Site C Clean Energy Project

Site C Fish Stranding Monitoring Program (Mon-12)

Construction Year 7 (2021)

Ecofish Research Ltd.
Suite 906 – 595 Howe Street
Vancouver, BC, V6C 2T5

December 20, 2022

Site C Mon-12

Fish Stranding Monitoring Program – Year 7

Prepared for:

BC Hydro and Power Authority
333 Dunsmuir Street
Vancouver, BC, V6B 5R3

December 20, 2022

Prepared by:

Ecofish Research Ltd.

Published by Ecofish Research Ltd., 600 Comox Rd., Courtenay, B.C., V9N 3P6

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

Citation:

Whelan C., L. Hull, M. Sparling, T. Sherstone, S. Nichol, and F.J.A. Lewis. 2022. Site C Mon-12 Fish Stranding Monitoring Program Year 7. Consultant's report prepared for BC Hydro by Ecofish Research Ltd., December 20, 2022.

Certification: *Certified - stamped version on file.*

Senior Reviewer:

Adam Lewis, M.Sc., R.P.Bio. No. 494
President, Senior Fisheries Scientist

Technical Leads:

Adam Lewis, M.Sc., R.P.Bio. No. 494
President, Senior Fisheries Scientist

Steve Nicholl, B.Sc., R.P. Bio. No. 3405
Environmental Technician, Project Manager

Disclaimer:

This report was prepared by Ecofish Research Ltd. for the account of BC Hydro. The material in it reflects the best judgement of Ecofish Research Ltd. in light of the information available to it at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, is the responsibility of such third parties. Ecofish Research Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions, based on this report. This numbered report is a controlled document. Any reproductions of this report are uncontrolled and may not be the most recent revision.

EXECUTIVE SUMMARY

Fish stranding monitoring is required at BC Hydro's Site C Clean Energy Project (the Project) to quantify fish stranding on the Peace River, as outlined in the monitoring plan for the Site C Fish Stranding Monitoring Program (Mon-12). This report provides an annual update of the Mon-12 program background, management questions and hypotheses, study area, field and supporting methods, and data collected from Construction Year 7 (2021). In October 2020 the Diversion Headpond was formed following the diversion of the Peace River through the Project's diversion tunnels, therefore, 2021 is the first monitoring year of monitoring with the Diversion Headpond present. Within the report an Action Threshold is used to assess whether stranding risk has increased in 2021 compared to baseline years (2017 – 2020).

Methodology for 2021 was based on previous years of study. The spatial sampling strategy of Mon-12 was modified in Construction Year 3 (2017) to follow the hierarchy of Reach > Channel Type > Mesohabitat > Microhabitat for modelled channel segments within each reach (i.e., Diversion Headpond, Reach 1, Reach 2, and Reach 3). Fish stranding and isolation rates within dewatered habitats were quantified through interstitial sampling, and the isolation rates of fish in pools were quantified through electrofishing sampling in pools.

The characteristics of each ramping event, and the extent and timing of crew response to events are summarized. The extent to which fish stranding and isolation varied among reaches, between single- and multi-thread channels, and low and high stranding risk mesohabitat are calculated. A breakdown of the age class and species representation are also shown.

Major findings from this seventh year of annual reporting are summarized below.

Ramping Events

- Searches were conducted on 18 days, following 12 ramping events in 2021.
- In general, the ramping events in 2021 were of smaller magnitude those monitored during baseline; No events with a combination of ≥ 750 m^3/s discharge decline, and ≥ 20 cm/hr stage decline[1,2] were searched.
- Field study duration was greater in 2021 (April to November) than during baseline monitoring (July through October).

Characteristics of Isolated/Stranded Fish

- Among the fish observed during interstitial sampling, the majority were young of year (i.e., >90%); this finding was consistent with results from previous years.

---

[1] One event occurred with a discharge decline of -759 m^3/s, and stage decline of -21.4 cm/hr on October 22; however, crews were not able to mobilize until October 23, after another ramping event had occurred.

[2] Measured at WSC gauge (07FA004) Peace River above Pine River.

- Juvenile and adult observations were relatively infrequent, and nearly all adult observations were of species that do not exceed 100 mm in length (i.e., sculpins and shiners).
- Sucker spp. and Longnose Dace continued to be two most commonly found groups in 2021, while sculpin spp. were not as common as previous years.
- Mountain Whitefish and Redside Shiner were found in higher numbers than previously observed.

Interstitial and Pool Sampling Stranding and Isolation Rates

- The combined interstitial stranding and isolation rate at high-risk sites (3.71 fish/100 m) was lower than the Action Threshold (6.22 fish/100 m), therefore, no immediate management actions have been triggered for sampling in 2022.
- The reach level combined interstitial stranding and isolation rate was lowest in the Diversion Headpond (1.74 fish/100 m), but higher in Reach 1 (5.17 fish/100 m) and Reach 2 (7.74 fish/100 m).
- Interstitial stranding and isolation were also measured in the Offset Channel Site 108R for the first time, and had a stranding only rate (4.48 fish/100 m) comparable to the stranding only rate in Reach 1 (4.26 fish/100 m).
- A high number of fish were found during pool sampling (with approximately 90% salvaged alive) compared to baseline; the fish were primarily concentrated in the Diversion Headpond (2021 Diversion Headpond observations = 635 fish, baseline total Diversion Headpond observations = 143 fish).

Management Hypotheses were detailed in the Site C Fish Stranding Monitoring Program (Mon-12; BC Hydro 2015). In this year of reporting only Hypothesis 1 can be evaluated (Hypotheses 2-4 are specific to the operational period).

Hypothesis 1: During Project construction, fish stranding in the Diversion Headpond increases relative to baseline conditions.

- After one year of construction monitoring this hypothesis is not currently supported.
- The combined interstitial stranding and isolation rate in the Diversion Headpond in 2021 (1.74 fish/100 m) was 31% of that during baseline (5.62 fish/100 m).

Fish stranding monitoring under the Mon-12 program will continue for construction Year 8 in 2022. Recommendations for refinements to the monitoring methods in 2022 can be found in the Site C Stranding Monitoring Program Recommendations Memo – Year 7 (Sherstone *et al.* 2022).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

LIST OF APPENDICES

1. INTRODUCTION

BC Hydro developed the Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program (FAHMFP; BC Hydro 2015a) in accordance with Provincial Environmental Assessment Certificate Condition No. 7 and Federal Decision Statement Condition Nos. 8.4.3 and 8.4.4 for the Site C Clean Energy Project (the Project). The Site C Fish Stranding Monitoring Program (Mon-12), included as Appendix M of the FAHMFP, aims to quantify fish stranding and isolation along the Peace River during baseline conditions compared that under construction and operations phases of the Project to address the primary fisheries management questions and hypotheses (BC Hydro 2015b; Section 2.3). Monitoring is focused on a study reach of the Peace River which extends from the estimated upstream extent of the future Diversion Headpond upstream of the Project to the Many Islands area in Alberta approximately 139 km downstream. The study reach is broadly divided into two sections: the future Diversion Headpond upstream of the Project (18 km) and the Peace River downstream to the Many Islands area in Alberta (122 km). The downstream section of the Peace River is further divided into three reaches (Reaches 1 to 3) with breaks at the Pine River and Alces River confluences (Map 1). Additionally, monitoring in 2021 included the Offset Channel Site 108R for the first time since its construction in 2020.

Ecofish Research Ltd. (Ecofish) was previously retained by BC Hydro to provide technical oversight of field data collection conducted by Ecora Engineering & Resource Group Ltd. (Ecora) during baseline monitoring from 2016-2019[3] (see baseline reports: Ecora 2018, 2019, 2020). An additional year of baseline monitoring was conducted by Ecofish[4] in 2020; the results for 2020, along with a summary of baseline sampling were presented in the first program synthesis report (referred to as the Year 4 Synthesis Report; Swain *et al.* 2022). Ecofish[4] led sampling again in 2021, which was the first year of monitoring during the construction period; results from 2021 are presented within this report, which represents the seventh year of reporting. Given that one year of data have now been collected during the Project's construction phase, this report is also the first to compare monitoring results during construction to the Action Threshold.

The objective of the Mon-12 program is to quantify and compare fish stranding and isolation in the Peace River between baseline and each of the construction and operational phases of the Project and thereby evaluate the effects of flow fluctuations during construction and operation on fish stranding. Monitoring results will then be used to determine if the Project is increasing fish stranding relative to baseline through comparison to an Action Threshold. Consistent with environmental effects detection thresholds in monitoring programs for hydroelectric projects (Lewis *et al.* 2013), the Action Threshold was defined as a 50% change relative to baseline conditions. The Action Threshold was implemented

---

[3] Data from the first year of monitoring in 2016 (Ecora 2017) differed in methods and scope and therefore are not included in Mon-12 multi-year comparisons; however, 2016 data collection assisted with the development of an effective sampling strategy for subsequent years (Nicholl and Lewis 2016).

[4] Golder Associates Ltd. supported Ecofish with field personnel and equipment; Halfway First Nation supported Ecofish with field personnel.

to quantitatively evaluate fish stranding risk relative to a benchmark established during construction, and determine if mitigation is needed.

This report has three objectives:

- Provide an annual summary of results from 2021 sampling for the Mon-12 program;
- Compare 2021 stranding rates to the Action Threshold developed from baseline values (Swain *et al.* 2022); and
- Address the primary Mon-12 fisheries management questions (detailed in Section 2.3.1) where data are sufficient to do so.

2. BACKGROUND

The sections below provide background information on general fish stranding risk during flow changes, potential for fish stranding in the Peace River due to the Project, the management questions and hypotheses of the Mon-12 program, and the Action Threshold for fish stranding.

2.1. Fish Stranding and Isolation

Rapid changes in flow and stage have the potential to cause fish stranding or isolation, both of which can occur when fish become separated from a stream channel during flow changes. Fish do respond to changes in flow by changing position to avoid dewatering, but may not perceive the changes or may be reluctant to leave the cover of coarse substrates (Nicholl and Lewis 2016). Fish stranding may result in injury or mortality of fish due to causes such as suffocation, trauma, or exposure to predation (Lewis *et al.* 2013). Fish are considered stranded when they are found dead out of water or are at imminent risk of death from the dewatering of previously wetted habitats (Golder 2014a).

Fish isolation occurs when fish become trapped in small, wetted areas that have become disconnected from the main channel. An isolated fish may not be at imminent risk of mortality but may be at an elevated risk from predation and deteriorating water conditions (i.e., increased water temperature, freezing, or reduced dissolved oxygen), and an isolated fish may become stranded if water depth continues to decrease due to subsurface outflow (Nicholl and Lewis 2016). The risk to isolated fish usually depends on physical characteristics of an isolated pool (i.e., size, depth, substrates, and presence of cover), weather (which can affect evaporation, temperature, and dissolved oxygen), and the length of time before the pool becomes reconnected to the main flow (Lewis *et al.* 2013). Young-of-year (YOY), juvenile, and small-bodied fish are often at a higher risk of stranding or isolation due to their typical association with shallow, near-shore habitats and reduced swimming capacity (Triton 2009; Lewis *et al.* 2013).

Fish stranding and isolation occurs naturally due to water level fluctuations but may be exacerbated by water management activities including those related to hydroelectric power generation that increase the relative frequency, rate, and magnitude of stage and flow reductions (Nagrodski *et al.* 2012; Irvine *et al.* 2015). The magnitude of fish stranding and isolation is typically closely related to the magnitude and rate of flow reductions (hereafter referred to as ramping events; Irvine *et al.* 2009). The risk of fish stranding and isolation is also influenced by a number of other factors including the duration of time habitat is wetted prior to a ramping event (i.e., wetted history), the rate at which a flow reduction occurs (i.e., ramping rate), and the physical characteristics of habitat dewatered by an event, including shoreline slope, substrates composition and cover, and the presence of depressions or other areas that retain water during stage reductions (Golder and Poisson 2010a, 2010b).

2.2. Potential Project Effects on Fish Stranding

The Peace River is a large river flowing east out of the Northern Rocky Mountains that joins the Athabasca River and eventually drains into the Arctic Ocean via the Mackenzie River. The Peace River has two existing operational impoundments in place, the WAC Bennett Dam and the Peace Canyon Dam (PCN), which regulate the downstream discharge of flow in response to variable demand in electricity within BC and abroad.

During Project construction, water from the Peace River is being diverted around the Site C dam footprint through two diversion tunnels with limited capacity. When flow pulses are generated at the PCN, these travel downstream to Site C and when the volume of water is greater than what can pass through the diversion tunnels, water backs up into the Diversion Headpond (to a maximum of approximately 18 km upstream of the dam). The Diversion Headpond drains when reduced flows from PCN allow the diversion tunnels to pass excess flow. Thus, the area encompassed by the Diversion Headpond fluctuates between Diversion Headpond-like and river-like conditions depending on flow releases from the PCN.

Although the objective of stranding monitoring under the Mon-12 program is to quantify and address potential effects of Site C on fish stranding, during baseline and the construction period the Mon-12 program targets ramping events related to PCN flow variability. Ramping events at PCN are the causes of the flow changes that pass through the Site C area and that cause the Diversion Headpond to fill and then drain. Further, because a baseline level of fish stranding existed without the Project due to these PCN-caused ramping events, field monitoring of fish stranding is timed to PCN-caused ramping events, and fish stranding related to the Project is evaluated relative to baseline conditions (i.e., conditions without the Project but with effects of flow variability related to operations of the PCN).

2.3. Management Questions and Hypotheses

Data collection was designed to address the primary fisheries management questions and hypotheses within Appendix M (Mon-12; Site C Fish Stranding Monitoring Program) of the Site C FAHMFP (BC Hydro 2015a). Data from 2021, which represent data from the first year of monitoring during Project construction, are compared with data from baseline years (2016-2020) to address management questions and hypotheses of the Mon-12 program, which are summarized below.

2.3.1. Management Questions

The primary objective of Mon-12 is to collect data that address four primary fisheries management questions (BC Hydro 2015b):

Q1. What is the magnitude of fish stranding in the Diversion Headpond relative to baseline conditions?

Q2. Which species and life stages of fish are most affected by stranding in the Diversion Headpond relative to baseline conditions?

Q3. During Project operation, what is the magnitude of fish stranding by species and life stage in the Peace River downstream of the Project relative to baseline conditions?

Q4. Do mitigation strategies (i.e., fish salvage and habitat enhancement) reduce fish stranding rates relative to baseline conditions?

The management questions will be addressed by testing the following hypotheses:

H1. During Project construction, fish stranding in the Diversion Headpond increases relative to baseline conditions.

H2. During Project operation, fish stranding in the Peace River between the Project and the Pine River confluence increases relative to baseline conditions.

H3. During Project operation, fish stranding in the Peace River between the Pine River confluence and the Many Islands area in Alberta is similar to baseline conditions.

H4. Proposed mitigation measures in the Diversion Headpond during the river diversion phase of Project construction and side channel enhancement and contouring in the Peace River downstream of the Project during operations are effective in reducing fish stranding rates.[5]

2.4. Action Threshold

For each year of construction (2021 to approximately 2025), annual monitoring of fish stranding rates and comparison to an Action Threshold. If the Action Threshold is exceeded mitigative actions (e.g., increased monitoring, salvage or channel modification) are required. Consistent with environmental effects detection thresholds in monitoring programs for hydroelectric projects (Lewis *et al.* 2013), the Action Threshold is the baseline stranding rate plus 50%. The specific statistic to be used as the Action Threshold is the combined rate of stranding and isolation of fish detected in high-risk sites during interstitial sampling across all reaches for the relevant baseline years (2017-2020), plus 50%. The baseline interstitial combined stranding and isolation rate was calculated in the Year 4 Synthesis Report (Swain *et al.* 2022) as 4.11 fish/100 m; thus, the Action Threshold for the construction phase is 6.22 fish/100 m.

---

[5] Side channel enhancement and contouring in the Peace River downstream of the Project (i.e., Offset Channel Site 108R) was constructed in 2020 to offset Project effects to fish and fish habitat.

3. METHODS

Stranding monitoring involved selecting sites for monitoring of stranding, and conducting field sampling during targeted ramping events. Field surveys entailed fish stranding surveys (i.e., searches) which were conducted to record and salvage stranded and isolated fish. The study area, site and ramping event selection, and the field sampling protocol (search) methods are outlined below. Also included are methods for data management and analysis.

