limnologist

Katie Healey, M.Sc., P.Geo. No. 48267

Senior Environmental Flow Scientist

Technical Leads:

Katie Healey, M.Sc., P.Geo. No. 48267

Senior Environmental Flow Scientist

Dan Greenacre, M.Sc.

Hydrologist

Natasha Nahirnick, M.Sc.

Environmental Scientist, Geomatics Specialist

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EXECUTIVE SUMMARY

Water Use Plans (WUPs) were developed for BC Hydro's hydroelectric facilities through a consultative process. As the Campbell River WUP process reached completion, uncertainties remained with respect to the effects of BC Hydro operations on aquatic resources. To address these uncertainties, several monitoring studies were initiated, including the *Campbell Watershed Riverine Fish Flow-Habitat Assessment* (JHTMON-6).

This report describes work completed during Year 2 of the JHTMON-6 Component 3 study, which focused on data collection required to apply hydraulic habitat modelling to assess optimum flow conditions for priority fish species. In Year 2, field data collection required for JHTMON-6 Component 3 was completed. Specifically, hydraulic data were collected in Year 2 in February, June, and July 2022 at moderate and high target flow ranges. These data were augmented with continuous water level data collected through related work for the JHTMON-13 *Campbell Watershed Riverine Fish Flow-Habitat Assessment*. Hydraulic data collected in Year 2 were combined with hydraulic and bathymetry data previously obtained during low flow conditions in Year 1. All data were provided to the BC Hydro modelling team in October 2022.

Planned next steps are for the BC Hydro modelling team to use the data described in this report to configurate and validate BC Hydro's Telemac-2D hydraulic model of the Lower Campbell River. The validated model will then be used to predict hydraulic conditions (i.e., depth and velocity in fish habitats) in the Lower Campbell River for a range of flow conditions. Results from hydraulic modelling will be used by LKT and Ecofish in Year 3 to analyze relationships between flow and hydraulically suitable fish habitat to answer the management questions in consultation with BC Hydro and a Fish Technical Committee.

Table i. Status of JHTMON-6 objectives, management questions and hypotheses after Year 2.

Study Objective	Management Questions	Management Hypotheses	Year 2 (2021/2022) Status
The objective of this study is to use a hydraulic model to identify preferred flow targets that support fisheries management objectives in the lower Campbell River	1. What hydraulic response model best predicts hydraulic/habitat conditions in the Lower Campbell River? 2. What are the seasonal fisheries habitat objectives that best support fisheries productivity in the Lower Campbell River?	*Habitat-flow objectives for lower Campbell River and hydraulic responses to flow changes developed for these terms of reference are not considerably different from those developed in the Water Use Plan.*	- BC Hydro's Telemac-2D model has been identified as the optimum model to complete flow-habitat analysis. This model is now the focus of JHTMON-6 Component 3. - Data collection for JHTMON-6 Component 3 data was successfully completed in Year 2 and all data were provided to the BC Hydro modelling team in October 2022. - Approximately one year remains in the study, which is scheduled for completion in March 2024. The remaining tasks comprise hydraulic modelling (to be led by BC Hydro), flow-habitat analysis, engagement (objectives definition and target setting), and reporting.

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1. INTRODUCTION

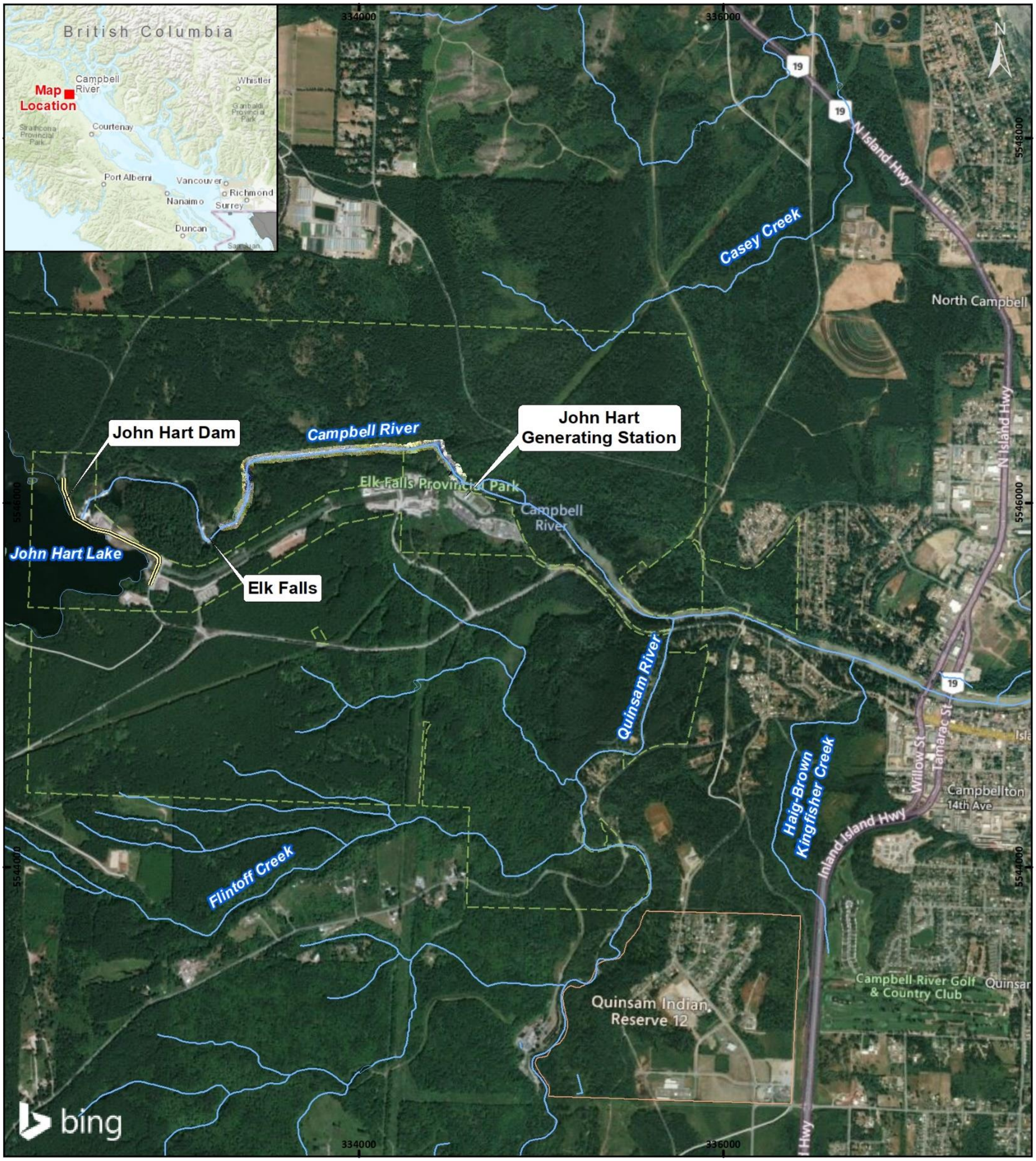
The purpose of this report is to describe work completed during Year 2 of Component 3 of *JHTMON-6 Flow-Habitat Analysis of Lower Campbell River*. This Campbell River Water Use Plan (WUP; BC Hydro 2012) monitoring study focuses on data collection and analysis to resolve uncertainties about hydraulic modelling and assess optimum flow conditions for priority fish species in the Lower Campbell River.

The Lower Campbell River lies on eastern Vancouver Island and drains into Discovery Passage at the City of Campbell River. The study area for JHTMON-6 is the section of the Lower Campbell River from the tailrace of John Hart Generating Station to the Highway 19 bridge immediately upstream of the Campbell River Estuary (Map 1). This section of the river may be affected by changes in generation flows at the John Hart facility and extends approximately 3.10 river km.

The Lower Campbell River has high fishery values; all five species of Pacific salmon use the Lower Campbell River for portions of their life histories, alongside anadromous and resident populations of several other fish species (FWCP 2018). Further background to the biogeoclimatic setting and fisheries in the Lower Campbell River is provided in an assessment of limiting factors (Abell *et al*. 2020).

Section 2 provides further background to the JHTMON-6 study. Methods are presented in Section 2.3 and results are presented in Section 4. Concluding remarks are presented in Section 5, which also summarizes tasks to be completed in the final year of this three-year study.