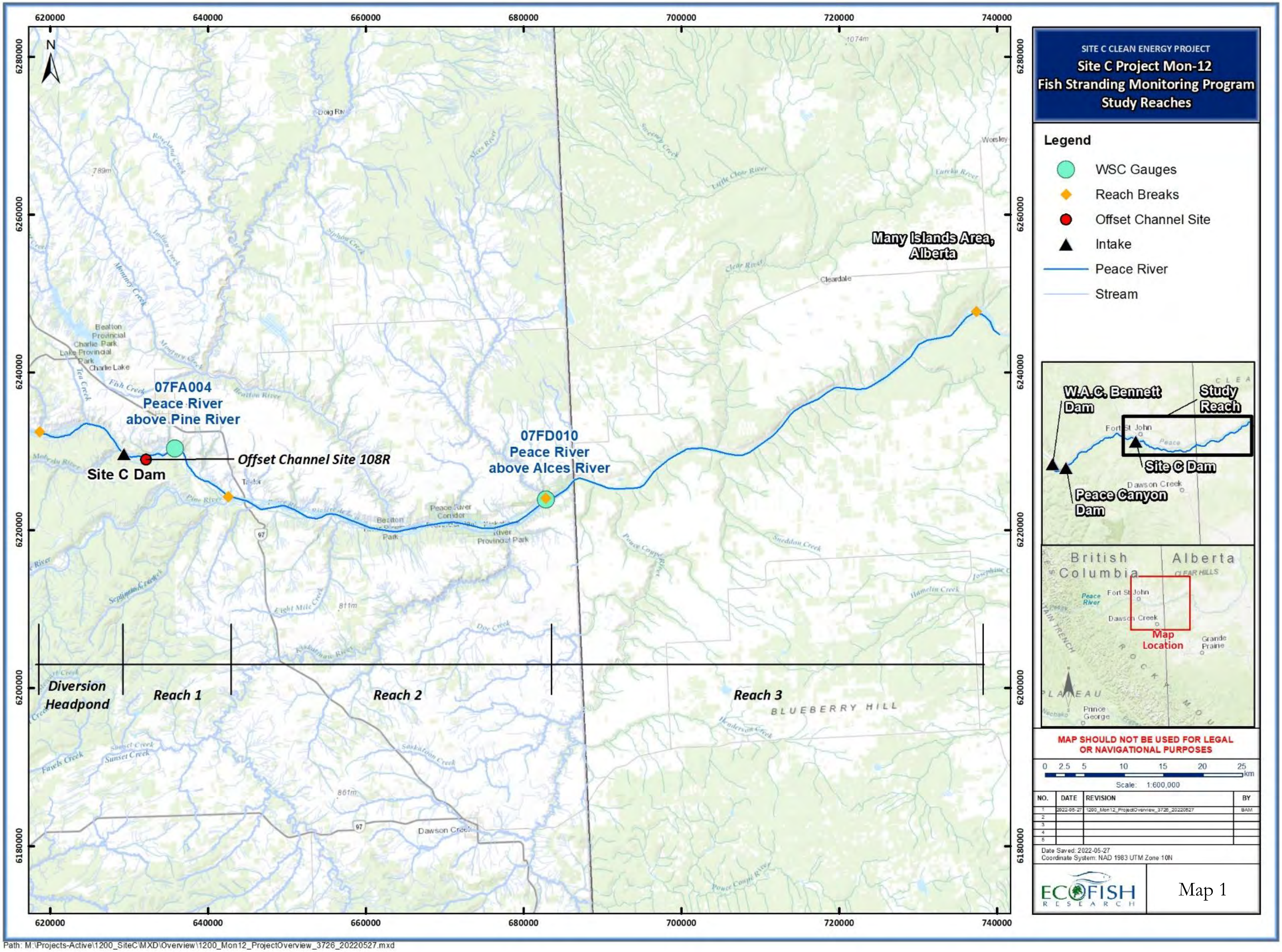
3.1. Study Area

The Mon-12 study area is comprised of approximately 139 km of the Peace River, from the Wilder Creek confluence, downstream to the Many Islands area in Alberta (Map 1). As defined by the Mon-12 monitoring plan (BC Hydro 2015b), this study area is split into two general sections:

1) The Site C Diversion Headpond (referred to as 'Diversion Headpond'), extending approximately 18 km, from the Wilder Creek confluence downstream to the Project dam site (monitored in 2017 – 2021); and
2) The Peace River downstream of the Project, extending approximately 121 km, from the Project dam site downstream to the Many Islands area in Alberta, which is further divided into three reaches:
    - Reach 1 – from the Project dam site downstream to the Pine River confluence (16 km; monitored in 2017 – 2021);
    - Reach 2 – from the Pine River confluence downstream to the Alces River confluence (42 km; monitored in 2017, 2019 and 2021); and
    - Reach 3 – from the Alces River confluence, downstream to the Many Islands area (63 km; monitored in 2017).

Monitoring was concentrated within sections of these reaches where the majority of stranding habitat was delineated by channel type and mesohabitat through spatial surveys and modelling, as described below in Section 3.2. Monitoring in 2021 was distributed throughout the Diversion Headpond and Reach 1, with the exception of the roughly 4 km of mainstem Peace River downstream of the Site C dam construction site.

Reach 2 was also monitored in 2021, and included two delineated areas, an upper, approximately 18 km section from Taylor Bridge, downstream to near the Beatton River confluence, and a lower, approximately 13 km section, from 5 km downstream of the Beatton River confluence, to approximately 4 km downstream of Raspberry Island in the Peace River Corridor Provincial Park. The monitored area in Reach 3 encompassed a delineated area roughly 8 km in length around the Many Islands area, at the downstream end of the reach. Monitoring in 2021 was also conducted in the Offset Channel Site 108R (Offset Channel). This offsetting area is located on river right approximately 2 km downstream of the Site C dam (Map 1) and consists of several constructed or recontoured side channels or backwaters meant to provide high quality fish habitat (BC Hydro 2015a) as required to offset site preparation (DFO 2015) and dam construction (DFO 2016).



SITE C CLEAN ENERGY PROJECT

Site C Project Mon-12
Fish Stranding Monitoring Program
Study Reaches

Legend

●	WSC Gauges
◆	Reach Breaks
●	Offset Channel Site
▲	Intake
—	Peace River
—	Stream

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 2.5 5 10 15 20 25 km

Scale: 1:600,000

NO.	DATE	REVISION	BY
1	2022-05-27	1200_Mon12_ProjectOverview_3726_20220527	BAM
2			
3			
4			
5			

Date Saved: 2022-05-27
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1200_SiteC\MXD\Overview\1200_Mon12_ProjectOverview_3726_20220527.mxd

3.2. Channel Delineation by Mesohabitat Type

The spatial sampling strategy of the Mon-12 study was modified in Construction Year 3 (2017) and applied in Construction Years 4 – 7 (2018 – 2021) to follow the hierarchy of Reach > Channel Type > Mesohabitat > Microhabitat, as described in Nicholl and Lewis (2016). Existing spatial data were used to delineate shorelines which were categorized to the mesohabitat level based on desktop review of available data.

First, the study area was delineated into the four reaches as defined in Section 3.1. Second, under the rationale that stranding risk is elevated in multi-thread channels due to increased habitat complexity, each reach was delineated into single and multi-thread channel segments based on the side channel inventory and mapping conducted by Mainstream (2013) for the future Diversion Headpond, and Northwest Hydraulic Consultants (NHC) (NHC 2012, 2013) for the downstream reaches. Where Mainstream or NHC had identified one or more side channels, all shorelines of the mainstem of the Peace River and associated side channels were delineated as multi-thread channel segments between the channel forks and confluences. Between these segments where no side channels had been identified, the Peace River was considered a single-thread channel segment.

Finally, discrete sections of shoreline were further delineated into mesohabitat types corresponding to stranding risk categories (high-risk, low-risk, and negligible risk) based on a review of spatial slope data derived from a digital elevation model (DEM), and river shorelines delineated from a River2D (Steffler and Blackburn 2002) model provided by BC Hydro and Fish Habitat Assessment Procedure (FHAP) data collected by Mainstream (2013). The River2D model provided minimum and maximum wetted shoreline margins within modelled sections of the future Diversion Headpond and the three downstream reaches. Where River2D data were not available, minimum and maximum wetted shoreline margins were delineated based on FHAP polygons. The DEM was generated using Blue Kenue™ software (NRC 2017) from which a slope layer with a 1 m grid cell size was created. The slope layer was classified into three stranding risk categories based on % gradient: high-risk (≤ 5%), low-risk (6 – 20%), and negligible risk (>20%) consistent with previous studies of fish stranding (e.g., Bell *et al.* 2008; Golder 2017), the slopes of sites established by Ecora, and associated stranding observations in the first year of monitoring in 2016 (Ecora 2017) and overlain with the River2D model and FHAP derived minimum and maximum wetted shoreline layers. These spatial data were then reviewed along with orthophotos by a fisheries biologist experienced in fish stranding studies to delineate all shorelines within the study reaches where model data were available. Shorelines were delineated into ≥ 100 m long mesohabitat sections composed of similar habitat units characterized as high, low, or negligible stranding risk based on the dominant slope categories as defined above (Map 2). The stranding risk classification at individual sites were then confirmed with clinometer measurements of shoreline slope and assessments of substrate and habitat structure in the field (Ecora 2020).

3.3. Stranding Monitoring Site Selection

Targeted high-risk monitoring sites were initially selected during field reconnaissance in 2016 based on habitat characteristics known to increase the risk of fish stranding and/or isolation (Ecora 2017). Specifically, Ecora focused monitoring effort on habitats where shoreline gradients were < 4%, characterized by large relative areas of potentially dewatered substrate (i.e., > 500 m²), prevalent cover (i.e., large relative substrates such as cobble and boulder, low substrate embeddedness, and/or woody debris), and natural stream habitats most likely to strand or isolate fish as described by Lewis *et al.* (2011):

- Where the river cross-section has a relatively flat slope with large substrate that could strand fish, or finer substrate with depressions that could trap fish;
- Cobble and gravel bars, with roughness characteristics that create refuges that juvenile fish are known to prefer and may be reluctant to leave during a ramp down event; and
- Side channels or shallow pools along stream margins that are known to be preferred by rearing juvenile fish.

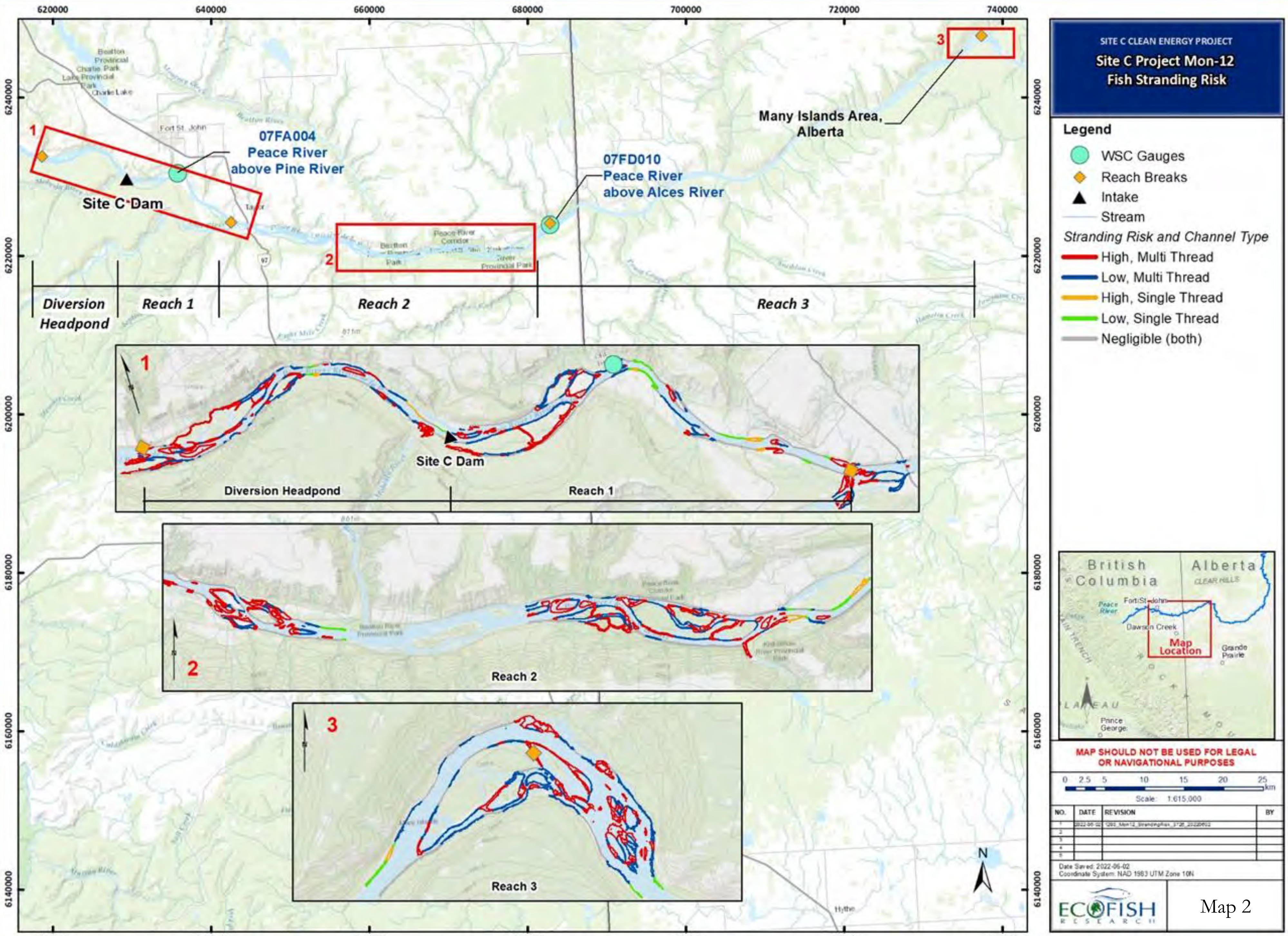
In subsequent baseline years, sites where stranding had been detected previously were repeatedly sampled, and additional targeted sites were established based on the above criteria augmented with linear mapping of shorelines as single- or multi-thread channel, and high, low, or negligible risk (Section 3.2) to ensure that areas of high stranding risk habitat representative of the overall shoreline characteristics of each study reach were monitored. Ecora characterized targeted sites as large polygons of shoreline composed of similar habitat. These polygons were repeatedly searched following multiple events when possible and were augmented with newly established sites when river stage and discharge made conditions at existing sites inappropriate for conducting searches. To determine whether targeted sites were representative of overall habitat and fish stranding within the reaches, 11% of searches were conducted at waypoints randomly selected through GIS mapping tools within each of the stratifications described in Section 3.2 except for negligible-risk mesohabitats, which were deemed unsuitable to monitor due to a lack of any appreciable stranding habitat (as confirmed by field observations). A list of these random waypoints was compiled and ordered using a random number generator in R (R Development Core Team 2020) and visited sequentially over the course of baseline monitoring. Typically, randomly selected sites were only searched once, with new randomly selected sites generated each year. However, in some cases where randomly selected sites were determined to be representative of high-risk stranding habitat, they were added to the list of targeted sites for a given stratification, and revisited following subsequent ramping events when conditions were appropriate based on the professional judgement of the monitoring crews. Stranding searches (as described in Section 3.5 below) were conducted over subsections of appropriate stranding habitat within targeted sites deemed to be appropriate based on an assessment of river and site conditions at the time of searches. Therefore, similar sections of habitat were typically searched in each site under similar conditions but varied over time due to differing river stage and discharge conditions among searched ramping events. Targeted sites searched following a given ramping event were selected based on whether appropriate stranding habitat had been dewatered within a site as determined by flow and stage conditions of, and following an event, and verification of conditions at specific sites in the field.

In 2021 site selection repeated sampling at sites searched during baseline years including sites classified as both targeted and random during the baseline site selection. Additionally, instances occurred where near the end of the day no baseline sites were nearby. On such occasions crews would visually select likely stranding habitat and conduct a search. Approximately 10 sites were selected in this manner. Lastly six sites were also searched in the newly created Offset Channel Site 108R. These sites were selected using visual identification of high-risk (5 sites) and low-risk (1 site) stranding habitat.

Upon evaluation of the results in 2021 it was noted that a limited number (5 sites) of low-risk sites had stranded fish observed. A desktop analysis was undertaken to determine whether these sites actually featured high-risk habitat. The evaluation resulted in reclassification of four sites from low-risk to high-risk based on gradient, substrate and pool formation.

SITE C CLEAN ENERGY PROJECT

Site C Project Mon-12 Fish Stranding Risk



Scale: 1:615,000

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

NO.	DATE	REVISION	BY
1	2022-06-02	1200_Mon12_StrandingRisk_3726_20220602	
2			
3			
4			
5			

Date Saved: 2022-06-02
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 2

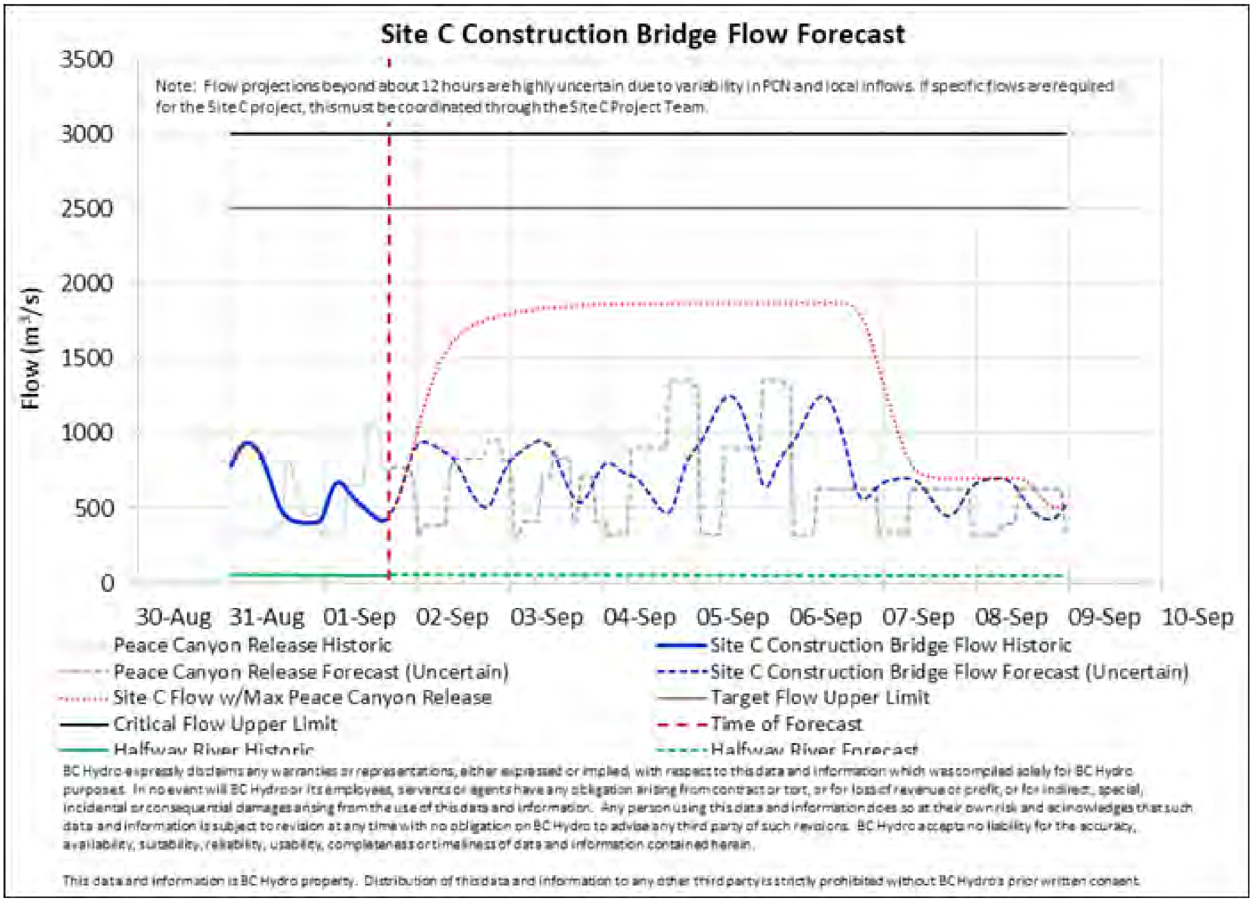
Path: M:\Projects-Active\1200_SiteC\MXD\Overview\1200_Mon12_StrandingRisk_3726_20220602.mxd

3.4. Ramping Event Selection

In previous years sampling trips were planned to s ample ramping events during the summer and fall seasons (generally July to October), though in 2021 monitoring was expanded to April through November, to ensure sufficient events were sampled. Sampling trips were planned to align with flow ramping events using PCN operations forecasts. For each ramping event, BC Hydro advised Ecofish of the planned timing, magnitude, and duration of the event. Each trip was planned using a Peace River flow report (Figure 1) to begin sampling when flows had finished declining at a site.