Project Overview



Legend

- Dam
- Watercourse/Waterbody
- First Nation Reserve
- Parks and Protected Areas

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 0.5 1 km

Scale: 1:30,000

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Map 1

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2. BACKGROUND

2.1. Management Questions

The JHTMON-6 study is designed to address the following management questions in the context of biological relevance to priority salmonid species:

1) What hydraulic response model best predicts hydraulic/habitat conditions in the Lower Campbell River?
2) What are the seasonal fisheries habitat objectives that best support fisheries productivity in the Lower Campbell River?

These two questions are presented in combination as Management Question 4 in the JHTMON-6 Terms of Reference (BC Hydro 2019) that encompass all three components of JHTMON-6.

2.2. Rationale

As the Campbell River WUP (BC Hydro 2012) process reached completion in 2012, several uncertainties remained with respect to the effect of BC Hydro operations on aquatic resources. In particular, discordance between the results of two past hydraulic modelling studies – a one-dimensional (1D) study (Burt and Burns 1995) and a two-dimensional (2D) study (Leake 2004) - led to uncertainty regarding the optimum flow conditions to provide habitat for priority fish species. These uncertainties led to a weak ability to predict changes in fish production in response to operational changes proposed during development of the WUP. JHTMON-6 is one of several monitoring studies that were developed to assess such uncertainties and confirm that expected environmental benefits are achieved.

Since JHTMON-6 Component 3 was originally conceived, BC Hydro has developed a 2D (vertically averaged) hydrodynamic model of the Lower Campbell River using the Telemac-2D model software. This model was previously updated and calibrated in 2010 (Scott pers. comm. 2020), but the model needs to be further updated to reflect current operating and morphological conditions from the new John Hart Generating Station tailrace downstream to the Highway 19 bridge. Accordingly, the current focus of the JHTMON-6 study is to update and apply BC Hydro's Telemac-2D model to complete flow-habitat analysis, rather than to re-evaluate discrepancies between the two preceding modelling approaches. The results of analysis will then be considered in collaboration with a Fisheries Technical Committee to identify whether modifications to flow management could better support fisheries management objectives for the Lower Campbell River.

During the JHTMON-6 study period, the updated Telemac-2D model will also be used to complete the *JHTMON-13 Campbell Watershed Riverine Fish Flow-Habitat Assessment*, which will involve assessing how load factoring and ramping affect fish in the Lower Campbell River (BC Hydro 2020a). The model data requirements for JHTMON-13 and this study are similar, although JHTMON-13 requires collecting data at high spatial resolution in the vicinity of stranding sensitive monitoring sites (SSMSs) that pose elevated stranding risk. Readers should consult BC Hydro (2020a) for further background to JHTMON-13.

2.3. Key Uncertainties

Following a Fish Technical Committee meeting on October 15, 2020, BC Hydro sought input from their Generation System Operations group regarding high priority periods that should be considered during studies for JHTMON-6 and JHTMON-13. These periods are summarized in Table 2 to provide additional detail regarding the flow conditions being considered in JHTMON-6. Resolving uncertainties associated with each of these periods has potential to provide greater operational flexibility for BC Hydro by allowing them to better manage flood risks and the demands for power generation.

Table 2. Key uncertainties identified by BC Hydro's Generation System Operations (GSO) team. Based on BC Hydro (2020b) and discussions during a meeting on December 15, 2020.

Period	WUP Preferred Flow Ranges (m^3/s)			JHTMON-13		JHTMON-6
	Preferred Min.	Fisheries Target	Preferred Max.	Load Factoring	Ramping	
Jan 1 – Feb 15	80	122	124	Currently permitted at flows of 76–124 m^3/s	Currently unconstrained at flows of 76–124 m^3/s	It is uncertain why the preferred maximum flow is only 2 m^3/s higher than the fisheries target. Can these be aligned?
Feb 16 – Feb 28	80	106	124	GSO seeks flexibility to load factor between flows of 80–124 m^3/s	GSO seeks flexibility to increase ramping rates	BC Hydro is unclear why the fisheries target flow (106 m^3/s) is lower during this period than during Jan 1 – Feb 15 (122 m^3/s). If appropriate, GSO seeks to align these values (i.e., increase to 122 m^3/s).
Mar 1 – Apr 14	60	100	104		GSO seeks flexibility to increase ramping rates	BC Hydro has identified that spawning habitat may dewater when flows decrease <80 m^3/s and side channel habitats dewater at flows <60 m^3/s. Thus, BC Hydro would like examine whether it is appropriate to increase the preferred minimum flow (e.g., to 80 m^3/s) to benefit fisheries. The current preferred minimum flow is designed to provide flexibility to maintain high reservoir levels in summer.
Apr 15 – Apr 30	80	80	124		GSO seeks flexibility to increase ramping rates	
May 1 – Jun 30	100	100	124		GSO seeks flexibility to increase ramping rates	BC Hydro questions whether the preferred minimum flow can be reduced during the later part of this period when smolt outmigration is potentially complete.
Jul 1 – Jul 19	28	40	124		GSO seeks flexibility to increase ramping rates	
Jul 20 – Sep 14	28	40	124		GSO seeks flexibility to increase ramping rates	
Sep 15 – Sep 21	28	40	124		GSO seeks flexibility to increase ramping rates	
Sep 22 – Oct 14	28	100	104		GSO seeks flexibility to increase ramping rates	
Oct 15 – Nov 15	80	122	124		GSO seeks flexibility to increase ramping rates	It is uncertain why the preferred maximum flow is only 2 m^3/s higher than the fisheries target. Can these be aligned?
Nov 16 – Dec 31	80	106	124	GSO seeks flexibility to load factor between flows of 80–124 m^3/s	GSO seeks flexibility to increase ramping rates	BC Hydro is unclear why the fisheries target flow (106 m^3/s) is lower during this period than during Jan 1 – Feb 15 (122 m^3/s). If appropriate, GSO seeks to align these values (i.e., increase to 122 m^3/s).

2.4. Study Approach and Project Status

The JHTMON-6 Component 3 management questions are being addressed with a combination of field and modelling studies (BC Hydro 2020a). The modelling component involves working with BC Hydro's modelling team to configure, validate, and apply BC Hydro's two-dimensional hydraulic model of the Lower Campbell River (Telemac-2D) to assess relationships between fish-habitat and flow. This model is also being developed to address related management questions under the JHTMON-13 ramping study concerning habitat availability and ramping for a range of operations (flows) in the Lower Campbell River. Although a common model is being used to inform both monitors, the data collection requirements to apply and validate the model differ between the two monitors. This difference is because JHTMON-6 requires understanding general changes in the availability of hydraulically suitable habitats in response to different operating flows. In contrast, JHTMON-13 requires understanding hydraulic changes in nearshore stranding sensitive habitats in response to short-term changes in flow and water level (ramping and load factoring). A phased approach is being undertaken to complete JHTMON-6 in tandem with related requirements for JHTMON-13.

Work undertaken in Year 2 focused on completing remaining data collection necessary for model validation. The JHTMON-6 Terms of Reference (BC Hydro 2019) identifies the tasks listed below; the status of each task has been added to provide an update:

1) Project Management – ongoing;
2) Review of Existing Information – completed in Year 1; see Greenacre *et al.* (2022);
3) Data Collection and Model Development – data collection was completed in Year 2, model validation is scheduled for Year 3;
4) Objectives Definition and Target Setting – this task was advanced during a workshop in February 2022 and is scheduled for completion in Year 3; and
5) Reporting – a final report will be prepared in Year 3 following this Year 2 Annual Report..

3. METHODS

3.1. Overview

Data collection requirements for JHTMON-6 Component 3 were completed in Year 2, as prescribed in the JHTMON-6 Background Review and Detailed Study Plan (Greenacre *et al.* 2022) that was finalized following review by BC Hydro and the JHTMON-6/13 Fish Technical Committee. Data collection began in Year 1 on June 2, 2021 and was completed in Year 2 on July 6, 2022.