Ramping events that were monitored generally involved the ramping down of discharge volume from a peak level (typically between 1,200 and 1,600 m^3/s) to a low level (typically 400 to 500 m^3/s). Prior to sampling in 2021 it was agreed by BC Hydro, Ecofish, and Golder that a minimum of five events would be targeted for sampling (i.e., conducting searches for stranded fish). Selection of events for monitoring included consideration of the magnitude of flow change (with high magnitude events (e.g., >500 m^3/s flow change) given priority), as well as ramping rate, time of year, wetted history, and duration of reduction.

Figure 1. Example of a flow report issued by BC Hydro every six hours to inform field coordination. Shown is the forecasted reduction event (blue dashed line) at Site C for ramping events that occurred on September 5 and 6, 2021.



Note: Flow projections beyond about 12 hours are highly uncertain due to variability in PCN and local inflows. If specific flows are required for the Site C project, this must be coordinated through the Site C Project Team.

BC Hydro expressly disclaims any warranties or representations, either expressed or implied, with respect to this data and information which was compiled solely for BC Hydro purposes. In no event will BC Hydro or its employees, servants or agents have any obligation arising from contract or tort, or for loss of revenue or profit, or for indirect, special, incidental or consequential damages arising from the use of this data and information. Any person using this data and information does so at their own risk and acknowledges that such data and information is subject to revision at any time with no obligation on BC Hydro to advise any third party of such revisions. BC Hydro accepts no liability for the accuracy, availability, suitability, reliability, usability, completeness or timeliness of data and information contained herein.

This data and information is BC Hydro property. Distribution of this data and information to any other third party is strictly prohibited without BC Hydro's prior written consent.

3.5. Field Sampling

Eighteen days of fish stranding surveys were completed over ten separate trips (ranging in duration from one to three days) between April 24 and November 7, 2021[6]. Maps of sampling sites within each reach are provided in Appendix A. Stranding surveys in 2021 were conduced in the Diversion Headpond, Reach 1, Reach 2, and the Offset Channel Site 108R.

Surveys were generally conducted between 07:00 and 19:00 by crews of two to four field technicians per crew. Sample sites were accessed using jet boats and where possible by foot/truck. Upon arrival at each site, the crews decided where to initiate sampling based on availability of recently dewatered substrates and/or formation of isolated pools. Generally, crews began searches at the upstream end of the Diversion Headpond, and moved downstream as the event trough travelled downstream. The downstream end of the site was recorded (UTM) using the iPad GPS and the following information was recorded on a fillable data-form within the iPad:

- Date and time arrived.
- Reach (Diversion Headpond, Reach 1, Reach 2, Offset Channel).
- Crew member names.
- Method of sampling (i.e., interstitial or pool; see below).
- Weather.
- Air temperature.
- Site location (main channel, side channel, mid channel bar/island).
- River kilometer and site location on river.

Representative site photos were taken using the iPads and saved in association with the GPS waypoint. Each evening the data were downloaded from the iPad and placed on Ecofish's secure network. Based on the site conditions and habitat availability, either interstitial sampling (using broad-based and hot-spot searches to locate stranded fish and those isolated in small pools) or pool sampling (searches focused on large pools where fish may be isolated) (described below) was completed. Often both interstitial and pool sampling occurred in the same general location, and the sampling was recorded under the same site name, but with different search methods. Results from pool and interstitial sampling are reported separately because fish in large isolated pools are more likely to survive than those that are stranded or found in small pools.

---

[6] Additionally, a single search took place on January 9, 2021.

3.5.1. Interstitial Sampling

Interstitial sampling was conducted within dewatered habitat at each selected monitoring site determined to be appropriate for searches following a specific ramping event (i.e., an interstitial sampling event). In 2017, the interstitial sampling methods initially involved searching 1 m² quadrats placed at regular intervals along 100 m transects within a portion of each site following methods similar to those used to monitor ramping events on the Duncan River (Golder 2014b). This method was intended to reduce searcher bias and increase accuracy of searches, however, it resulted in low detection success during the first two trips due to the non-random occurrence of fish stranding and isolation as described by Ecora (2018). Consequently, interstitial sampling methods were revised for the remainder of 2017 and subsequent years of baseline monitoring (2018 to 2020) to adopt a combination of broad-based (visual overview) searches and hot-spot searches (targeted excavation of substrate) as described below.

Broad-based searches were conducted along a length of transect over a portion of an overall site where dewatered stranding habitat was present under conditions at the time of sampling. A transect length of 100 m was targeted for broad-based searches, although lengths varied from 15 to 450 m in length (median = 100 m) depending on the relative dimensions of dewatered stranding habitat at a given site. The width of broad-based searches varied depending on the width of dewatered stranding habitat at a given site, ranging from 1 to 100 m (median = 10 m).

During each broad-based search, crews searched the transect in an upstream direction covering the shoreline from the wetted edge up to the estimated extent that the substrate was wetted prior initial stage declines associated with the ramping event being searched. During the broad-based search, areas of highest stranding risk were identified for hotspot searches. The length and width of the searched area, number of searchers, effort per searcher (minutes), start and end time of each search, and weather conditions were recorded, and representative photographs and waypoints of the upstream and downstream extent were taken for each broad-based search. If searches were conducted in a newly established site, or a new section of stranding habitat within an established site, % substrate composition, cover (vegetation or other), and shoreline slope were also recorded. Where shoreline slope was not recorded in the field, values were extracted from the DEM described in Section 3.2 at the location of the site waypoint on a map. Presence of bird activity or signs of scavenger presence (e.g., fresh tracks) within sites was recorded, as scavenging and predation may result in the removal of isolated or stranded fish within a site prior to their detection during searches.

Once a broad-based search was complete, five hotspot transects were selected to characterize the highest risk stranding habitat within the broad-based area based on characteristics described by Lewis *et al.* (2011) (e.g., shallow depressions, small pools of residual water, and/or areas with abundant coarse substrate or other cover) and professional judgement. At each hotspot transect, measuring tapes were used to delineate the dimensions of the area to be searched. An area of 20 m² was targeted for each hotspot transect to sample a combined area of approximately 100 m² at each site. Within each hotspot transect, crews worked close to the ground (i.e., on hands and knees), and overturned all large substrate and other cover to search for fish. The length, width, number of searchers, search effort per searcher (minutes), and representative photographs were recorded for each hotspot search. All fish that were observed or captured during interstitial sampling were processed and recorded as described in Section 3.5.3.

3.5.2. Pool Sampling

Pool sampling was conducted by two to three person crews using backpack electrofisher units (Smith-Root LR-24) within pools isolated from the Peace River mainstem by the searched ramping events where present in selected monitoring sites using the following procedure.

- Upon arrival at each site, reconnaissance of the area was conducted to determine the presence and suitability of isolated pools within the site. To be suitable for sampling, pools needed to be ≥ 1 m^2, have a maximum depth of ≥ 5 cm, and be disconnected from the mainstem (i.e., isolated), with no evidence of consistent surface or subsurface flow.
- Up to three pools were sampled per site. Where more than three pools were present at a given site, the three pools with the highest likelihood of containing fish were selected based on habitat suitability, size, substrate composition, and cover.
- Sampled pools were first searched visually to verify fish presence and then sampled through 2 to 3 electrofishing passes to determine fish abundance and salvage isolated fish where possible. Electrofishing voltage, frequency, and duty cycle settings were set using the LR-24 quick setup based on water conditions, and manually adjusted as necessary to optimize capture success.
- For each sampled pool, the wetted length, width, maximum depth, and where possible, estimated maximum pre-event length, width, and depth (referred to as bankfull measurements) were recorded along with water temperature, visibility, substrate composition, presence of cover, electrofishing effort (seconds), electrofisher settings, and representative photographs, and a waypoint of pool locations were recorded using an iPad or handheld GPS. In 2018 through 2021, all additional suitable pools to those sampled within a site were enumerated, visually inspected for fish presence, and estimated wetted and bankfull length, width, and maximum depth were recorded.

Pools were selected for sampling each time a site was visited based on conditions and suitability of individual pools present at the time. Accordingly, over the course of baseline monitoring, some pools were repeatedly sampled whereas others were only sampled once. This is in contrast to pool sampling conducted on the Duncan River (i.e., Golder 2018), where pools at each site were initially demarcated and a new subset of which were sampled to determine fish presence during each subsequent site visit.

3.5.3. Fish Sampling

All fish observed or captured during interstitial or pool sampling were recorded, as well as those observed incidentally outside of specifically surveyed areas. All live fish were placed in buckets filled with river water until processing and released to the mainstem or connected side channel habitat adjacent to where they were originally captured, once they had recovered. Each fish was identified to species, except when poor relative condition (i.e., desiccation or decay), or when a fish was briefly observed but not captured, and species could not be verified. In these cases, general species group (e.g., sucker, sculpin, cyprinid) was recorded if possible. The fork length of each fish (or total length for sculpins) was recorded to the nearest millimeter using a measuring board or fish viewer (or estimated for fish that were not captured), and the relative life stage YOY, juvenile, or adult) was determined based on general length-at-age keys derived from reference material (McPhail 2007; McPhail and Carveth 1993; Mainstream 2011; Table 1). Fish were classified as stranded if they were completely out of the water at the time of observation, and isolated if they were immersed in water. Fish condition (live or dead) and the cause of mortality (i.e., natural, ramping event induced, or from sampling/processing) were recorded. Representative photographs of fish at each site were taken, and in 2020 and 2021, voucher specimens of mortalities were retained for verification of uncertain species identification in the field.

Table 1. Fish species (including common and scientific names) that were captured or observed during baseline Mon-12 monitoring, and general length-at-age ranges for YOY, juvenile, and adults.

Group	Species		Min. Length-at-Age (mm)		
	Common Name	Scientific Name	YOY[1]	Juvenile	Adult
Sport fish	Arctic Grayling	*Thymallus arcticus*	< 130	130	300
	Burbot	*Lota lota*	< 80	80	400
	Kokanee	*Oncorhynchus nerka*	< 90	90	200
	Mountain Whitefish	*Prosopium williamsoni*	< 100	100	200
	Northern Pike	*Esox Lucius*	< 130	130	351
	Rainbow Trout	*Oncorhynchus mykiss*	< 150	150	250
	Yellow Perch	*Perca flavescens*	< 55	55	120
	Walleye	*Sander vitreus*	< 110	110	301
Suckers	Largescale Sucker	*Catostomus Macrocheilus*	< 50	50	300
	Longnose Sucker	*Catostomus Catostomus*	< 50	50	300
	White Sucker	*Catostomus commersonii*	< 50	50	300
Minnows	Flathead Chub	*Platygobio gracilis*	< 90	90	180
	Lake Chub	*Couesius plumbeus*	< 30	30	81
	Longnose Dace	*Rhinichthys cataractae*	< 30	30	61
	Northern Pikeminnow	*Ptychocheilus oregonensis*	< 60	60	180
	Redside Shiner	*Richardsonius balteatus*	< 50	50	65
	Trout-Perch	*Percopsis omiscomaycus*	< 30	30	80
Sculpins	Prickly Sculpin	*Cottus asper*	< 40	40	61
	Slimy Sculpin	*Cottus cognatus*	< 40	40	61
	Sculpin *spp.*	*Cottus spp.*	< 40	40	61

[1] YOY = young-of-year.

References: McPhail 2007, McPhail and Carveth 1993, Mainstream 2011.

3.6. Hydrometric Data

Hydrometric data (discharge and primary water level) for this report were provided by BC Hydro. The hydrometric data were used to calculate ramping event characteristics including stage change, discharge change, and wetted history. Data were provided for the following stations:

- PCN Total Reservoir Release Flow (termed PCN in this report); and
- Peace River above Pine River (termed PAP in this report) (Water Survey Canada Hydrometric Station 07FA004).

Hydrology data for Peace River above Alces River were not provided in this report because Reach 3 was not monitored in 2021[7].

Site-specific hydrometric data were not available; the hydrometric stations provide hydrometric data representative for each monitored event to facilitate comparison between events, both within this monitoring report and in comparison to previous years. For simplicity and consistency, all ramping rates were calculated from PAP data, which is central to most sites searched in 2021. Ramping events are expected to attenuate with distance downstream (e.g., due to channel friction and inflow) therefore it is likely that the ramping rates at SSMSs will differ from those as measured at PAP. Further, differences in channel morphology (e.g., channel width and bankslope) between hydrometric gauging locations and SSMSs will result in differences in hydrometric response at each location. Generally, ramping rates at SSMSs upstream of PAP (i.e., Diversion Headpond and uppermost SSMSs of Reach 1) may be underestimated relative to PAP, while ramping rates at sites downstream of PAP (i.e., lowermost SSMS of Reach 1 and Reach 2) may be overestimated relative to PAP.

3.7. Data Management

All data were recorded on an enterable form (using the iForm platform) using an electronic tablet. Each evening, PDF copies of the data along with photos, waypoints and digital backups were uploaded to Ecofish's secure network for storage. After each day of data collection, the data were also collated into a summary email which was sent to supervising BC Hydro personnel. After each field trip data were entered into Ecofish's online database (Ecodat).

3.8. Quality Assurance

All field crew were required to review the field protocol prior to data collection (Nicholl and Lewis 2016). During the first major search event, which occurred in April 2021, crews from Ecofish, Golder, and Halfway and Blueberry First Nations participated in stranding searches

---

[7] Note that in the previous synthesis report (Swain *et al.* 2022) PAP was used to characterize hydrology during all ramping events. For future synthesis modelling PAP will be used to represent ramping downstream of Site C, and we anticipate the BC Hydro gauge Peace River at Tea Creek (PTE2) will be the most accurate gauge for the Headpond.

together in order to provide refresher training (where relevant) and gain a consistent understanding of the methods.

One quality assurance measure also related to field methods: as described in Section 3.5.1, part of the protocol for interstitial sampling was to conduct a QA/QC review of one hotspot immediately following the initial sampling by a second crew that had not done the original sampling to ensure that fish were not being missed and to evaluate search effectiveness.

After each day of fieldwork the crew would review data collection forms and notes to correct any mistakes that occurred during data collection. Data forms were reviewed and cross-referenced with past records to ensure consistency and identify potential sources of error. Once the data were entered into digital form, but prior to analysis, the data underwent a further detailed QA by a crew lead experienced in fish stranding sampling at Site C to minimize the potential for errors in the data.

3.9. Data Analysis

Prior to data analysis, records for each sampling event were collated and exported from Ecodat into a MS Excel spreadsheet. All data analysis was conducted on the statistical platform R. Results of the analysis were output into Excel for formatting. It should be noted that results from the Offset Channel were included within data summaries but were not included in comparisons of stranding rates among reaches or to the Action Threshold, given that this area is being created as an offset and therefore is not part of the area monitored for Project effects.

3.9.1. Ramping Events

The start of searched ramping events was defined as the time of the maximum stage preceding the first stage decline following the beginning of flow reductions as measured at PCN. The end time was defined as the minimum stage during an event. As site-specific hydrometric data are not recorded, hydrology metrics were calculated from data measured at the nearest WSC station (PAP in 2021) for each searched event; including total flow change (m^3/s), derived from subtracting the minimum flow from the maximum flow for a given event, flow ramping rate (m^3/s per hr) and stage change rate (cm/hr), calculated as the maximum change in flow and stage in one hour over the course of an event, respectively, and wetted history (days). Flow ramping rate and stage change rate were calculated by:

1) Calculating the maximum flow or stage observed over the past hour for each data point i as:

$$hmax(t_i) = \max\left(h(t_{i-k}), \ldots, h(t_{i-1})\right)$$

where h is flow or stage, k is the number of data points recorded per hour, and t is time, and

2) Calculate the maximum flow or stage decrease over the past hour relative to time t_i, $\Delta hmax(t_i)$, as:

$$\Delta hmax(t_i) = h(t_i) - hmax(t_i)$$

Wetted history was calculated for every data point of a ramping event as the time period (in days) since stage was last less or equal to the stage measured at a gauge. The median values of these wetted histories (i.e., the duration that 50% of the habitat dewatered by the event had been wetted) over the course of individual ramping events were used to qualitatively contextualize the severity of ramping events measured in 2021.

3.9.2. Interstitial Sampling - Fish Stranding and Isolation

The rates of fish stranding and isolation from interstitial sampling events were calculated as a linear density for each site through dividing the combined number of stranded or isolated fish observed during both broad-based and hotspot searches at a given site by the length of the broad-based transect searched. Combining broad-based and hotspot searches was justified given that stranding and isolation is not evenly distributed throughout a site, but rather concentrated in smaller areas of the highest-risk habitat (i.e., Lewis *et al.* 2013); this supports an assumption of interstitial sampling that any obvious fish stranding would be noted during broad-based searches, and that the majority of the highest risk habitat within the site would be searched thoroughly during hotspot searches, and thus most stranding and isolation within dewatered habitat would be detected. Because observed fish densities were often very low, these linear density estimates (i.e., fish/m) were multiplied by 100 to be expressed as fish/100 m in order to present more tangible numbers in figures and summary tables. While stranding and isolation rates can be reported in terms of area (i.e., fish/m^2), linear rates of stranding and isolation (i.e., fish/100 m) were used, as accurate estimates of dewatered area were not available at all sites following all ramping events. Consistent with Swain *et al.* (2022), we calculated the "combined rate" (the rate of fish stranding and isolation combined) to quantify the combined effect and to minimize the number of zeros in the dataset.