In summary, JHTMON-6 Component 3 fieldwork in Year 1 focused on data collection during low flows, whereas fieldwork in Year 2 focused on data collection during moderate and high flows (target flow ranges are described in Section 3.2). All fieldwork was originally planned to occur in Year 1, but fieldwork was extended into Year 2 because high rainfall in fall 2021 resulted in high flows that persisted above the target ranges until summer 2022. Table 3 summarizes all JHTMON-6 and JHTMON-13 field data collection activities, including data type, timing, and collection methods. Detailed methods for each activity are described in subsequent sections.

Table 3. Summary of JHTMON-6/13 field data collection activities undertaken in JHTMON-6 Component 3 Year 1 and 2.

Data Type	Extent	Field Dates	Study Year	Approx. Discharge (m^3/s; 08HD003)	Sampling Method[1]
Hydraulic data	Longitudinal surveys (tailrace to Hwy bridge)	September 9-11, 2021	1	30	RTK GPS + ADCP
		June 29-30, 2022	2	115-120	RTK GPS + ADCP
		July 4-5, 2022	2	75-80	RTK GPS + ADCP
	Cross-sections (CBR-TRQ01 to CBR-TRQ06, excluding TRQ04)	September 8-10, 2021	1	30	RTK GPS + ADCP or Wading
	Cross-section (CBR-TRQ02a)	June 29-30, 2022	2	115-120	ADCP
	Cross-sections (CBR-TRQ01a, and CBR-TRQ02a)	July 4-5, 2022	2	75-80	RTK GPS + ADCP or Wading
Bathymetry	Cross sections, and longitudinally along contours (CBR-DSSD01 to CBR-DSSD08)	July 12-15, 2021; September 2-3, 2021	1	30	RTK GPS
Continuous water level monitoring	Stranding sensitive sites (CBR-DSSD01 to CBR-DSSD11)	June 2-3, 2021; June 22-23, 2021; August 16-17, 2021; October 4-5, 2021;	1	30 to >100	Level logger
		February 16-18, 2022; July 5-6, 2022	2	75 to 128	Level logger
Substrate	Stranding sensitive sites (CBR-DSSD01 to CBR-DSSD11)	July 12-15, 2021; September 2-3, 2021	1	30	RTK GPS + Photos
RPAS survey	Study area	September 3, 2021	1	30	RPAS

[1] "RTK GPS" = Real-Time Kinematic Global Positioning System; "ADCP" = Acoustic Doppler Current Profiler; and "RPAS" = Remotely Piloted Aerial System

3.2. Hydraulic Data

3.2.1. Field Data Collection

To collect data to validate hydraulic model predictions and develop habitat-flow relationships, positionally referenced hydraulic data were collected in the Lower Campbell River from John Hart Generating Station to the Highway 19 bridge. Data were collected relating to water surface elevation, depth, and velocity at each of the following three flow ranges:

- Low flows (28 to 40 m^3/s);
- Moderate flows (40 to 100 m^3/s); and
- High flows (100 to 124 m^3/s).

Longitudinal surveys were used to provide extensive water surface elevation and depth/bathymetry data throughout the study area that could be used to validate the 2D (depth-averaged) model. Additional data were collected at cross-sectional transects to provide supporting data relating to in-stream discharge, water depth, and velocity, particularly at First and Second islands, which was identified by BC Hydro as a key uncertainty of the existing Telemac-2D hydraulic model (Greenacre *et al.* 2022).

Longitudinal surveys of water surface elevation and depth were collected along the length of the study area at each target flow range, focussing on the river thalweg (Map 2; Map 3). Data were collected during low flow conditions (30–34 m³/s) on September 9–11, 2021 using a radio-controlled boat equipped with an acoustic Doppler current profiler (ADCP), depth sonar, and real-time kinematic global positioning system (RTK GPS). The radio-controlled boat was accompanied by a field crew member transported in a 3.7 m NRS self-bailing raft with a rowing frame to provide safe piloting and maintain line of sight while transiting the river. RTK GPS measured position, and ADCP and depth sonar data were collected by synchronising the time and measurement interval of each instrument, such that data could be joined during data processing. These data were collected during moderate and high flow conditions using the same equipment, except the radio-controlled boat was replaced by a manually operated trimaran because the supplier was unable to provide the radio-controlled boat as it was damaged while leased to another operator. High and moderate flow data collection were completed on June 29–30, 2022 (115–120 m³/s) and July 4–5, 2022 (75–80 m³/s), respectively, during stepped decreases in flow during annually scheduled ramp-down in flows.

Water depth and velocity were also collected along cross-sectional transects at each target flow (Table 3; Map 2; Map 3) to measure discharge at the time of longitudinal surveys, and to provide additional data to characterize flow routing around First and Second islands. Under low flow conditions during Year 1, water depth and velocity distribution were measured using the radio-controlled boat described above. In areas that were shallower than the minimum operable depth of the ADCP, water depth and velocity were measured by wading with a standard USGS magnetic head current meter (Price AA) and 1.4 m top-set wading rod supported by RTK GPS for recording positional information. At moderate and high flow, a non-remote controlled ADCP was used to collect data in Year 2 as the radio-controlled boat was unavailable. Measurement of depth and velocity along cross-sections at moderate and high flows was therefore limited to transects that could be measured by manually guiding the ADCP by hand or operated while rowing the raft. These transects were on the river-right side of First and Second islands during moderate flows, and the river-right side of Second Island at high flows.

3.2.2. Data Processing

Hydraulic data were processed in several steps. To georeference the data, measured water depths and velocities profiles collected with ADCP were joined with water surface elevation data collected using RTK GPS according to their respective date-time signatures. Raw data were then cleaned by visualizing data using graphs and using GIS to identify and remove any values that were considered erroneous based on careful inspection. Typical examples of suspected erroneous data were: (1) elevation values for which RTK-GPS accuracy was outside of target accuracy (<=0.05 m) due to interference by overhead trees or bridge crossings; and (2) sections where water depth was shallower than the minimum operating depth of the ADCP (0.5 m).

3.3. Bathymetry

Hydraulic modelling using Telemac 2-D requires a Digital Elevation Model (DEM) to quantify control of hydraulic conditions by streambed topography (i.e., bathymetry). Bathymetry data were collected during longitudinal surveys described in Section 3.2 and via the aerial surveys described in Section 3.6. Furthermore, discussion with the BC Hydro modelling team identified a need to collect additional bathymetric data at high spatial resolution at localized areas where historical data were determined to have relatively high uncertainty due to bed shifts and gravel placement in more recent years (e.g., channels around First and Second islands). Additionally, a requirement of JHTMON-13 is to collect high spatial resolution bathymetry data at stranding sensitive habitats to inform assessment of ramping risks. Thus, additional high spatial resolution bathymetry data were collected under JHTMON-13 around the islands and at nearshore stranding sensitive areas (Map 4) to supplement the DEM that will be used for the Telemac-2D model.

These additional bathymetric data were obtained in July and September 2021, when water levels were at a seasonal minimum and a large proportion of the stranding sensitive areas was dewatered. Data were collected in pre-defined dry or shallow wadable areas using an RTK GPS rover and base station unit. In areas that could not be waded, bed elevations were measured with a high accuracy georeferenced depth sounder mounted to a radio-controlled boat with an ADCP unit. Cross-section surveys were also performed, including establishing georeferenced benchmarks to enable transects to be resurveyed if required in future. Surveys captured changes in bank profile by measuring the top of bank, toe of the bank, wetted edges, centres of depressions, and abrupt changes in the channel profile, but excluded flatter areas where depths were near-constant. Water depths were recorded at the time of each survey, along with the associated point record number. Surveys involved recording approximately one survey point every 2–5 m of length along each longitudinal contour (e.g., wetted edge, toe of bank), with some variation depending upon the topography and the total length of the site. Survey data were processed to remove points that did not meet accuracy requirements (i.e., <5 cm of vertical accuracy) which occurred in certain areas where RTK GPS positioning was hampered by overhanging riparian vegetation.