3.9.3. Pool Sampling – Fish Isolation

The weighted average density of fish in sampled isolated pools within each site was calculated as the total number of isolated fish caught through electrofishing within all sampled pools in that site on a given date divided by the combined area of the sampled pools. As for linear densities derived from interstitial sampling, areal densities of isolated fish in sampled pools were multiplied by 100 and expressed as number fish/100 m^2 in order to present more tangible density estimates in figures and summary tables.

3.9.4. Water Transit Time

Similar to flood wave propagation, ramping events transit along the reaches at a certain pace. Stranding searches were planned to coincide with the minimum stage of the ramping event (i.e., the ramping event end) at each site; such alignment with the ramping event end would allow the full dewatering effect of the ramping event to be observed, while minimizing the potential for predation and scavenging of stranded or isolated fish (i.e., removal of such fish from a site prior to detection). Generally, crews began searches at the upstream end of the Diversion Headpond, and moved in a downstream direction through each reach as the minimum stage travelled downstream. Water transit time was assessed to evaluate whether differences in search timing may confound stranding and isolation observations between reaches searched in 2021.

For each ramping event monitored in 2021, the ramping event end was estimated for each event at six hydrometric stations (data provided by BC Hydro): PCN, Above Bear Creek, below Bear Creek, at Tea Creek, at construction bridge, and PAP. These times were used to calculate a linear relationship between river kilometer (rkm) downstream of PCN and transit time for each event. These relationships were used to estimate the time at which the minimum stage of each event would have occurred at each site, based on rkm of the site. The site-specific ramping event end times were compared to the time the site was searched (i.e., average of arrival and departure times), and reported as an elapsed time. Searches conducted prior to the estimated event end were calculated as negative elapsed times, and searches conducted after the estimated event end were calculated as positive elapsed times.

Dependent on PCN operations and Site C construction requirements, some flow reductions were held near the minimum stage for multiple days; in these cases, search effort may have continued on the subsequent day. For such events, results were separated into primary searches (i.e., searches conducted same day) and secondary searches (i.e., searches conducted subsequent day). An average elapsed time was compiled for primary and secondary searches for each reach.

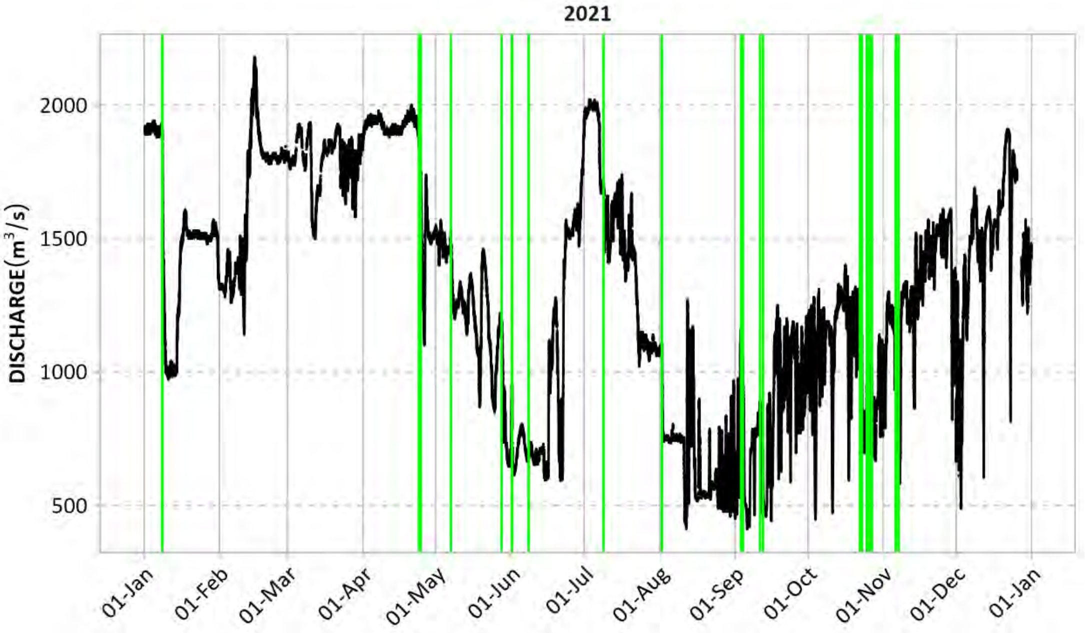
4. RESULTS

4.1. Ramping Events

4.1.1. Discharge and Stranding Searches

In 2021 stranding searches were primarily conducted between mid April and early November. The dates of stranding search events are shown in Figure 2 relative to discharge at PAP. Generally, flows outside this period were too high and stable, or ramping events were too short, to justify searches. Plots of discharge data from the PAP hydrology station for each sampling trip can be viewed in Appendix B.

Figure 2. **Discharge record for WSC 07FA004 (Peace River above Pine River; PAP) in 2021 with the dates of stranding search events highlighted in green.**



4.1.2. Hydrology During Searched Events

The severity of ramping events is generally a function of wetted history, magnitude of flow reduction, and the rate of stage decline (Golder and Poisson 2010a, 2010b). Hydrometric data from the PAP gauge are provided to represent each event, to provide a standard comparison to results from previous events. In 2021, two ramping events had relatively long wetted history compared to others: the event on April 23 (median wetted history of 43.59 days) and the event on August 1 (median wetted history of 40.81 days; Table 2). The April 23 event was associated with a relatively large magnitude flow reduction (-780 m^3/s) and a slow ramping rate (-5.6 cm/hr). The August 1 event had a relatively small flow reduction (-338 m^3/s) and a moderate ramping rate (-10.6 cm/hr).

Most events searched in 2021 had relatively modest associated ramping events. The two largest flow changes were the first two events, on January 9 (-915 m^3/s), and on April 25 (-780 m^3/s); however, the stage ramping rate on these occasions was relatively moderate (under 10 cm/hr). Only three events had ramping rates that exceeded 10cm/hr: August 2 (-10.6 cm/hr), October 22 (-10.4 cm/hr) and November 6 (13.0 cm/hr). No events searched had the characteristics of a major ramping event (e.g., -20 cm/hr stage decline, -750 m^3/s flow decline).

The PAP hydrology station is located downstream of the Project, and since diversion will not accurately represent ramping events upstream of the project. As an alternate representation of flow changes affecting the Diversion Headpond, a summary of the PCN ramping events that correspond to the PAP ramping events is presented in Table 3. This comparison reveals that the total change in flow at PCN is similar in magnitude to PAP; however, the ramping rates diminish in magnitude between PCN and PAP. Site specific ramping rates are not estimated because stage/flow data for individual sites are not available. These results illustrate that attenuation occurs, but with high variability: for some events the ramping rate at PCN was 10 times that at PAP, while for other events the difference was as small as 2.5 times. More detailed analysis of the factors influencing attenuation was not completed, but can be addressed in future synthesis reports.

Table 2. Summary of hydrometric data from the PAP hydrometric station for all searched ramping events in 2021.

Year	Hydrographic Station	Trip	Reduction Start		Reduction End		Stage (cm)				Flow (m3/s)				Wetted History (days)		
			Date	Time (PST)	Date	Time (PST)	Start	End	Total Change	Ramping Rate (cm/hr)	Start	End	Total Change	Ramping Rate (m^3/s/hr)	10th %tile	Median	90th %tile
2021	Peace Above Pine River	1	08-Jan-21	03:15	09-Jan-21	17:00	249	126	123.1	-8.3	1910	995	-915	-70	7.3	7.9	8.5
		2	23-Apr-21	17:30	25-Apr-21	21:30	230	145	85.5	-5.6	1890	1110	-780	-50	0.1	43.6	73.7
		3	01-Jun-21	01:25	01-Jun-21	11:45	119	60	58.9	-9.8	950	630	-320	-54	0.3	0.6	151.4
		4	06-Jul-21	21:30	07-Jul-21	14:00	255	221	34.4	-4.7	1960	1670	-290	-40	6.5	7.6	8.1
		5	01-Aug-21	16:10	02-Aug-21	2:10	143	94	49.1	-10.6	1100	762	-338	-66	1.1	40.8	41.1
		6	04-Sep-21	00:50	04-Sep-21	16:40	134	39	95.5	-9.9	1050	531	-519	-50	0.2	0.6	0.9
		7	12-Sep-21	07:15	12-Sep-21	15:30	76	32	44.3	-9.0	711	500	-211	-44	0.1	0.3	0.5
		8	22-Oct-21	22:05	23-Oct-21	12:10	149	75	73.6	-10.4	1140	704	-436	-64	0.2	0.5	0.8
		8	25-Oct-21	00:40	25-Oct-21	10:00	119	74	44.2	-9.0	948	702	-246	-50	0.2	0.5	2.7
		8	25-Oct-21	22:25	26-Oct-21	23:55	127	72	54.9	-8.5	1000	692	-308	-49	0.0	0.4	3.9
		9	05-Nov-21	20:20	06-Nov-21	11:30	159	75	83.7	-13.0	1210	703	-507	-76	0.2	4.6	8.7
		9	07-Nov-21	00:10	07-Nov-21	11:35	111	50	61.0	-8.6	902	581	-321	-43	0.2	0.6	15.9

Table 3. Summary of hydrometric data from PCN for all searched ramping events in 2021 (note: stage data are not available from PCN).

Year	Hydrographic Station	PAP Event Number	Reduction Start Date	Reduction Start Time (PST)	Reduction End Date	Reduction End Time (PST)	Flow (m^3/s) Start	Flow (m^3/s) End	Flow (m^3/s) Total Change	Flow (m^3/s) Ramping Rate ($m^3/s/hr$)
2021	PCN	1	07-Jan-21	17:00	08-Jan-21	9:00	1960	1240	-720	-488
		2	23-Apr-21	05:00	23-Apr-21	17:00	1860	1340	-520	-206
		2	24-Apr-21	04:00	24-Apr-21	18:00	1800	1250	-550	-385
		3	31-May-21	12:00	31-May-21	23:00	663	314	-349	-285
		4	06-Jul-21	10:00	06-Jul-21	19:00	1790	1250	-540	-411
		5	01-Aug-21	09:00	01-Aug-21	20:00	1030	648	-382	-332
		6	03-Sep-21	12:00	04-Sep-21	4:00	1250	407	-843	-394
		7	11-Sep-21	21:00	12-Sep-21	0:00	808	404	-404	-394
		8	21-Oct-21	17:00	22-Oct-21	0:00	1340	404	-936	-463
		8	24-Oct-21	13:00	24-Oct-21	23:00	1000	627	-373	-353
		8	25-Oct-21	13:00	25-Oct-21	23:00	1010	625	-385	-319
		9	05-Nov-21	12:00	06-Nov-21	0:00	1280	629	-651	-509
		9	06-Nov-21	15:00	06-Nov-21	23:00	908	310	-598	-265

4.2. Fish Stranding and Isolation

4.2.1. Sampling Timing, Location, and Effort

4.2.1.1. Stranding/Isolation Searches

Sampling in 2021 was conducted over 18 days between April 24 and November 7 (Table 4)[8]. The sampling effort was unevenly allocated among between reaches in 2021 as in past years. In 2021 multiple occasions arose where crews were on site for other work and were able to conduct one day searches after ramping events; thus, nine 'trips' were conducted. In total, searches were conducted at 189 sites: 141 interstitial sites were searched, and 48 pool sites were searched (Table 4). A mapbook of site locations is available in Appendix A. Photos of representative sampling sites are available for each reach in Appendix C.

Table 4. Summary of searches conducted on field sampling trips in 2021.

Trip	Sampling Day	Date	Search Method		Total Sites Searched
			Interstitial Sampling	Pool Sampling	
Trip 1	Day 1	January 9	1	0	1
Trip 2	Day 1	April 24	1	0	1
	Day 2	April 25	7	5	12
	Day 3	April 26	10	1	11
Trip 3	Day 1	June 1	13	9	22
	Day 2	June 2	13	9	22
Trip 4	Day 1	July 7	3	1	4
Trip 5	Day 1	August 1	1	0	1
	Day 2	August 2	10	1	11
	Day 3	August 3	13	2	15
Trip 6	Day 1	September 4	12	2	14
Trip 7	Day 1	September 12	4	4	8
Trip 8	Day 1	October 23	11	4	15
	Day 2	October 24	11	5	16
	Day 3	October 25	5	2	7
	Day 4	October 26	2	0	2
Trip 9	Day 1	November 6	11	0	11
	Day 2	November 7	13	3	16
Total	**18 Days**		**141**	**48**	**189**

Note: An additional site was searched on May 13 at the request of BC Hydro, but not associated with a specific ramping. This event has been excluded from further analyses.

---

[8] One site search also took place on January 9, 2021 at the request of BC Hydro.

4.2.1.2. Fish Stranding and Isolation Observations

In 2021, most isolated fish encountered were alive (853/911 fish; 93.6%), and most stranded fish were found dead (189/236 fish; 80.1%; Table 5). Most searches found no fish (35/189; 18.5%). It was more common to encounter isolated (911/1,147; 79.4%) than stranded (236/1,147; 20.6%) fish.

Table 5. Summary of fish observed during interstitial and pool searches in 2021.

Search Type	Number of Searches	Sites with Fish	Isolated Fish (Live/Dead)	Stranded Fish (Live/Dead)	Total Fish Collected (Live/Dead)
Interstitial	141	21	164 (143/21)	236 (47/189)	400 (190/210)
Isolated Pool	48	18	747 (710/37)	0 (0/0)	747 (710/37)
Total	**189**	**35**	**911 (853/58)**	**236 (47/189)**	**1,147 (900/247)**

4.2.1.3. Interstitial Sampling Effort and Results

In 2021 interstitial searches were conducted in the Diversion Headpond, Reach 1, Reach 2, (Table 6) and the Offset Channel Site 108R (Table 7). Most searches occurred in the Diversion Headpond (84 searches) while Reach 1 (21 searches) and Reach 2 (23 searches) had similar effort: this effort level was comparable to the 2017 – 2019 effort (Ecora 2018, 2019, 2020). Across all reaches the average isolation rate was 1.43 fish/100 m, the stranding rate was 1.96 fish/100 m and the combined stranding and isolation rate was 3.38 fish/100 m.

Among reaches, the combined isolation and stranding rate was lowest in the Diversion Headpond (1.74 fish/100m), higher in Reach 1 (5.17 fish/100 m), and highest in Reach 2 (7.74 fish/100 m). Individual isolation and stranding rates were similar in the Diversion Headpond and Reach 2[9], but in Reach 1 stranding rate was roughly 4x the isolation rate. Interstitial searches were also conducted at 13 sites in the Offset Channel (Table 7). The combined isolation and stranding rate was 4.71 fish/100 m in the Offset Channel, with nearly all fish found stranded.

Across all reaches, high risk sites had higher stranding and isolation rates than low risk sites. The results for channel type were less conclusive; single and multi-thread results were comparable in the Diversion Headpond but differed substantially in Reach 1.

---

[9] All isolation in Reach 2 was recorded at one site (PCR-R2SD-RL131.0), on August 3, 2021. The pool where fish were found was approximately 0.25 m deep, and 1,000 m^2. The field crew noted that the fish did not appear at risk of becoming stranded.

Table 6. Fish isolation and stranding numbers and rates (fish per 100 m) by reach, channel type, and risk type for interstitial searches conducted in 2021.

Reach	Channel Type	Risk Type	Area Searched (m^2)	Length Searched (m)	Number of Searches	Isolation [1]			Stranding [1]			Combined Isolation and Stranding [1]		
						# of Fish	Mean	SE	# of Fish	Mean	SE	# of Fish	Mean	SE
DH	Multi Thread	High Risk	181,674	5,618	62	35	0.95	0.7	37	1.21	0.7	72	2.16	1.2
		Low Risk	7,730	620	7	0	0.00	0.0	3	0.39	0.4	3	0.39	0.4
		Negligible	5,300	200	2	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0
	Single Thread	High Risk	2,100	135	2	2	1.59	0.4	2	1.18	1.2	4	2.76	0.8
	Unknown	High Risk	30,630	950	10	1	0.10	0.1	3	0.30	0.2	4	0.40	0.2
		Low Risk	2,800	70	1	0	0.00	-	0	0.00	-	0	0.00	-
	DH Subtotal		**230,234**	**7,593**	**84**	**38**	**0.8**	0.5	**45**	**1.0**	0.5	**83**	**1.7**	0.9
Reach 1	Multi Thread	High Risk	46,094	1,397	15	21	1.2	1.2	60	5.9	4.2	81	7.1	4.2
		Low Risk	2,350	190	2	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
	Single Thread	High Risk	13,501	409	4	2	0.5	0.5	1	0.2	0.2	3	0.7	0.7
	Reach 1 Subtotal		**61,945**	**1,996**	**21**	**23**	**0.9**	**0.5**	**61**	**4.3**	**0.2**	**84**	**5.2**	**0.7**
Reach 2	Multi Thread	High Risk	60,350	2,492	23	100	4.3	4.3	92	3.4	1.9	192	7.7	4.6
	Reach 2 Subtotal		**60,350**	**2,492**	**23**	**100**	**4.3**	**4.3**	**92**	**3.4**	**1.9**	**192**	**7.7**	**4.6**
Grand Total			**352,529**	**12,082**	**126**	**161**	**1.4**	**0.9**	**198**	**2.0**	**0.7**	**359**	**3.4**	**1.1**

[1] The unit for all rates presented = fish/100 m

Note: DH = Diversion Headpond, SE = Standard Error

Table 7. Fish isolation and stranding numbers and rates (fish per 100 m) by reach, channel type, and risk type for interstitial searches conducted within the Offset Channel in 2021.

Reach	Channel Type	Risk Type	Area Searched (m^2)	Length Searched (m)	Number of Searches	Isolation [1]			Stranding [1]			Combined Isolation and Stranding [1]		
						# of Fish	Mean Rate	SE	# of Fish	Mean Rate	SE	# of Fish	Mean Rate	SE
OC	Multi Thread	High Risk	22,367	769	12	3	0.25	0.3	38	4.86	3.1	41	5.11	3.1
		Low Risk	1,554	42	1	0	0.00	-	0	0.00	-	0	0.00	-
	OC Total		**23,921**	**811**	**13**	**3**	**0.23**	**0.2**	**38**	**4.48**	**2.9**	**41**	**4.71**	**2.9**

[1] The unit for all rates presented = fish/100 m

Note: OC=Offset Channel, SE=Standard Error

4.2.1.4. Pool Sampling Effort and Results

Pool searches were conducted in the Diversion Headpond, Reach 1, Reach 2, (Table 8) and the Offset Channel Site 108R (Table 9). The most pool searches occurred in the Diversion Headpond (31 searches) while Reach 1 (5 searches) and Reach 2 (6 searches) had similar effort to 2017 – 2019 (Ecora 2018, 2019, 2020). The average pool isolation rate across all reaches was 7.64 fish/100 m. Pool searches (excluding Offset Channel Site 108R) resulted in nearly double the fish observations (743 total fish observed) compared to interstitial searches (359 fish observed; Table 6).

When comparisons are made by reach, the Diversion Headpond had the highest pool isolation rate (8.29 fish/100m)[10]. Reach 1 had a lower rate (3.23 fish/100 m), while Reach 2 had a rate comparable to the Diversion Headpond (7.64 fish/100 m). Isolated pool searches were also conducted on 6 occasions in the Offset Channel (Table 9), and had a relatively low rate of 2.33 fish/100 m.

Isolated pools were only found at low-risk sites in the Diversion Headpond and had a similar rate of isolation as high-risk sites. Single thread sites were found only in Reach 1 and had a higher rate of isolation than multi thread sites.

Table 8. Pool sampling search results by reach, channel type, and risk type for searches conducted in 2021.

Reach	Channel Type	Risk Type	Area Searched (m^2)	Length Searched (m)	Number of Searches	Isolation[1]		
						# of Fish	Mean Rate	SE
DH	Multi Thread	High Risk	4,992	634	25	615	8.62	4.1
		Low Risk	1,000	171	5	20	8.30	8.2
		Negligible	43	17	1	0	0.00	n/a
DH Total			***6,035***	***822***	***31***	***635***	***8.29***	***3.5***
Reach 1	Multi Thread	High Risk	298	47	2	2	1.00	1.0
	Single Thread	High Risk	567	101	3	34	4.72	3.7
Reach 1 Total			***865***	***148***	***5***	***36***	***3.23***	***2.2***
Reach 2	Multi Thread	High Risk	1,173	205	6	72	7.98	4.9
Reach 2 Total			***1,173***	***205***	***6***	***72***	***7.98***	***4.9***
Grand Total			**8,074**	**1,174**	**42**	**743**	**7.64**	**2.7**

[1] The unit for all rates presented = fish/100 m

Note: DH=Diversion Headpond, SE=Standard Error

---

[10] Of the 685 fish found isolated in the Headpond in 2021, 464 fish were found alive (and 19 were found dead) at a single site on June 2, 2021 (PCR-DHSD-RL94.5). The site was characterized as a side channel near Wilder Creek that became isolated into a series of pools during a ramping event.

Table 9. Pool sampling search results for the Offset Channel for searches conducted in 2021.

Reach	Channel Type	Risk Type	Area Searched (m^2)	Length Searched (m)	Number of Searches	Isolation [1]		
						# of Fish	Mean Rate	SE
OC	Multi Thread	High Risk	216	77	6	4	2.33	1.5

[1] The unit for all rates presented = fish/100 m

Note: OC=Offset Channel, SE=Standard Error

4.2.1.5. Incidental and Mainstem Fish Observations

A total of 37 fish were observed incidentally (i.e., outside of searched sites) in all reaches (including the offset channel), the majority of which were dead (32 fish; Table 10). Additionally, a total of 214 fish were observed in waters with connectivity to the Peace River mainstem, all of which were alive.

Table 10. Summary of incidental and mainstem observations that occurred outside of searched sites in 2021.

Reach [1]	Incidental (alive/dead)	Mainstem (alive/dead)
DH	7 (0/7)	4 (4/0)
1	0 (0/0)	60 (60/0)
2	26 (4/22)	150 (150/0)
Total	**33 (4/29)**	**214 (214/0)**
OC	4 (1/3)	0 (0/0)

[1] DH=Diversion Headpond, OC=Offset Channel

4.2.2. Characteristics of Isolated/Stranded Fish

4.2.2.1. Species and Life-stage

The summaries of fish observed by age class show that for both interstitial (Table 11) and pool searches (Table 12), YOY made up the majority (i.e., ≥90%) of all fish observations. In interstitial searches juveniles and adults were found in equal numbers, whereas in pool sampling juveniles were more common. All adults found in both methods belonged to species that have small body size (see Table 1). A selection of representative photos of fish is provided in Appendix D.

In interstitial sampling the most common single species class were Mountain Whitefish (*Prosopium williamsoni*; 145 fish), and sucker spp. (150 fish)[11]. Redside Shiner (*Richardsonius balteatus;* 35 fish) and Sculpin spp. (29 fish) were also relatively common, while all other species were found relatively infrequently.

The species makeup in pool searches differed from interstitial searches, with the most common species class observed were Longnose Dace (*Rhinichthys cataractae*; 375 fish) and sucker spp. (237 fish). Several other species were observed with moderate frequency (i.e., 20 – 45 individuals) including Redside Shiner, sculpin spp., Lake Chub (*Couesius plumbeus*) and Mountain Whitefish.

Table 11. Species and life history classes of fish observed during interstitial sampling in 2021 (Note: Fish from the Offset Channel have been included in this table).

Group	Species	YOY	Juvenile	Adult	Unknown	Totals	Group Total	Percent of Total
Unknown		26	0	0	0	26	26	7%
Minnow	Lake Chub	3	2	0	0	5	48	12%
	Longnose Dace	8	0	0	0	8		
	Redside Shiner	32	0	3	0	35		
Sculpin	Prickly Sculpin	0	0	0	0	0	31	8%
	Sculpin spp.	1	0	1	0	2		
	Slimy Sculpin	19	0	10	0	29		
Sportfish	Mountain Whitefish	145	0	0	0	145	145	36%
	Northern Pike	0	0	0	0	0		
Suckers	Large Scale Sucker	2	2	0	0	4	150	38%
	Longnose Sucker	16	0	0	0	16		
	Sucker spp.	120	10	0	0	130		
Totals		**372**	**14**	**14**	**0**	**400**	**400**	**100%**
Percent of Total		**93%**	**4%**	**4%**	**0%**			

---

[11] Sucker spp. was used when fish were too small to identify past genus, but refers to one of White Sucker (*Catostomus commersonii*), Longnose Sucker (*Catostomus catostomus*), and Largescale Sucker (*Catostomus macrocheilus*).

Table 12. Species and life history classes of fish captured during pool sampling in 2021. (Note: Fish from the Offset Channel have been included in this table).

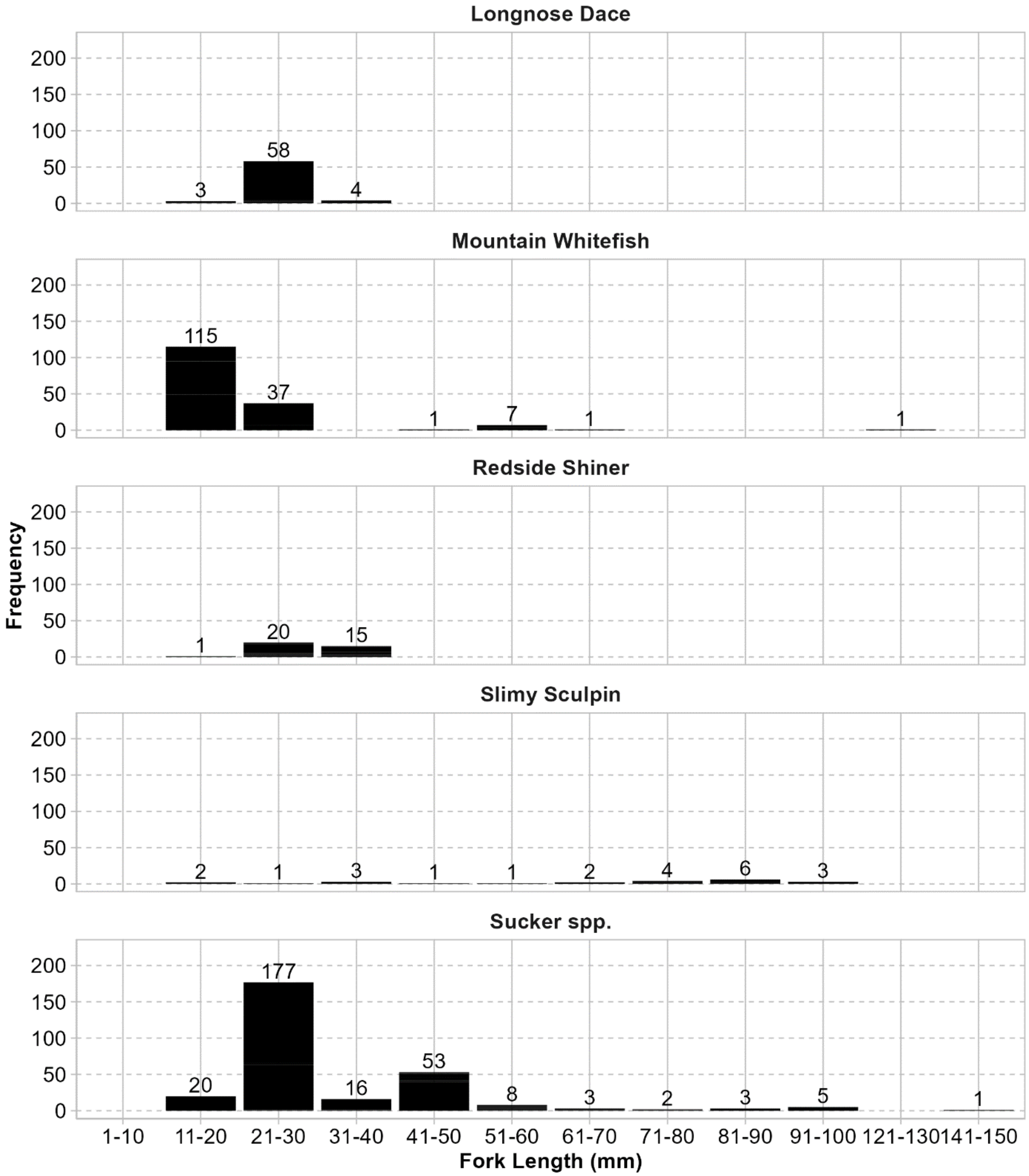
Group	Species	YOY	Juvenile	Adult	Unknown	Totals	Group Total	Percent of Total
Unknown		7	0	0	0	7	7	94%
Minnow	Lake Chub	15	4	1	3	23	441	59%
	Peamouth Chub	1	0	0	0	1		
	Longnose Dace	276	6	0	93	375		
	Northern Pikeminnow	1	0	0	0	1		
	Redside Shiner	40	1	0	0	41		
Sculpin	Sculpin spp.	17	0	0	0	17	37	5%
	Slimy Sculpin	13	1	6	0	20		
Sportfish	Burbot	1	1	0	0	2	25	3%
	Kokanee	2	0	0	0	2		
	Mountain Whitefish	14	4	0	0	18		
	Northern Pike	0	1	0	0	1		
	Rainbow Trout	1	1	0	0	2		
Suckers	Large Scale Sucker	0	12	0	0	12	237	32%
	Longnose Sucker	4	15	0	0	19		
	Sucker spp.	192	9	0	4	205		
	White Sucker	0	1	0	0	1		
Totals		**584**	**56**	**7**	**100**	**747**	**747**	**100%**
Percent of Total		**78%**	**7%**	**1%**	**13%**			

4.2.2.2. Size and Age Class

Length-frequency histograms are presented below for the most common species or genus captured, and include Longnose Dace, Mountain Whitefish, Redside Shiner, sculpin spp., and sucker spp. (Figure 3). The length-frequency plots include all fish collected during interstitial and pool sampling.

The histograms indicate that among all species included, a majority of fish captured were ≤30 mm. The small fork lengths suggest that many of the fish observed were newly emerged YOY which may have poor swimming ability.

Figure 3. Length frequency of all measured Longnose Dace, Mountain Whitefish, Redside Shiner, sculpin spp., and sucker spp. by fork length for 2021. (Note: fish from the Offset Channel have been included in these figure).



4.2.3. Water Transit Times

An analysis of water transit times for searched ramping events was conducted to determine whether there were differences between reaches in the elapsed time between search times relative to minimum stage at each site. Table 13 provides the average elapsed time for sites in each reach, calculated from the water transit time for each event monitored.

Average elapsed time for interstitial searches was similar between the Diversion Headpond and Reach 2, with primary searches conducted between 3 and 4 hours after the event minimum on average. Interstitial searches in Reach 1 typically occurred longer after the event end (i.e., >6 hours); however, this difference did not appear to align with variations in stranding rates between reaches (e.g., stranding rates were most similar between Reach 1 and Reach 2; see Table 6 in Section 4.2.1.3). Elapsed times were similar among reaches for interstitial secondary searches, which were conducted on the subsequent day for select events where the flow reduction at PCN was maintained for an extended period.

Average elapsed time for pool searches was similar between Reach 1 and Reach 2, with primary searches conducted between 1 and 1.5 hours after the event minimum on average. Pool searches in the Diversion Headpond typically occurred longer after the event end (i.e., approximately 3 hours on average); however, this difference did not correlate with variations in isolation rates between reaches (e.g., isolation rates were most similar between the Diversion Headpond and Reach 2; see Table 8 in Section 4.2.1.4). Elapsed times were similar among reaches for pool secondary searches.

Overall, the evaluation of water transit time did not indicate a difference in elapsed time for searches that would explain variation in stranding or isolation rates between reaches; however, the influence of search time relative to event end time on stranding and isolation rates will be evaluated further in the next multi-year synthesis report.

Table 13. Comparison of the average elapsed time between ramping event end and searches for each reach sampled in 2021.

Seach Type	Reach	Primary Searches			Secondary Searches		
		Sites	Average Elapsed Time (hh:mm)	SE (hh:mm)	Sites	Average Elapsed Time (d hh:mm)	SE (hh:mm)
Interstitial Sampling	Diversion Headpond	76	03:42	00:36	18	1 04:46	03:00
	Reach 1	10	06:50	01:37	12	1 05:08	03:50
	Reach 2	11	03:19	01:39	12	1 03:27	04:14
Pool Sampling	Diversion Headpond	21	02:57	01:16	9	1 06:25	00:42
	Reach 1	1	01:10	n/a	5	1 06:04	02:01
	Reach 2	3	01:18	03:22	3	1 01:50	03:20

4.3. Comparison of Stranding and Isolation Among Years

4.3.1. Interstitial Sampling

Interstitial sampling results for all risk/channel types for each year during the baseline period (2017 to 2020) are shown along with 2021 results below (Table 14). The interstitial isolation rate for 2021 (1.43 fish/100 m) was slightly lower than the baseline period (1.58 fish/100 m). Similarly, the stranding rate was slightly lower in 2021 (1.96 fish/100 m) than the baseline period (2.54 fish/100 m), and the combined stranding and isolation rate in 2021 (3.38 fish/100 m) was lower than the baseline years (4.11 fish/100 m).

Combined isolation and stranding rates by reach (for years with data), suggest that a reduction has occurred in the Diversion Headpond between baseline (5.62 fish/100 m) and 2021 (1.74 fish/100 m). In contrast, the combined rate has increased in Reaches 1 and 2 between baseline to 2021. The 2021 mean rate for Reach 1 (5.17 fish/100 m) was close to the largest mean rate observed in Reach 1 during baseline (5.31 fish/100 m in 2020), whereas in 2021 the mean for Reach 2 (7.74 fish/100 m) was substantially higher than any of the means from baseline years (which ranged from 0.38 – 0.39 fish/100 m). Sampling has only been conducted for a single year in Reach 3 (sampled in 2017) and the Offset Channel Site 108R (sampled in 2021); therefore, multi-year comparisons are not possible for these reaches.

Table 14. Summary of fish isolation and stranding numbers and rates (fish/100 m) recorded during interstitial sampling compared among baseline (2017 to 2020) and construction (2021) years by reach. Note that results from the Offset Channel Site 108R (OC) are not included in these 2021 totals.