3.4. Continuous Water Level Monitoring

To provide a continuous record of water level, water level loggers (Solinst Edge) were installed at 10 stranding sensitive monitoring sites (SSMSs). A key reason for deploying these loggers was to quantify ramping rates to support JHTMON-13, although these data also support model validation required for JHTMON-6 as they provide water level records for sites throughout the model spatial domain and spanning the range of target flows for this study. SSMSs are locations where fish may be at increased risk of stranding and/or isolation during a ramp down (i.e., operational decrease in river flow). SSMSs were identified based on the location of historical sites, review of aerial imagery, and ground-truthing during field reconnaissance. SSMSs generally had the following characteristics (Lewis *et al.* 2013):

- Relatively flat-sloped stream bottom cross-section containing large substrate that can strand fish, or finer substrate with depressions that can trap fish; and
- Cobble and gravel bars that have even slopes with steep sides, where substrate creates refuges that juvenile fish prefer and may be reluctant to leave during a ramp down (micro-stranding sites).

Each SSMS was marked with a permanent benchmark attached to a tree or rock, and the upstream and downstream boundaries of each SSMS were defined with flagging tape attached to a tree or shrub. Each site was photographed and georeferenced by recording a central GPS waypoint. Habitat data were also collected at each site by characterizing habitat type, substrate composition, roughness, embeddedness, vegetation cover, and bank slopes.

3.5. Substrate

Information about substrate characteristics is necessary to characterize roughness in the hydraulic model, and to inform determination of habitat suitability based on species-specific substrate preferences. Based on review of the requirements of the Telemac-2D model during discussions with the BC Hydro modelling team, previously collected substrate data are expected to be suitable to configure the Telemac-2D model and finer resolution data are not required for this purpose because the hydraulic model has low sensitivity to fine-scale variations in bed roughness (Scott, pers. comm. 2021). Therefore, roughness parameters used in the updated Telemac-2D model will be determined by the BCH modelling team using the existing substrate data, which are dated 2011 (see Greenacre *et al.* 2022 for details of existing data).

However, more detailed recent information about substrate is valuable for JHTMON 6 Component 3 to determine habitat suitability when developing habitat-flow relationships. Specifically, we plan to characterize spatial variability in habitat suitability for individual model cells throughout the study area. Therefore, recent and high spatial resolution data regarding substrate will support with accurately characterizing how habitat suitability varies spatially for priority species and life stages of fish. Substrate information is also valuable for JHTMON-13 to evaluate stranding risk. Accordingly, additional substrate data were obtained under the scope of JHTMON-13 by collecting georeferenced photos during SSMS surveys, and by collecting high resolution aerial imagery (Section 3.6) during low flows when visibility is high, and substrate is partly exposed. Images of substrate will be processed by delineating spatial polygons that characterize substrate materials based on the dominant type present, e.g., boulder, cobble, gravel (example photographs of substrate types are presented in Section 4.4). These polygons will then be incorporated into the calculation of hydraulic habitat suitability by quantifying the weighted usable area (WUA) of habitat for each simulation flow and priority species as follows:

$$WUA = \Sigma_i^n (A_i * D_i * V_i * S_i)$$

Where A_i is the area of computational cell i, D_i is the suitability of depth at cell i, V_i is the suitability of velocity at cell i, and S_i is the suitability of substrate at cell i. Habitat flow relationships that account for substrate preferences will be developed based on the WUA calculated across all simulation flows.

3.6. Remotely Piloted Aerial System (RPAS) Survey

On September 3, 2021, a Remotely Piloted Aerial System (RPAS; "drone") survey was conducted throughout the ~3.1 km study area of the Campbell River between the John Hart Generating Station tailrace and the Highway 19 bridges. Early September was selected to target low-flow conditions and maximize substrate visibility. Discharge in the Lower Campbell River at the time of the survey was 32 m^3/s (WSC gauge 08HD003). The goal of the survey was to collect high-resolution nadir (downward-facing) imagery, to be later processed into a full-coverage, high-quality photogrammetrically orthorectified image (orthomosaic) and a digital surface model (DSM). The DSM can then be used by the BC Hydro modelling team to support development of the DEM that will be used to configure bathymetry in the model (Section 3.3)[1]. As described in the Results (Section 4.5), the DSM provided accurate elevation data for exposed areas of the river channel, although not for areas that were submerged. The DSM therefore contributed to the DEM within areas of the channel bed that were dry at the time of the survey and provided synoptic water surface elevation data for the time of the survey. The orthomosaic provided high quality imagery of the study area that informed characterization of substrate type (Section 3.5).

A DJI Mavic 2 Pro RPAS was operated by a Transport Canada certified advanced RPAS pilot to conduct at least two flight lines at a consistent altitude for each section of the stream. To maintain line-of-sight within 500 m of the RPAS, a total of seven predetermined access points for aircraft launch were used along the length of the study area. Photos were collected with high overlap (~90% overlap) to maximize data quality and achieve complete coverage of the study area. Photo exposure settings were manually adjusted over the course of the flight to maximize streambed visibility across variable light conditions.

[1] A DEM represents the earth as a bare surface devoid of vegetation, water, and man-made features, whereas a DSM retains these features, in this case because they cannot be excluded when using drone photogrammetry.

To improve the accuracy of the DSM data, ground control points (GCPs) were established across the study site on surveyed benchmarks and marked with temporary, high-visibility, non-toxic spray chalk for identification from the air. GCPs were surveyed with an RTK GPS system with accuracy of 1-2 cm and marked with a permanent metal pin for potential use on repeat surveys in the future.

Upon completion of the survey, raw imagery was processed into a single, full-coverage orthomosaic and DSM using Pix4D Mapper software, projected in NAD83 UTM Zone 10N. GCP coordinates were used during processing to improve the 3D accuracy of the output products. Horizontal and vertical accuracy of the output orthomosaic and DSM are described in Section 4.5.

3.7. Modelling Support and Engagement

As per the Consultation Plan included in the Detailed Study Plan (Greenacre *et al.* 2022), Laich-Kwil-Tach Environmental Assessment Ltd. Partnership (LKT) and Ecofish Research Ltd. (Ecofish) met with BC Hydro and the Fish Technical Committee at a workshop at the end of Year 1 on February 25, 2022 with the aim to: (1) present the JHTMON-6 background review and study plan; (2) provide an update on study progress and discuss outstanding work; (3) discuss fisheries objectives and habitat suitability criteria; and (4) confirm plans for future engagement with the committee.

4. RESULTS

Final data collection for JHTMON-6 was completed on July 5, 2022. Data collected under target flow conditions (Table 3; Section 2.2) were provided to the BC Hydro modelling team in separate packages and are summarized below. The BC Hydro modelling team confirmed that the data were complete and suitable for the planned modelling during a meeting on November 4, 2022 (Scott, pers. comm. 2022).

4.1. Hydraulic Data

Georeferenced hydraulic data relating to water surface elevation, depth, and velocity were successfully collected under each of the following three flow conditions between September 2021 to July 2022:

- Summer low flows (30 to 34 m^3/s, to fulfill the target range of 28 to 40 m^3/s);
- Moderate flows (75 to 80 m^3/s, to fulfill the target range of 40 to 100 m^3/s); and
- High flows (115 to 120 m^3/s, to fulfill the target range of 100 to 124 m^3/s).

Longitudinal profiles of water surface elevation and bed elevation (corresponding to the measured depth) extending from the John Hart Generating Station to the Highway 19 bridge are shown in Figure 1, Map 2, and Map 3. Longitudinal profiles provide broad coverage throughout the length of the study area. Gaps in longitudinal data coverage – which occurred along the right side of First Island at low flows, and the left side of the river upstream of Second Island at all three flows – reflect shallow or turbulent conditions that precluded collection of data using an ADCP. However, data at the upstream end of Second Island were obtained during detailed bathymetry surveys (Map 4).

Water depth and velocity data (Table 4) were collected along cross-sectional transects during moderate and high target flow conditions present in Year 2 (Table 3) to measure discharge at the time of longitudinal surveys, and to provide additional data to characterize flow routing around First and Second islands.