Period	Year	Reach	Isolation [1]					Stranding [1]					Combined Isolation and Stranding [1]				
			# of Fish	Mean Rate	Min. Rate	Max. Rate	SE	# of Fish	Mean Rate	Min. Rate	Max. Rate	SE	# of Fish	Mean Rate	Min. Rate	Max. Rate	SE
Baseline	2017	DH	6	0.66	0.0	5.6	0.6	13	1.19	0.0	6.1	0.7	19	1.84	0.0	7.1	0.9
		1	5	2.16	0.0	15.2	2.2	1	0.11	n/a	n/a	n/a	6	2.28	0.0	15.2	2.1
		2	5	0.29	0.0	2.2	0.2	1	0.10	n/a	n/a	n/a	6	0.39	0.0	2.2	0.2
		3	42	5.37	0.0	57.6	3.3	37	4.34	0.0	65.7	3.3	79	9.70	0.0	65.7	4.4
	2018	DH	46	0.92	0.0	21.3	0.4	2	0.07	0.0	3.2	0.1	48	0.98	0.0	21.3	0.4
		1	16	0.51	0.0	20.0	0.3	25	0.50	0.0	27.3	0.4	41	1.00	0.0	27.3	0.6
	2019	DH	0	0.00	n/a	n/a	n/a	0	0.00	n/a	n/a	n/a	0	0.00	n/a	n/a	n/a
		1	0	0.00	n/a	n/a	n/a	1	0.01	n/a	n/a	n/a	1	0.01	n/a	n/a	n/a
		2	6	0.08	0.0	1.7	0.0	15	0.30	0.0	12.0	0.2	21	0.38	0.0	12.0	0.3
	2020	DH	218	4.70	0.0	135.0	2.9	603	10.79	0.0	193.0	4.4	821	15.49	0.0	328.0	7.2
		1	0	0.00	n/a	n/a	n/a	62	5.31	0.0	18.6	2.1	62	5.31	0.0	18.6	2.1
	2017-2020	DH	270	1.97	0.0	135.0	1.0	618	3.66	0.0	193.0	1.5	888	5.62	0.0	328.0	2.4
		1	21	0.42	0.0	20.0	0.2	89	0.76	0.0	27.3	0.3	110	1.18	0.0	27.3	0.4
		2	11	0.12	0.0	2.2	0.1	16	0.26	0.0	12.0	0.2	27	0.38	0.0	12.0	0.2
		3	42	5.37	0.0	57.6	3.3	37	4.34	0.0	65.7	3.3	79	9.70	0.0	65.7	4.4
		All	**343**	**1.58**	**0.0**	**135.0**	**0.6**	**759**	**2.54**	**0.0**	**193.0**	**0.8**	**1102**	**4.11**	**0.0**	**328.0**	**1.3**
Construction	2021	DH	38	0.75	0.0	40.0	0.5	45	0.99	0.0	40.0	0.5	83	1.74	0.0	60.0	0.9
		1	23	0.92	0.0	17.4	0.8	61	4.26	0.0	60.0	3.0	84	5.17	0.0	60.0	3.1
		2	100	4.35	0.0	100.0	4.3	92	3.39	0.0	42.5	1.9	192	7.74	0.0	100.0	4.6
		All	**161**	**1.43**	**0.0**	**100.0**	**0.9**	**198**	**1.96**	**0.0**	**60.0**	**0.7**	**359**	**3.38**	**0.0**	**100.0**	**1.1**

[1] The unit for all rates presented = fish/100 m

Note: DH=Diversion Headpond, SE=Standard Error

4.3.2. Pool Sampling

Numbers of fish detected during pool sampling in the Diversion Headpond were substantially greater in 2021 (635 fish) than in any baseline year (ranged from 7 to 143 fish). Similarly, rates of isolation in pools were greater in 2021 (8.29 fish/100 m) than in baseline years. The number of fish observed in Reaches 1 and 2 was comparable to baseline. In 2021 the Reach 1 pool isolation rate (3.23 fish/100 m) was slightly higher than the baseline average for Reach 1 (1.05 fish/100 m), while in Reach 2 the rate (7.98 fish/100 m) was substantially higher than the average rate during baseline years (1.34 fish/100 m) and similar to the 2021 rate for the Diversion Headpond.

The total number of fish observed in isolated pools in 2021 (743 fish) was nearly double that of all baseline years combined (427 fish). Although more pool area was electrofished in 2021 than any baseline year (see Swain *et al.* 2022), comparison of the isolation rates indicates that fish were isolated at higher rates in 2021 (7.64 fish/100 m) than in the baseline (1.38 fish/100 m). The larger standard error in 2021 (2.7) than for baseline years (0.5) indicates that variability in isolation rates was higher 2021; the isolation rate was influenced by the observation of a high number of fish at a few sites.

Table 15. Summary of fish detected isolated in pools compared among baseline (2017 to 2020) and construction (2021) years by reach.

Period	Year	Reach	Isolation[1]				
			# of Fish	Mean Rate	Min. Rate	Max. Rate	SE
Baseline	2017	DH	19	2.03	0.0	11.5	0.9
		1	42	2.47	0.0	7.0	1.0
		2	18	1.04	0.0	6.6	0.5
		3	71	1.84	0.0	20.9	0.8
	2018	DH	59	1.30	0.0	9.3	0.4
		1	63	0.91	0.0	8.9	0.4
	2019	DH	7	0.34	0.0	1.4	0.1
		1	14	0.58	0.0	3.2	0.2
		2	36	1.50	0.0	14.7	0.6
	2020	DH	58	1.66	0.0	6.0	0.7
		1	40	1.14	0.0	5.3	1.0
	2017-2020	DH	143	1.31	0.0	11.5	0.3
		1	159	1.05	0.0	8.9	0.3
		2	54	1.34	0.0	14.7	0.5
		3	71	1.84	0.0	20.9	0.8
		All	**427**	**1.38**	**0.0**	**20.9**	**0.5**
Construction	2021	DH	635	8.29	0.0	79.7	3.5
		1	36	3.23	0.0	11.9	2.2
		2	72	7.98	0.0	24.3	4.9
		All	**743**	**7.64**	**0.0**	**79.7**	**2.7**

[1] The unit for all rates presented = fish/100 m

Note: DH=Diversion Headpond, SE=Standard Error

5. DISCUSSION

5.1. Annual Comparison to Action Threshold

For each year of construction a comparison will be made to an Action Threshold. The Action Threshold is specified as the average combined interstitial isolation and stranding rate obtained during interstitial sampling for all high-risk sites during baseline years, plus 50%. Accordingly, the Action Threshold was established as 4.11 fish/100 m + 50% = 6.22 fish/100 m (Table 16).

Table 16. Summary of fish found isolated, stranded, and combined isolated and stranded for all interstitial searches conducted at high-risk sites during baseline years and Year 1 of construction (2021) (note that results from the Offset Channel were not included).

Period	Year	Isolation [1]			Stranding [1]			Combined Isolation and Stranding [1]		
		# of Fish	Mean Rate	SE	# of Fish	Mean Rate	SE	# of Fish	Mean Rate	SE
Baseline	2017	58	3.57	1.8	52	2.72	1.8	110	6.29	2.5
	2018	61	0.87	0.3	27	0.36	0.3	88	1.23	0.4
	2019	6	0.05	0.0	15	0.16	0.1	21	0.21	0.1
	2020	218	3.87	2.4	665	9.83	3.6	883	13.7	5.9
	2017-2020	**343**	**1.58**	**0.6**	**759**	**2.54**	**0.8**	**1102**	**4.11**	**1.3**
Construction	**2021**	**161**	**1.57**	**0.9**	**195**	**2.13**	**0.8**	**356**	**3.71**	**1.2**

[1] The unit for all rates presented = fish/100 m

Note: DH=Diversion Headpond, SE=Standard Error

In 2021 the interstitial isolation and stranding rates at all high-risk sites (3.71 fish.100 m) was lower than the Action Threshold (6.22 fish/100 m); therefore, no immediate management actions have been triggered for sampling in 2022.

In the first year of Diversion Headpond operation the Action Threshold proved a useful tool to complete a straightforward comparison of stranding risk between 2021 and baseline. The values used for comparison were restricted to interstitial sampling which had the highest risk of mortality (mortality was 53% for interstitial sampling, 5% for isolated pool searches). Only high-risk sites were included, where most fish were stranded/isolated (i.e., high-risk sites; 356/359 fish observed). Lastly the comparison provided a value that encompassed all reaches, recognizing the importance of the entire study area.

5.2. Ramping Events

When compared to baseline years, the ramping events (all measurements below refer to PAP) that occurred in 2021 were similar to events monitored in 2019. In 2019 total flow declines seldomly exceeded 750 m^3/s, and stage changes were generally less than 20 cm/hr, while in 2021 this flow and stage change rate were not exceeded. In 2017 and 2018 ramping events nearly always exceeded flow declines of 750 m^3/s, and stage declines of -20 cm/hr. In terms of wetted history, ramping events monitored in 2021 had longer wetted histories relative to baseline; four searched events in 2021 had median wetted histories that exceeded 7 days (with a maximum of 43.6 days), while this only occurred once in baseline (maximum of 9.6 days on August 10). In the Year 4 Synthesis Report (Swain *et al.* 2022) it was noted probability and magnitude of interstitial stranding and isolation increased with wetted history length.

5.3. Fish Stranding and Isolation

The results of stranding and isolation monitoring in 2021 differed from predictions made in the Mon-12 Fish Stranding Monitoring Program (BC Hydro 2015b). The interstitial isolation and stranding rates recorded in the Diversion Headpond were lower in 2021 (1.74 fish/100 m) than in the baseline (5.62 fish/100 m), while downstream in Reach 1 (5.17 fish/100 m) and Reach 2 (7.74 fish/100 m) the interstitial isolation and stranding rates were higher in 2021 than in the baseline (1.18 and 0.38 fish/100 m respectively). In contrast, Mon-12 (BC Hydro 2015b), predicted a mildly elevated stranding risk in the Diversion Headpond during the Diversion Headpond operation period, while downstream of Site C there would be no change to the stranding risk. The longer wetted histories in 2021 may have contributed to the increased rate of stranding in the downstream reaches compared to baseline years, but other factors may also contribute.

In 2021 a higher number of fish were captured from isolated pools within the Diversion Headpond than has been previously recorded. In particular, the majority of fish in isolated pools were observed at a single site (464/747 fish in 2021; detailed in Section 4.2.1.4). This site was located near the Wilder Creek confluence, a large side channel complex that is inundated when the Diversion Headpond is at the 90th percentile stage, but disconnected at the 50th percentile stage. Based on inspection of drone imagery the area between river kms 94 and 95 represent the area in the Diversion Headpond most likely to become isolated during flow reductions due to the presence of several shallow side channels.

Monitoring in 2021 was the first year of comprehensive study of stranding within Offset Channel Site 108R. The results from 2021 indicate that stranding occurred with a moderate degree of frequency in the Offset Channels (though little isolation was observed). The interstitial stranding rate in the Offset Channels was 4.48 fish/100 m, while nearby the rate in Reach 1 was 4.26 fish/100 m. Though only one year of monitoring data are available for the Offset Channels, available data indicate little difference in stranding risk between the two areas, despite the purposeful construction of the Offset Channel to reduce stranding. A single year of monitoring is insufficient to determine the exact cause of the strandings, though past experiences suggest bank morphology, fish abundance, or species and lifestage of fish present may all play a role.

Most stranded fish are YOY, rather than juveniles or adults, consistent with the literature on stranding (Nagrodski *et al.* 2012). In general, the species captured were consistent with past years, except for an increase in the number of Mountain Whitefish and Redside Shiner stranded.

5.4. Management Hypotheses

H1: During Project construction, fish stranding in the Diversion Headpond increases relative to baseline conditions.

- After one year of construction monitoring this hypothesis is not currently supported.
- The combined interstitial stranding and isolation rate in the Diversion Headpond in 2021 was 31% of baseline, and in 2021 the stranding only rate was 27% of baseline (Table 14).

H2: During Project operation, fish stranding in the Peace River between the Project and the Pine River confluence increases relative to baseline conditions.

- This management hypothesis cannot be evaluated until the operational period.

H3: During Project operation, fish stranding in the Peace River between the Pine River confluence and the Many Islands area in Alberta is similar to baseline conditions.

- This management hypothesis cannot be evaluated until the operational period.

H4: Proposed mitigation measures in the Diversion Headpond during the river diversion phase of Project construction and side channel enhancement and contouring in the Peace River downstream of the Project during operations are effective in reducing fish stranding rates.

- This management hypothesis cannot be evaluated until the operational period.

6. CONCLUSION

This report represents Year 7 of monitoring for the Site C Fish Stranding Monitoring Program. This is the first year of monitoring since the Site C diversion tunnels were completed, and the Peace River was diverted, forming the Diversion Headpond. The results in 2021 were similar to those of baseline, and while variability is present, they do not appear to indicate large changes in the stranding risk across the study area. Monitoring will continue in future years to determine if changes to the stranding risk occur between baseline, construction, and operations.

REFERENCES

BC Hydro. 2015a. Fisheries and Aquatic Habitat Monitoring and Follow-up Program. Report prepared by BC Hydro for the Site C Clean Energy Project. 38 p. + Appendices.

BC Hydro. 2015b. Site C Mon-12 – Site C Fish Stranding Monitoring Program. Report prepared by BC Hydro for the Site C Clean Energy Project. 11 p.

Bell, E., S. Kramer, D. Zajanc, J. Aspittle. 2008. Salmonid fry stranding mortality associated with daily water level fluctuations in Trail Bridge Reservoir, Oregon. North American Journal of Fisheries Management 28: 1515–1528. doi: 10.1577/M07-026.1.

DFO (Fisheries and Oceans Canada). 2015. *Fisheries Act* Authorization (15-HPAC-00170). Issued September 30, 2015. 6 pp.

DFO (Fisheries and Oceans Canada). 2016. Reissuance of *Fisheries Act* Authorization (15-HPAC-01160). Issued August 22, 2016. 16 pp.

Ecora (Ecora Engineering and Resource Group Ltd.). 2017. Site C Fish Stranding Monitoring Program (Mon-12). Draft Report. Report prepared for BC Hydro and Power Authority, January 13, 2017.

Ecora (Ecora Engineering and Resource Group Ltd.). 2018. Site C Fish Stranding Monitoring Program (Mon-12) Year 2 (2017). Report prepared for BC Hydro and Power Authority, February 5, 2018.

Ecora (Ecora Engineering and Resource Group Ltd.). 2019. Site C Fish Stranding Monitoring Program (Mon-12) 2018 Data Report. Report prepared for BC Hydro and Power Authority, January 9, 2019.

Ecora (Ecora Engineering and Resource Group Ltd.). 2020. Site C Fish Stranding Monitoring Program (Mon-12) 2019 Data Report. Report prepared for BC Hydro and Power Authority, January 24, 2020.

Golder (Golder Associates Ltd.) 2014a. Lower Columbia River [CLBMON #42(A)] and Kootenay River Fish Stranding Assessments: Annual summary (April 2013 to April 2014). Report prepared for BC Hydro, Columbia Power Corporation, and FortisBC, Castlegar, BC. Golder Report No. 10-1492-0042 and 10-1492-0100: 25p. + 1 app.

Golder (Golder Associates Ltd.). 2014b. DDMMON-16 Lower Duncan River fish stranding impact monitoring: Year 6 report (April 2013 to April 2014). Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 12-1492-0117F.

Golder (Golder Associates Ltd.). 2017. DDMMON-16 Lower Duncan River fish stranding impact monitoring: Year 8 report (April 2015 to April 2016). Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 1535517D: 69 p. + 3 app.

Golder (Golder Associates Ltd.) 2018. DDMMON-16 Lower Duncan River fish stranding impact monitoring: Year 9 Report (April 2016 to April 2017). Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 1535517F: 54 p. + 3 app.

Golder Associates Ltd. and Poisson Consulting Ltd. 2010a. Columbia and Kootenay River Fish Stranding Protocol Review: Literature Review and Fish Stranding Database Analysis. 34 p + appendices.

Golder Associates Ltd. and Poisson Consulting Ltd. 2010b. Duncan Dam Project Water Use Plan. Lower Duncan River. Implementation Year 2. Reference: DDMMON#15. Lower Duncan River Stranding Protocol Development and Finalization. Study Period: 2010. 47 p.

Irvine, R.L., T. Oussoren, J.S. Baxter, and D.C. Schmidt. 2009. The effects of flow reduction rates on fish stranding in British Columbia, Canada. River Research and Applications 25:405-415.

Irvine, R.L., J.L. Thorley, R. Westcott, D. Schmidt, and D. DeRosa. 2015. Why do fish strand? An analysis of ten years of flow reduction monitoring data from the Columbia and Kootenay Rivers, Canada. River Research and Applications 31:1242–1250.

Lewis, A., C. Zyla., and P. Gibeau. 2011. Flow Ramping Guidelines for Hydroelectric Projects: Developing, Testing, and Compliance Monitoring, Draft V1. Consultant's report prepared by Ecofish Research Ltd for Clean Energy BC, Department of Fisheries and Oceans Canada, and the BC Ministry of Environment.

Lewis, F.J.A., A.J. Harwood, C. Zyla, K.D. Ganshorn, and T. Hatfield. 2013. Long term Aquatic Monitoring Protocols for New and Upgraded Hydroelectric Projects. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/166. ix + 88 p.

Lewis, A., I. Girard, K. Healey, S. Nicholl, K. Akaoka, N. Swain. B. Mossop, D. Hunter. 2020. Diversion Headpond Fish Stranding Management Plan – Site C Clean Energy Project. Consultant's report prepared for BC Hydro by Ecofish Research Ltd., July 3, 2020.

Mainstream (Mainstream Aquatics Ltd.). 2011. Site C fisheries studies – 2010 Peace River Fish Inventory. Prepared for B.C. Hydro Site C Project, Corporate Affairs Report No. 10005F: 102 p. + plates and appendices.

Mainstream (Mainstream Aquatics Ltd.). 2013. Site C Fisheries Studies – Peace River Habitat Assessment. Mainstream Aquatics Ltd., M. Miles and Associates Ltd, Integrated Mapping Technologies Inc.

McPhail, J.D. 2007. The Freshwater Fishes of British Columbia. University of Alberta Press.

McPhail, J.D. and R. Carveth. 1993. Field Key to the Freshwater Fishes of British Columbia. Resources Inventory Committee (Canada).

Nagrodski, A., G.D. Raby, C.T. Hasler, M.K. Taylor, and S.J. Cooke. 2012. Fish stranding in freshwater systems: Sources, consequences, and mitigation. Journal of Environmental Management 103 (2012) 133-141.

NHC (Northwest Hydraulic Consultants). 2012. Peace River Hydraulic Habitat Study (Contract Q9-9105). Prepared for BC Hydro. Report No. 09005D: 65 p.

NHC (Northwest Hydraulic Consultants). 2013. BC Hydro Site C Clean Energy Project: Fish Habitat Mitigation - Peace River Channel Restoration Opportunities Downstream of Site C. Prepared for BC Hydro, March 2014.

Nicholl, S. and A. Lewis. 2016. Site C Fish Stranding Monitoring Methods. Consultant's memorandum prepared for BC Hydro by Ecofish Research Ltd. October 27, 2016.

NRC (National Research Council Canada). 2017. Blue Kenue^{TM}: software tool for hydraulic modellers. Available online at: https://nrc.canada.ca/en/research-development/products-services/software-applications/blue-kenuetm-software-tool-hydraulic-modellers Accessed on June 7, 2021.