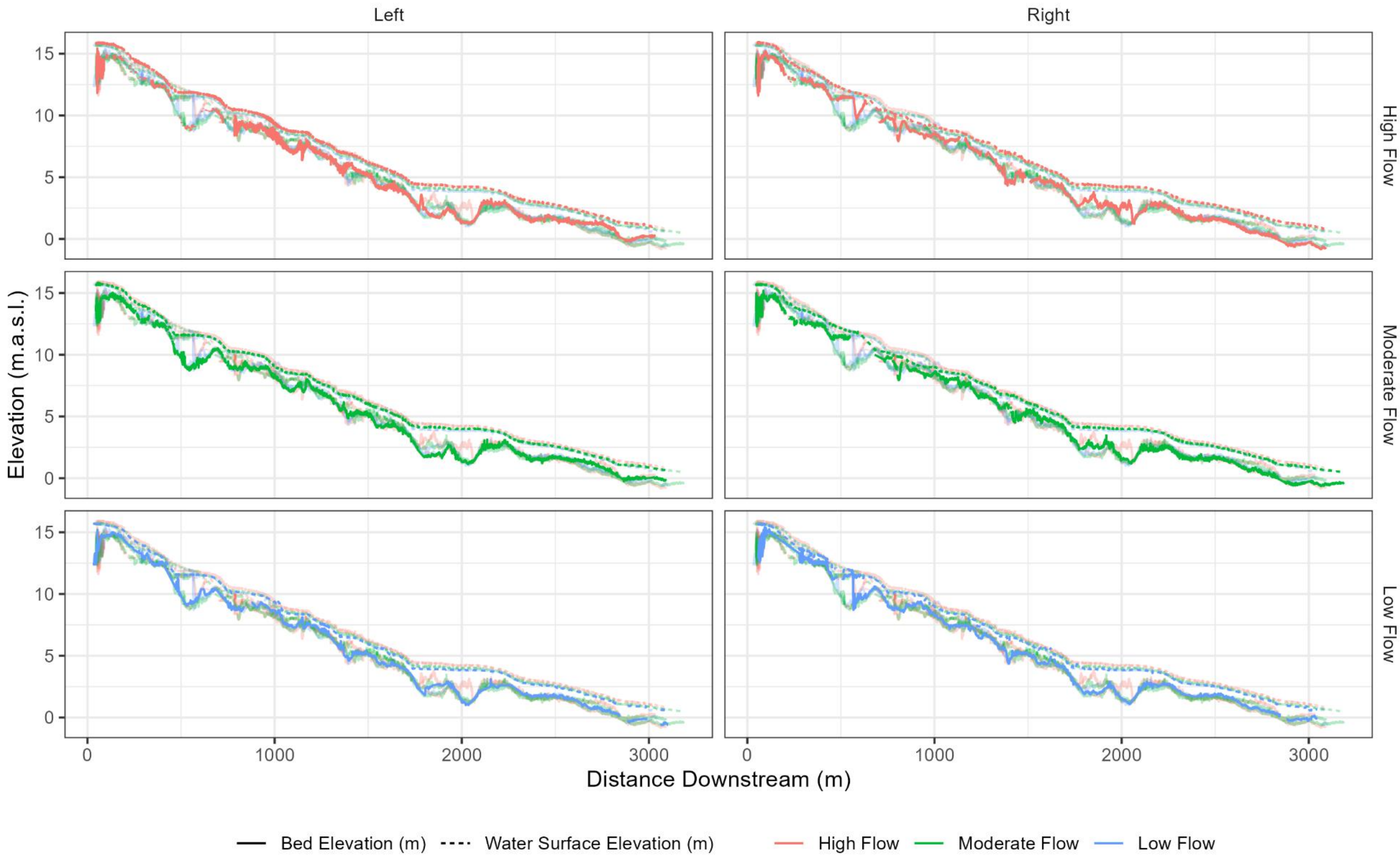
Table 4. Summary of depth and velocity data collected at cross-sectional transects.

Location	Description	Transect ID	Target Flow		
			Low	Moderate	High
North and south channel around First Island	Quantify flow routing around island; high value habitat and gravel enhancement location; location of historical transect[1]	CBR-TRQ01a	X	X	-
		CBR-TRQ01b	X	-	-
North and south channel around Second Island	Quantify flow routing around island; high value habitat and gravel enhancement location; location of historical transect[1]	CBR-TRQ02a	-	X	X
		CBR-TRQ02b	X	-	-
Confluence of powerhouse and Elk Canyon	Quantify depth and velocity distribution between powerhouse and Elk Falls	CBR-TRQ03	X	n/a	n/a
Downstream of First Island	High value spawning and rearing habitat	CBR-TRQ04	-	n/a	n/a
Quinsam River confluence	Assess effect of Quinsam River inflow on hydrodynamics around the confluence	CBR-TRQ05	X	n/a	n/a
Downstream of Logging Road bridge	Location of historical transect[1]	CBR-TRQ06	X	n/a	n/a

[1]Location approximates location of historical transect based on Figure 11 in Burt and Burns (1995)

[2] "X" denotes measurements collected per the study plan, while "n/a" denotes non-target measurements; "-" denotes target measurements that could not be completed due to adverse conditions (i.e. insufficient water or unsafe flow) at respective water levels

Figure 1. Longitudinal profiles of the streambed and water surface elevation (m.a.s.l.) of the Lower Campbell River from the John Hart Generating Station to the Highway 19 bridge, under low, moderate, and high flow conditions.



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4.2. Bathymetry

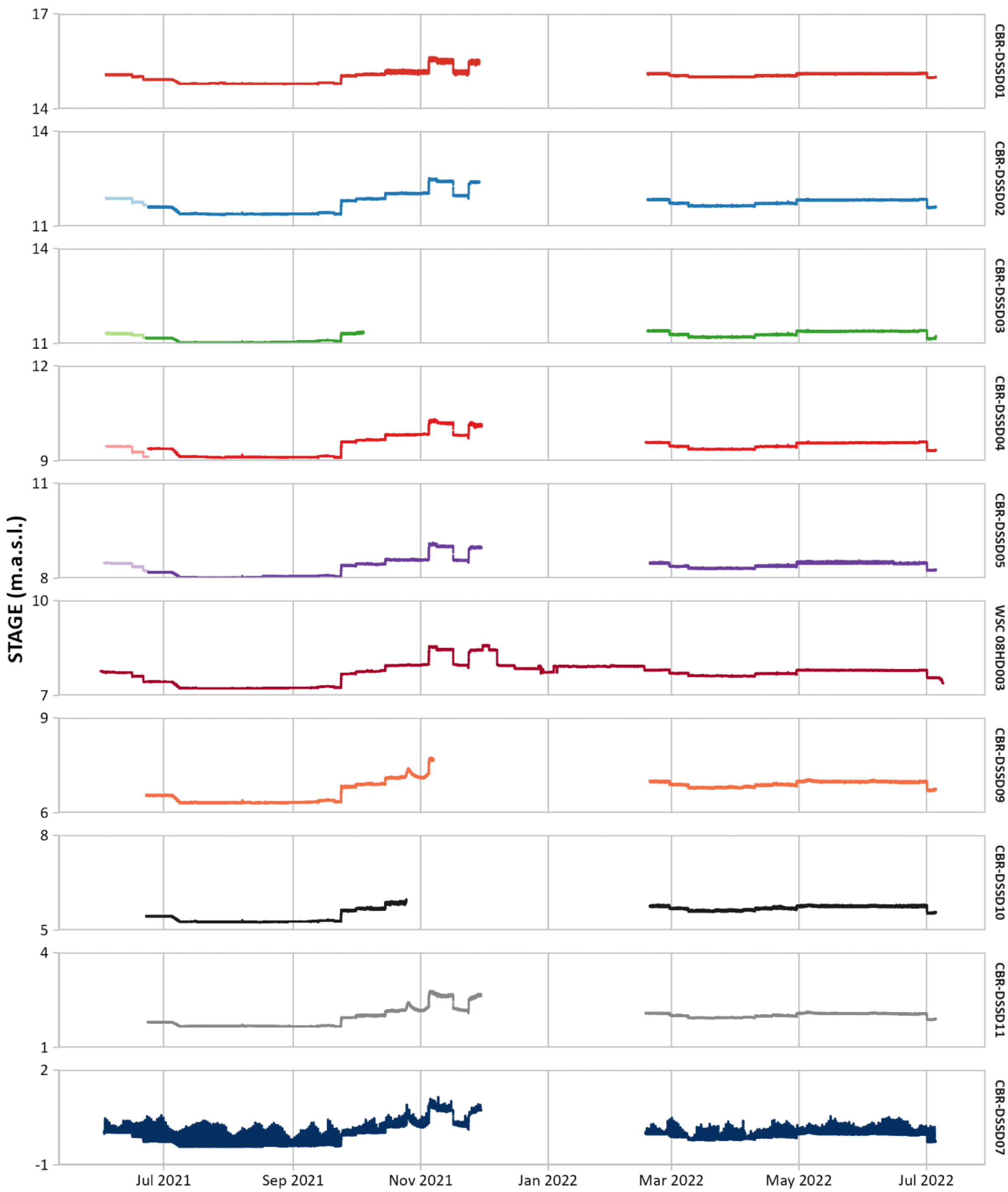
Extensive bathymetry data collected during longitudinal surveys (Map 2; Map 3) are described in Section 4.1 and shown as bed elevation profiles in Figure 1. Additional detailed bathymetry and water surface elevation data were collected under low flow conditions at seven stranding sensitive areas, and from cross-sections (i.e., bed-profiles) at four additional sites (Map 4). These data supplement the DSM derived from RPAS orthoimagery (Section 4.5), which provides additional coverage for streambed areas exposed at the time of survey (Map 5).

4.3. Continuous Water Level Monitoring

Eight SSMSs were initially established during reconnaissance surveys on June 2 and 3, 2021 (CBR-DSSD01 to CBR-DSSD08), with water level loggers installed at each SSMS to provide continuous monitoring. Three additional SSMSs (CBR-DSSD09, CBR-DSSD10, and CBR-DSSD11) were established on June 22 and 23, 2021, to provide one additional monitoring site, and replace two previously established sites: CBR-DSSD06, which was found to be strongly influenced by the tide; and CBR-DSSD08, which was susceptible to dewatering at lower water levels. The location of each of these sites, alongside corresponding detailed bathymetry point data, are shown in Map 4.

Water level data were originally intended to be retrieved in November 2021; however, monitoring was extended until summer 2022 to provide continued water level data at each site until the completion of hydraulic data collection. Water level data therefore provide a continuous record of the water surface elevation at each location from early June to late November 2021, and from mid-February to early July 2022. A data-gap from November 29, 2021 to February 16, 2022 occurred because data logger storage memory was exceeded while the loggers were inaccessible due to high flow conditions.

Figure 2. **Continuous water level time-series data measured at stranding sensitive monitoring sites and Water Survey of Canada (WSC) hydrometric station 08HD003 from June 2021 to July 2022. Light coloured time-series at some sites in June 2021 denote periods when the logger was relocated to prevent dewatering.**



4.4. Substrate

Example georeferenced photos collected during SSMS and RPAS surveys are shown in Figure 3. Photographs will be analyzed in Year 3 to inform habitat-flow analysis for JHTMON-6, and for assessing stranding risks for JHTMON-13.

Figure 3. Examples of imagery for characterizing substrate in the lower Campbell River, from georeferenced photos taken during SSMS surveys (upper), and RPAS surveys (lower).

4.5. Remotely Piloted Aerial System (RPAS) Survey

The orthomosaic developed following the RPAS survey is presented in Map 2 to Map 5 (see high quality imagery along the river corridor).

The DSM of the Lower Campbell River developed from RPAS survey imagery provided high quality data to develop the DEM for the hydraulic model, although the positional accuracy of the data varied within the study area. High positional accuracy was obtained in DSM coverage of the study area upstream of the Quinsam River confluence; accuracy was lower for areas downstream of the Quinsam River confluence (a minor portion of the study area; Map 3). The lower accuracy of the DSM downstream of the Quinsam River confluence was mostly likely due to the river channel there being mostly wetted at the time of the survey, with limited exposed areas present that could be used to construct an accurate surface model through photogrammetry, as water refraction causes significant shifts in the calculated positions of tie points. For the sections upstream – which contained larger exposed areas to use as tie points between images, as well as a higher density of GCPs – the accuracy of modelled GCP coordinates was very high (RMSE = 0.04 m horizontal, 0.01 m vertical, based on seven GCPs). For the section downstream of the Quinsam River confluence, the accuracy was poor (RMSE = 3.25 m horizontal, 3.78 m vertical, based on two GCPs). As such, only the upstream sections from the John Hart Generating Station to the Quinsam River confluence were included in the DSM for hydraulic model configuration (Map 5). This approach was confirmed with the BC Hydro modelling lead, who confirmed that this approach is suitable because existing uncertainty regarding bathymetry is low for the minor portion of the study area downstream of the Quinsam River confluence (Scott, pers. comm. 2022) – note that bathymetry data collected using other methods (Section 4.2), as well as historical observations, are available for this area.

Note that RPAS surveys that were completed under JHTMON-13 on September 3, 2021 were replicated in 2022 under a separate scope of work led by LKT to assess potential gravel movement resulting from high flow conditions during winter 2021-2022, when flows reached >260 m^3/s following a large regional storm that occurred in November 2021 and after another event in February 2022. Data from this second survey have not yet been processed and there is currently no plan to use these data for JHTMON-6/13, although it may be feasible to incorporate these data into the studies to assist hydraulic model configuration as part of additional scope.

4.6. Modelling Support and Engagement

The JHTMON-6 and JHTMON-13 workshop with the Fish Technical Committee on February 25, 2022 addressed the following main agenda items (BC Hydro 2022):

- 2021 field program update;
- Hydraulic modelling update;
- Priority species and habitat suitability index curves; and
- Review of fisheries management objectives.

A second workshop is provisionally scheduled for later in 2023 (Year 3) when the modelling work is complete. This workshop was initially planned for early 2023 (end of Year 2) but, in consultation with BC Hydro, the workshop has been postponed to allow for sufficient time to complete the remaining analysis.

Following completion of field data collection and quality checks, all data required for model configuration and validation were provided to the BC Hydro modelling team in two data packages, with the second and final data package transferred to BC Hydro on October 5, 2022. Data provided were as follows:

- Longitudinal water surface elevation and depth profiles at all three flow targets (.xlsx file).

- Depth and velocity cross-sections along First and Second islands and additional transects at low flows, First and Second islands only at moderate flows, and the Second Island side-channel at high flows (.xlsx).
- Detailed bathymetry and water surface elevation data for stranding sensitive areas collected during low flows (.xlsx).
- RPAS orthoimagery and DSM collected during low flow, including delineated dry areas (.tif).

Following receipt of the final data package by the BCH modelling team, data were reviewed and discussed at a meeting between Ecofish and the BCH modelling team lead on November 4, 2022 when it was determined that data were sufficient to address model uncertainties (Scott, pers. comm. 2022) identified in the Study Plan (Greenacre *et al.* 2022). We understand that BC Hydro plans to finalize configuration and commence validation of the Telemac-2D model in 2023, with validation and hydraulic modelling anticipated to be completed by summer 2023.

5. CONCLUSION AND NEXT STEPS

Data collection for JHTMON-6 Component 3 data was successfully completed in Year 2 and all data were provided to the BC Hydro modelling team in October 2022. Approximately one year remains in the study, which is scheduled for completion in March 2024 (Greenacre *et al.* 2022). The remaining tasks comprise modelling, analysis, engagement (objectives definition and target setting), and reporting.

We anticipate that next steps for the BC Hydro modelling team are to use the data described in this report to: (1) update the Telemac-2D model using an updated DEM and complete model calibration, and (2) validate the model to verify that predictions are suitably accurate, based on comparing model predictions with measurements of water surface elevation, depth, and velocity. The validated model will then be used to predict hydraulic conditions (i.e., depth and velocity in fish habitats) in the Lower Campbell River for a range of flow conditions (Table 2). Results from hydraulic modelling will be used by LKT and Ecofish to analyze relationships between flow and hydraulically suitable fish habitat to answer the management questions (Section 2.1) in consultation with BC Hydro and the Fish Technical Committee.

A second workshop with the Fish Technical Committee is planned for Year 3 once hydraulic modelling is complete (to be led by BC Hydro) and draft results are available from flow–fish habitat analysis (to be led by LKT and Ecofish). We understand that BC Hydro plans to schedule this second workshop for summer or fall 2023 once modelling is complete (the workshop was originally planned for approximately February 2023; Greenacre *et al.* 2022). As per the Consultation Plan included in the Detailed Study Plan (Greenacre *et al.* 2022), a third and final meeting with the Fish Technical Committee is planned for the end of Year 3, with an aim to confirm preferred flow targets that support fisheries management objectives.