R Development Core Team. 2020. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Sherstone, T., C. Whelan, A. Lewis. 2022. Site C Fish Stranding Program Recommendations Memo. Consultant's memorandum prepared for BC Hydro by Ecofish Research Ltd. June 3, 2022.

Swain, N., E. Clark, M. Sparling, S. Nicholl, and A. Lewis. 2022. Site C Mon-12 Fish Stranding Monitoring Program Synthesis Review. Consultant's report prepared for BC Hydro by Ecofish Research Ltd., April 15, 2022.

Triton (Triton Environmental Consultants Ltd.) 2009. Middle Columbia River Juvenile Fish Stranding Assessment (Year 2009) Reference: CLBMON#53 Columbia River Water Use Plan Monitoring Program: Middle Columbia River Juvenile Fish Stranding Assessment Study Period: 2009-2010. 44 p. + appendices.

APPENDICES

Appendix B. Ramping Event Discharge Plots

LIST OF FIGURES

Figure 1. Discharge at Peace River above Pine River (PAP) for January 9, 2021 (Trip 1, Day 1). The vertical green line shows the beginning of the ramping event, and the vertical red line shows the end of the ramping event.

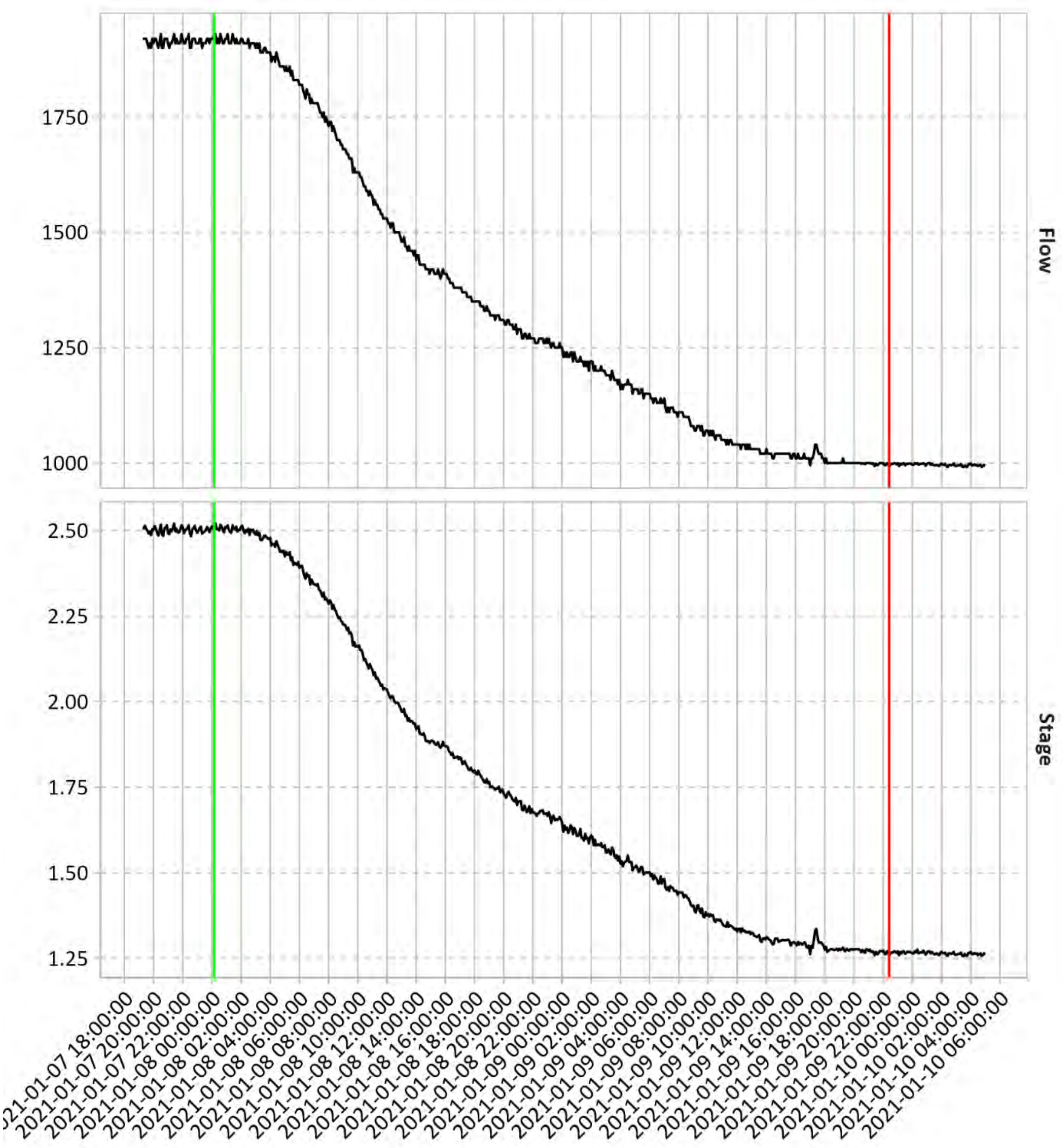


Figure 2. Discharge at PAP for April 23-24, 2021 (Trip 2, Day 1).

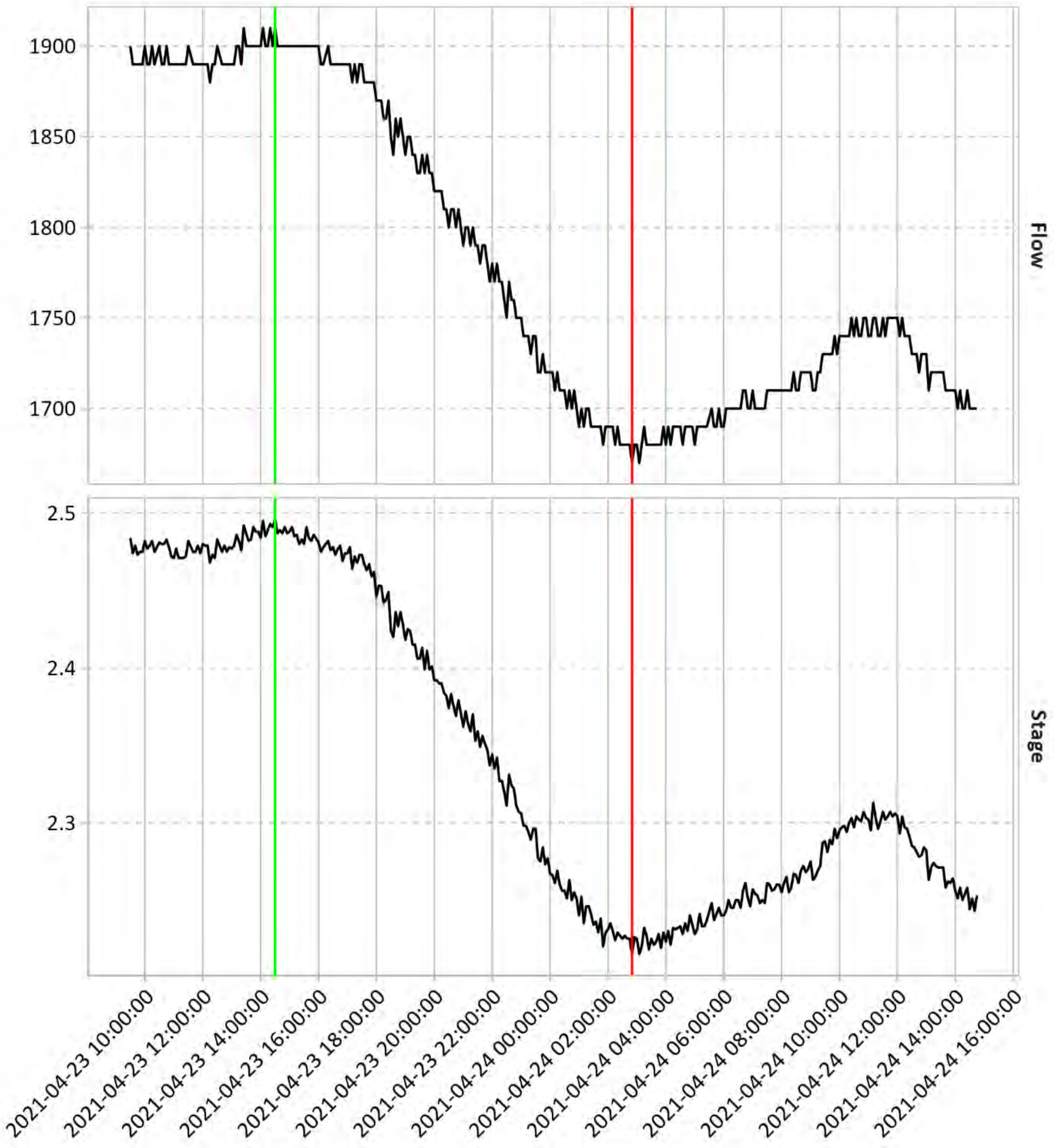


Figure 3. Discharge of PAP for April 24-26, 2021 (Trip 2, Days 2 and 3).

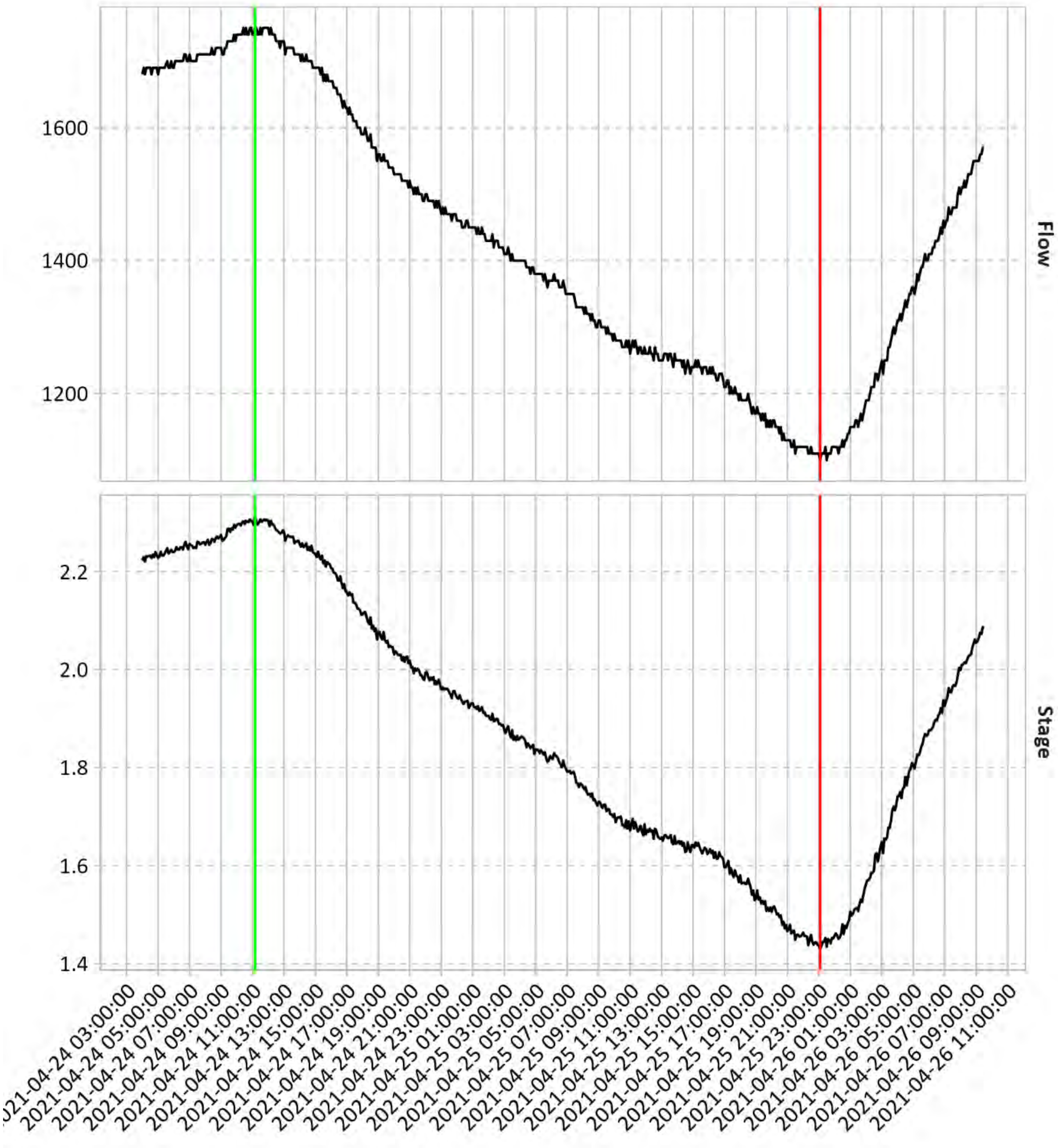


Figure 4. Discharge of PAP for May 31 – June 1, 2021 (Trip 3, Day 1-2).

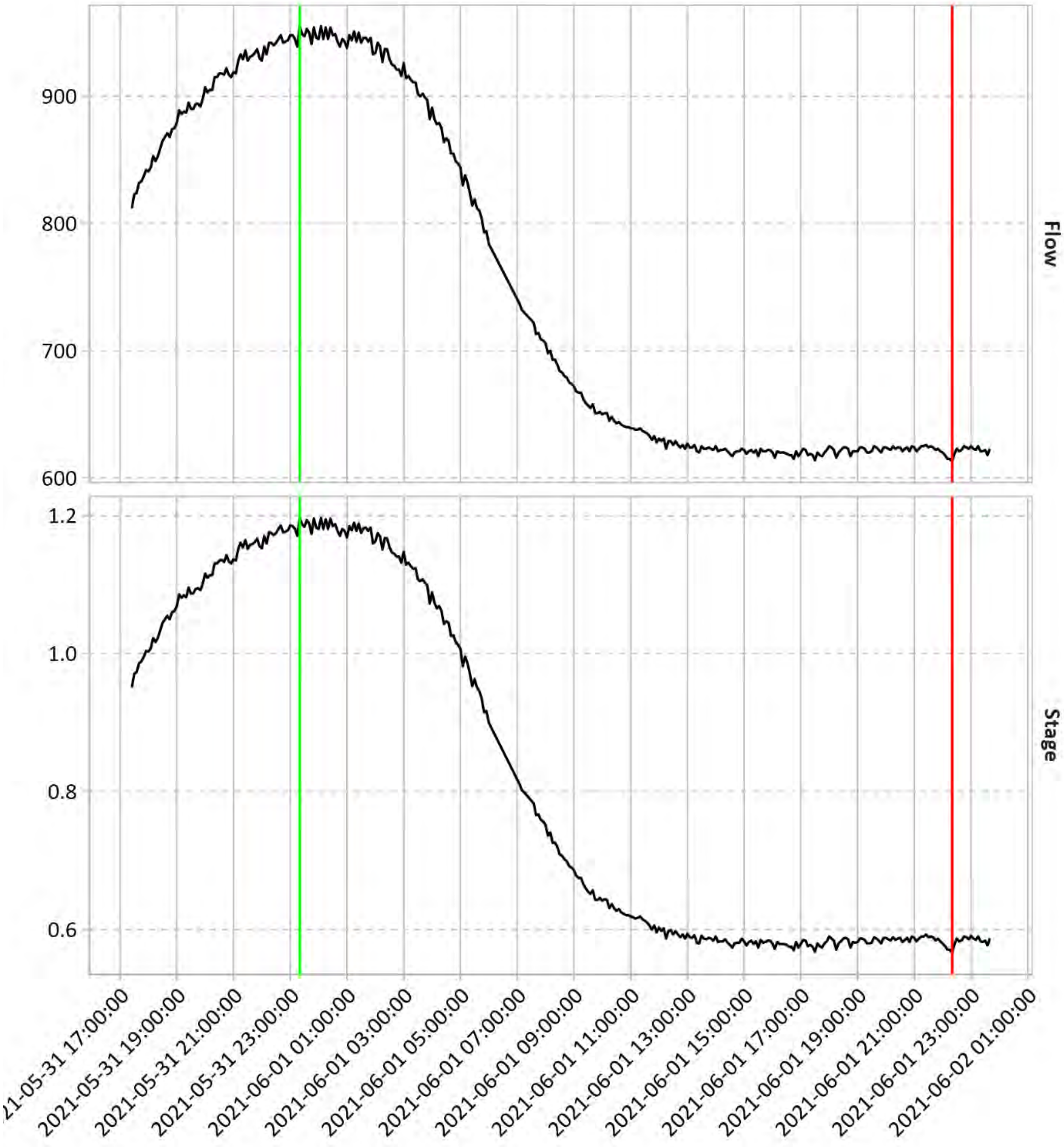


Figure 5. Discharge of PAP for July 6-7, 2021 (Trip 4, Day 1).