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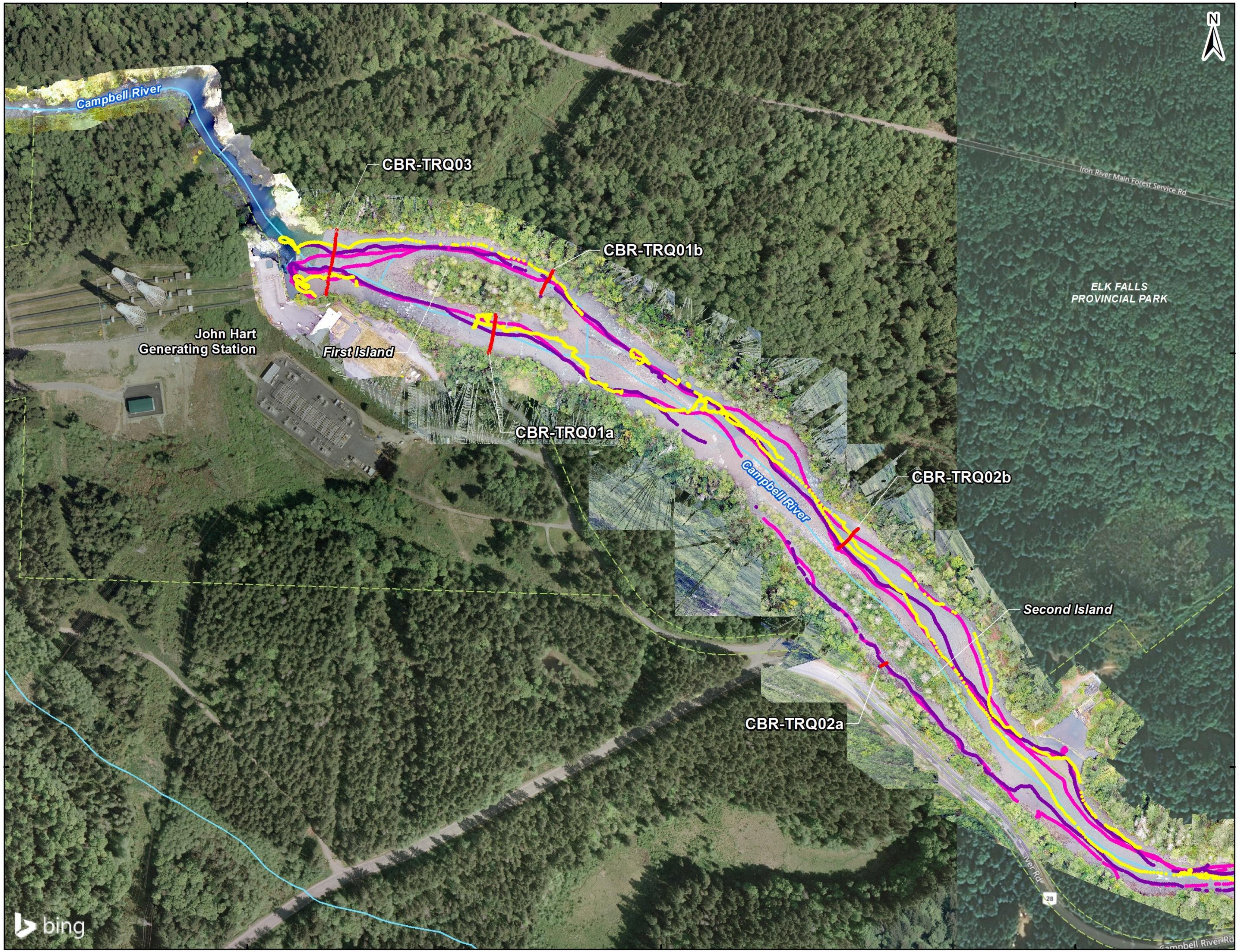
Personal Communications

Scott, S., Operations Planning Engineer, BC Hydro. Presentation to BC Hydro, LKT, and Ecofish on January 23, 2020 titled "Lower Campbell River Telemac2D Model". PowerPoint slides forwarded to K. Healey (Ecofish) on June 9, 2021.

Scott, S., Operations Planning Engineer, BC Hydro. Microsoft Teams meeting with Ecofish to review collected JHTMON-6 and JHTMON-13 data for 2D modelling on November 4, 2022.

PROJECT MAPS



JHTMON CAMPBELL RIVER WATER USE PLAN

JHTMON-6 Component 3 - Longitudinal Water Surface & Depth/Velocity Cross-Sections (Western Extent)

Legend

- Depth and Velocity Transect
- High Flow Longitudinal Profile
- Medium Flow Longitudinal Profile
- Low Flow Longitudinal Profile
- Parks and Protected Areas

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 50 100 200 m

Scale: 1:4,500

NO.	DATE	REVISION	BY
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Date Saved: 2023-01-17
Coordinate System: NAD 1983 UTM Zone 10N

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Map 2

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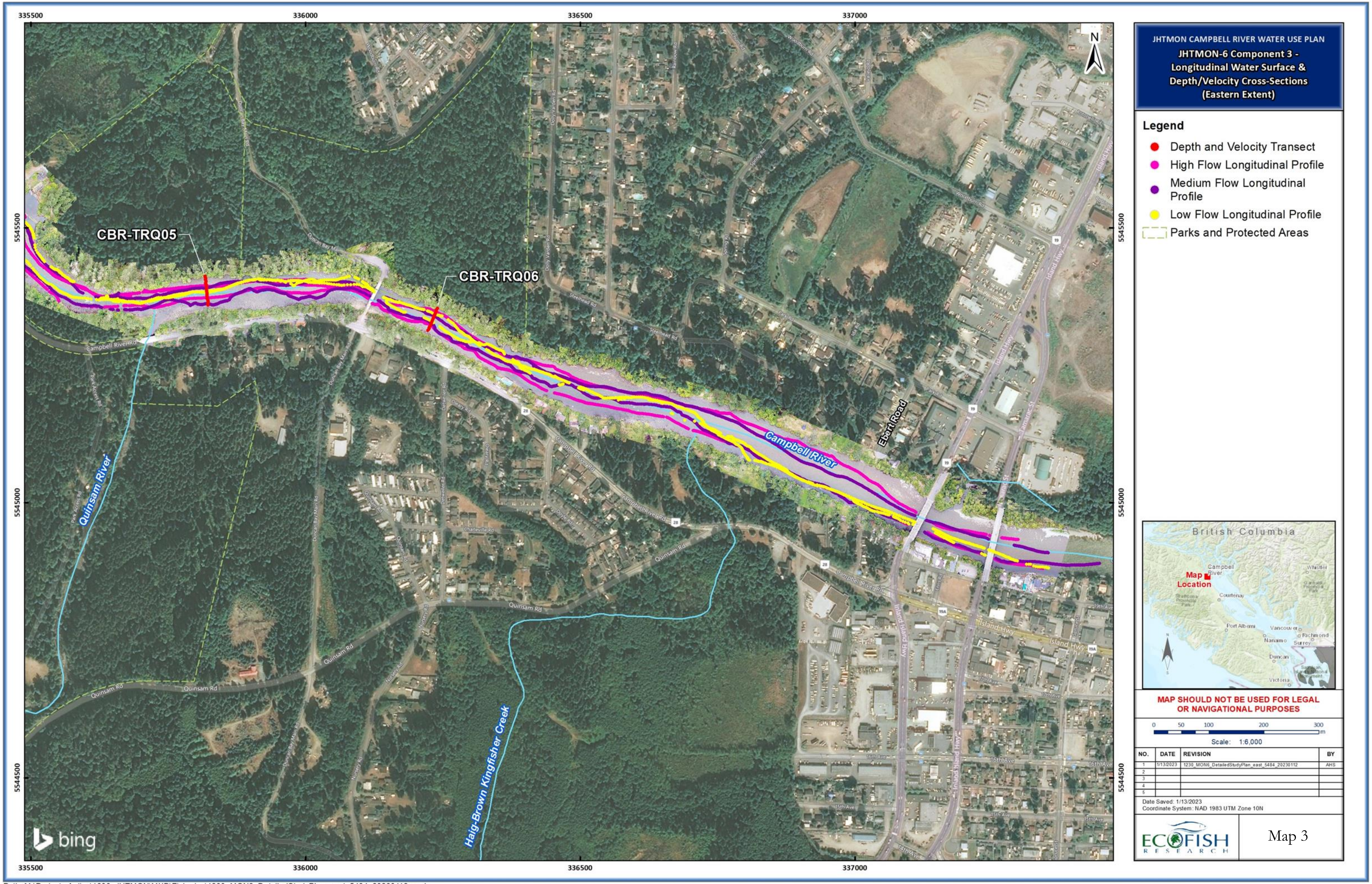

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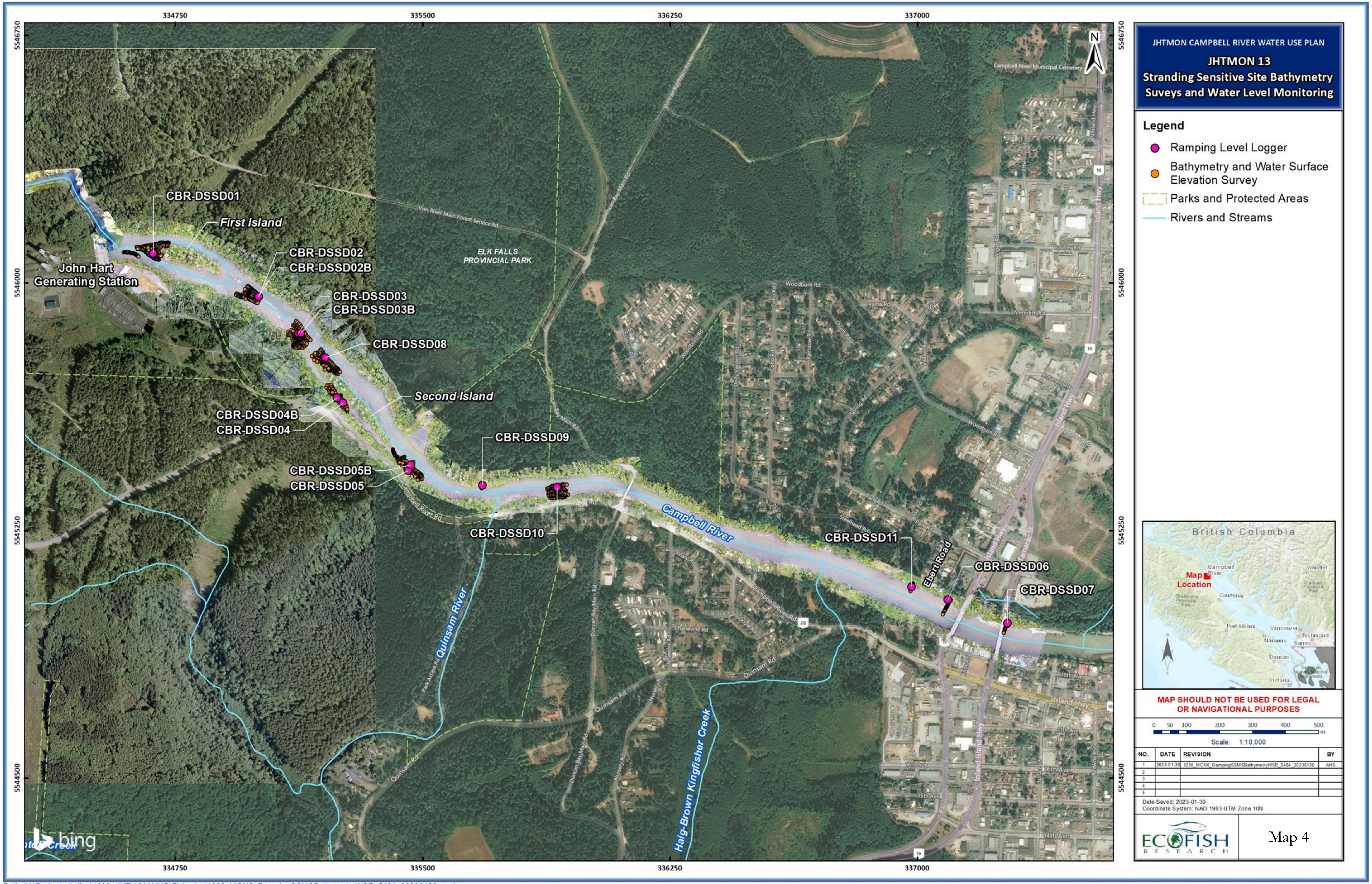

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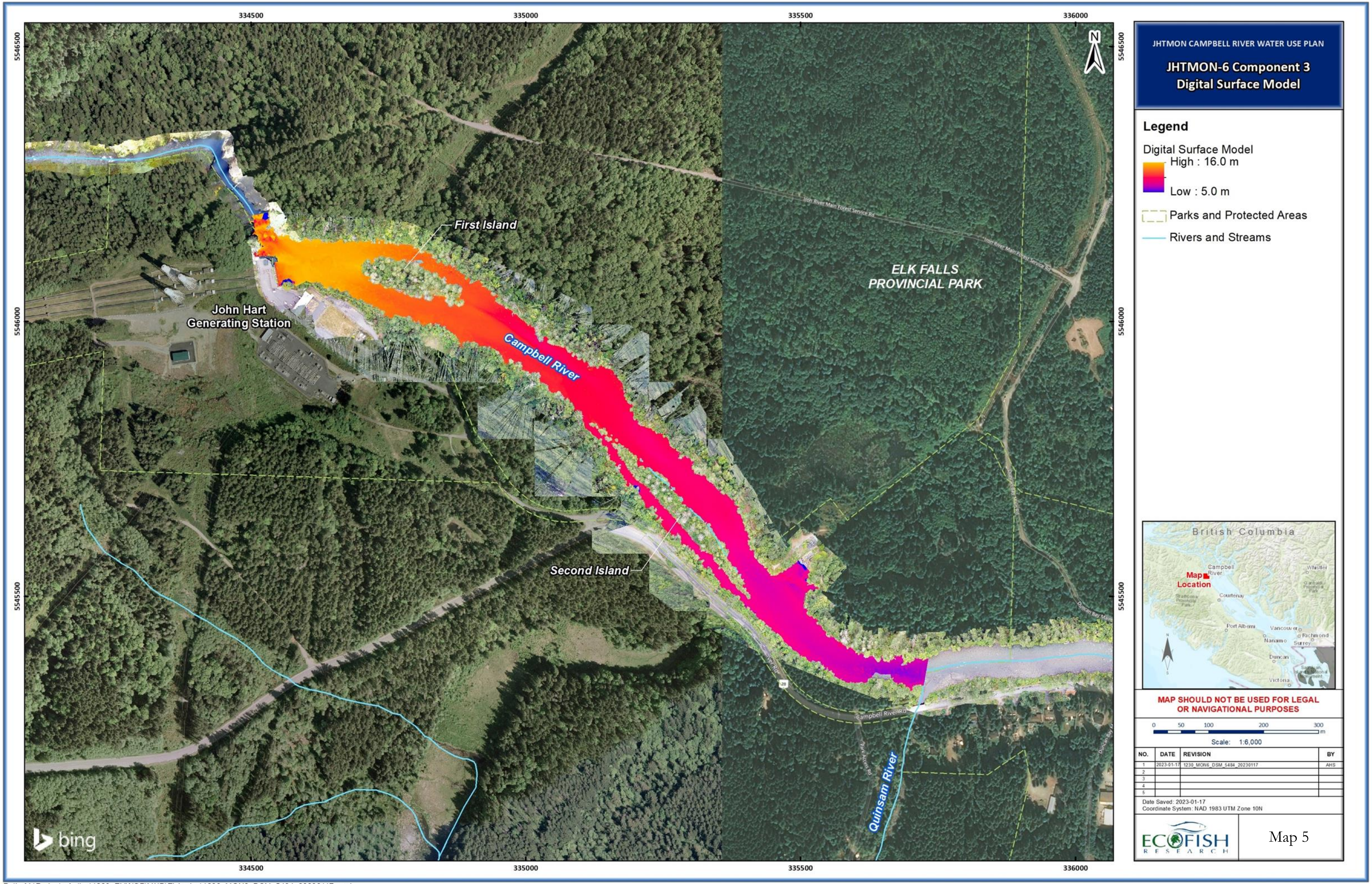

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