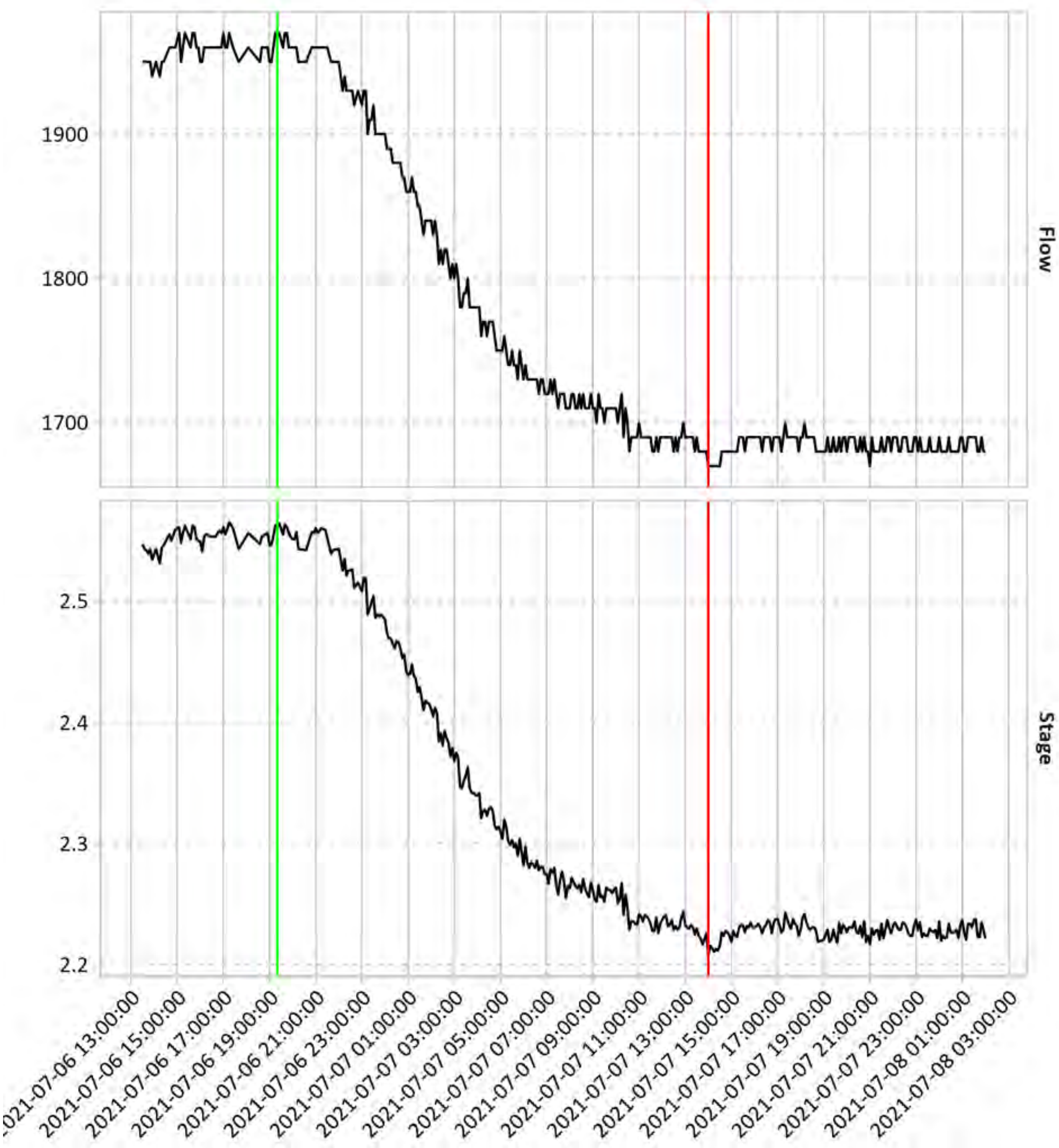


Figure 6. Discharge of Peace River at Pine for August 1-3, 2021 (Trip 5, Day 1-3).

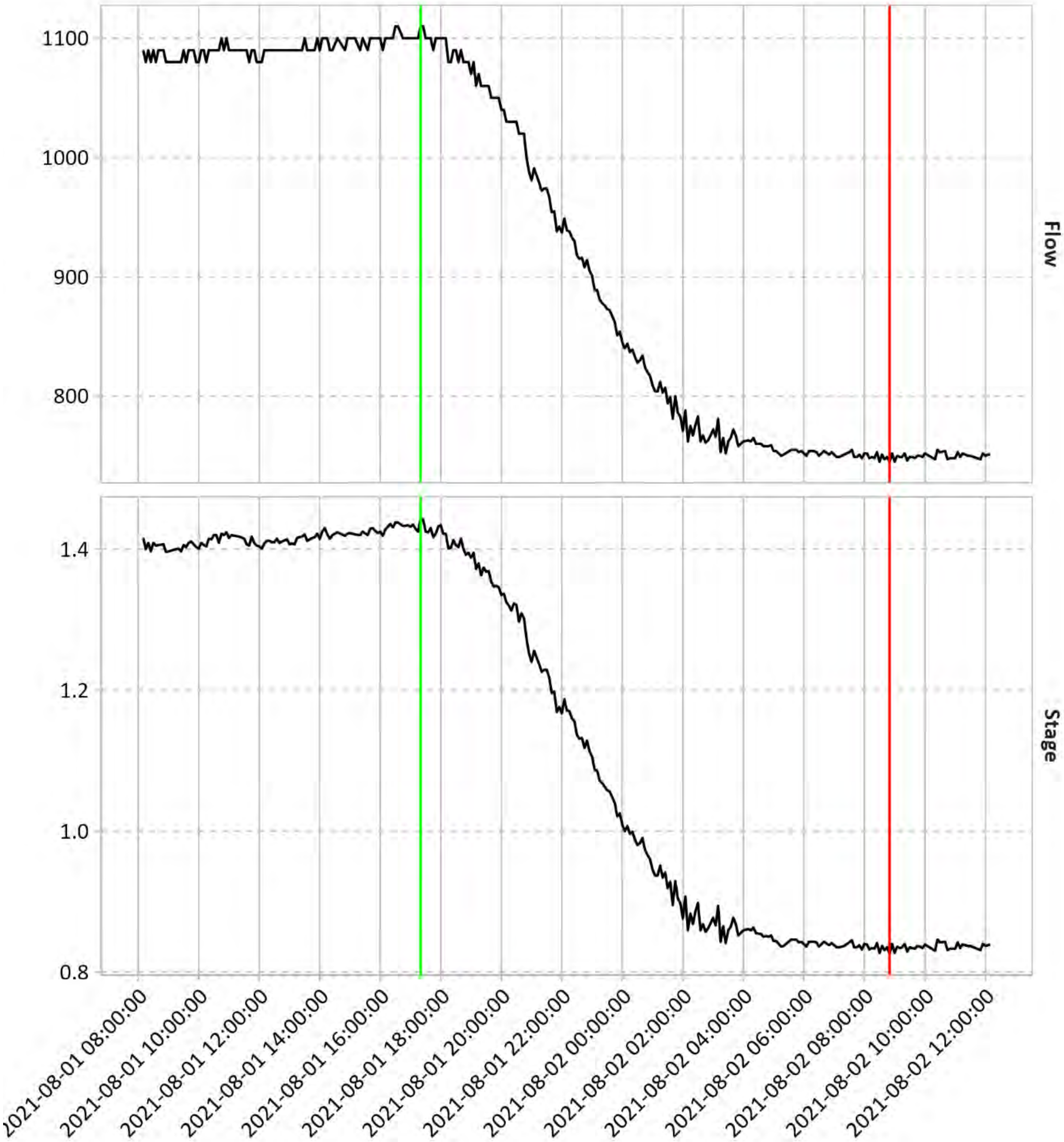


Figure 7. Discharge of Peace River at Pine for September 3-4, 2021 (Trip 6, Day 1).

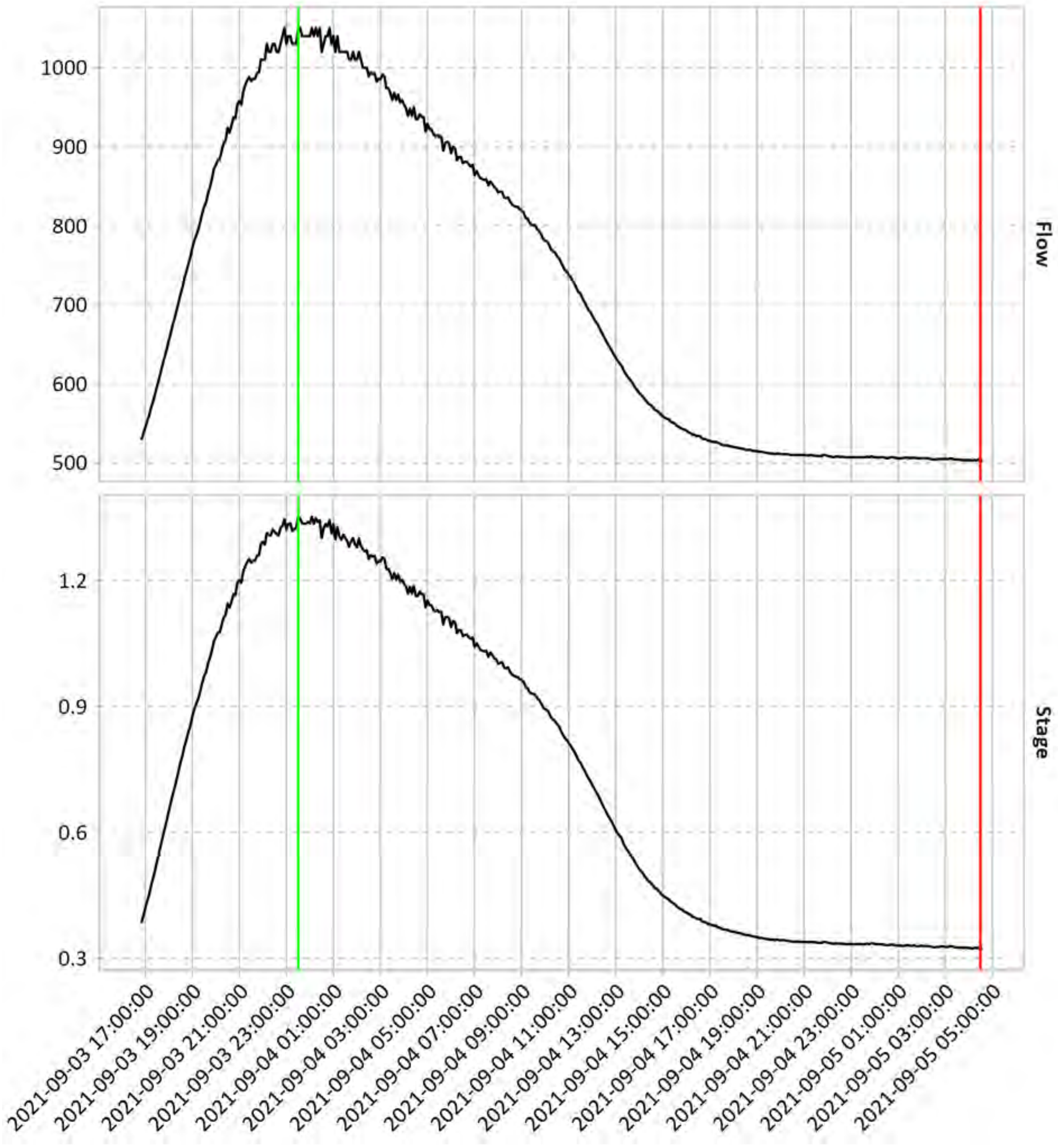


Figure 8. Discharge of Peace River at Pine for September 11 - 13, 2021 (Trip 7, Day 1).

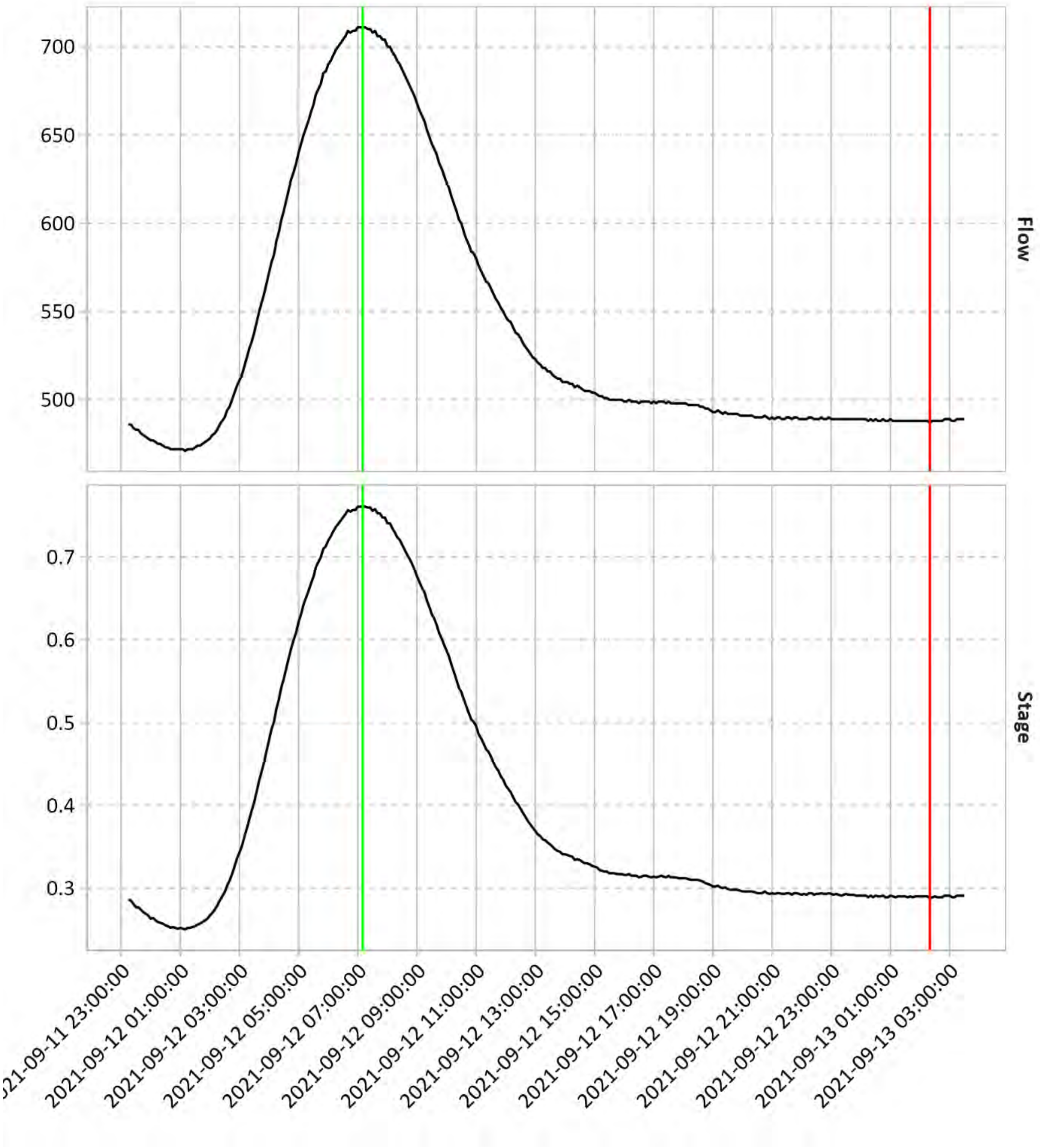


Figure 9. Discharge of Peace River at Pine for October 21 - 23, 2021 (Trip 8, Day 1).

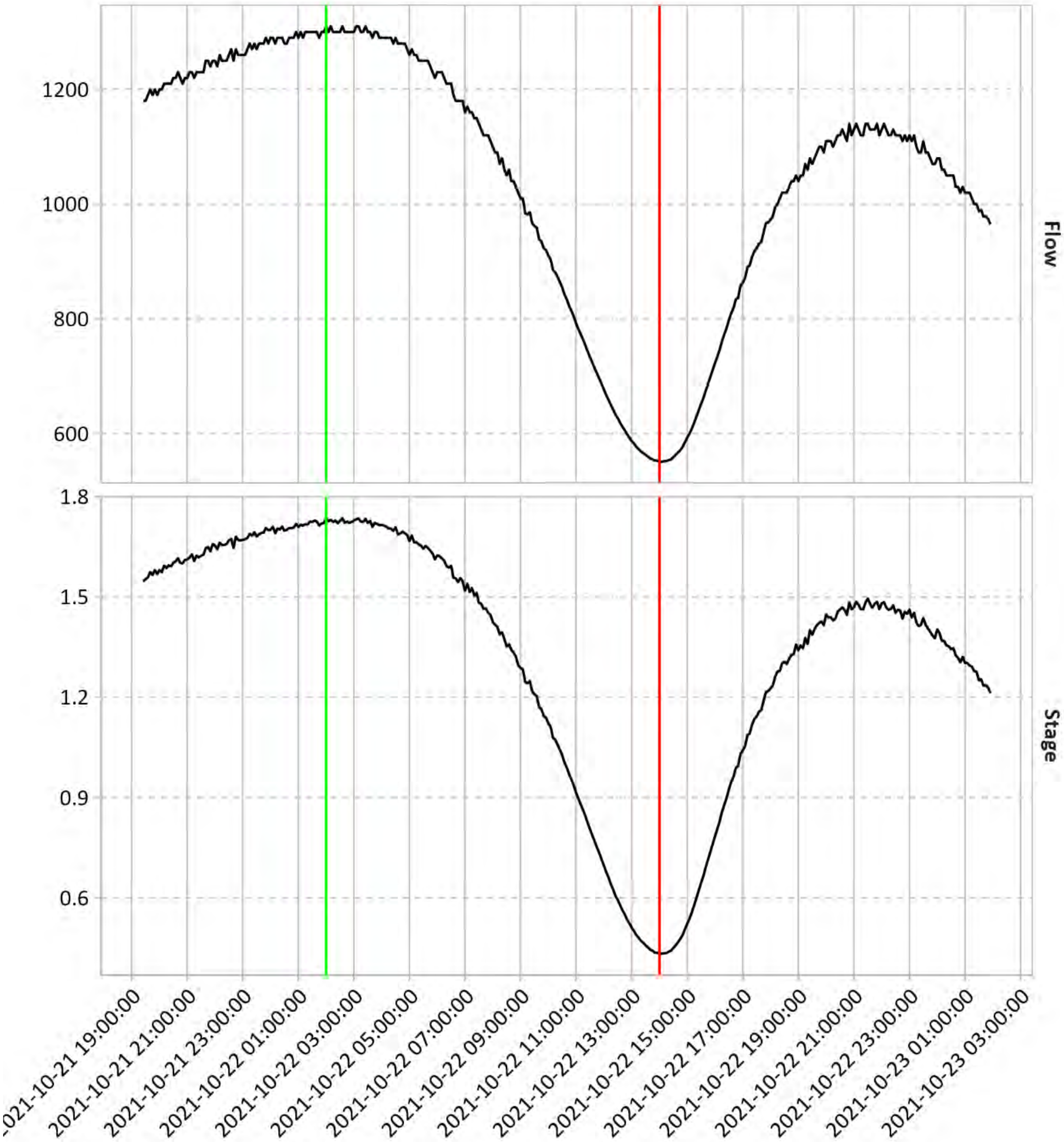


Figure 10. Discharge of Peace River at Pine for October 22 - 24, 2021 (Trip 8, Day 2).

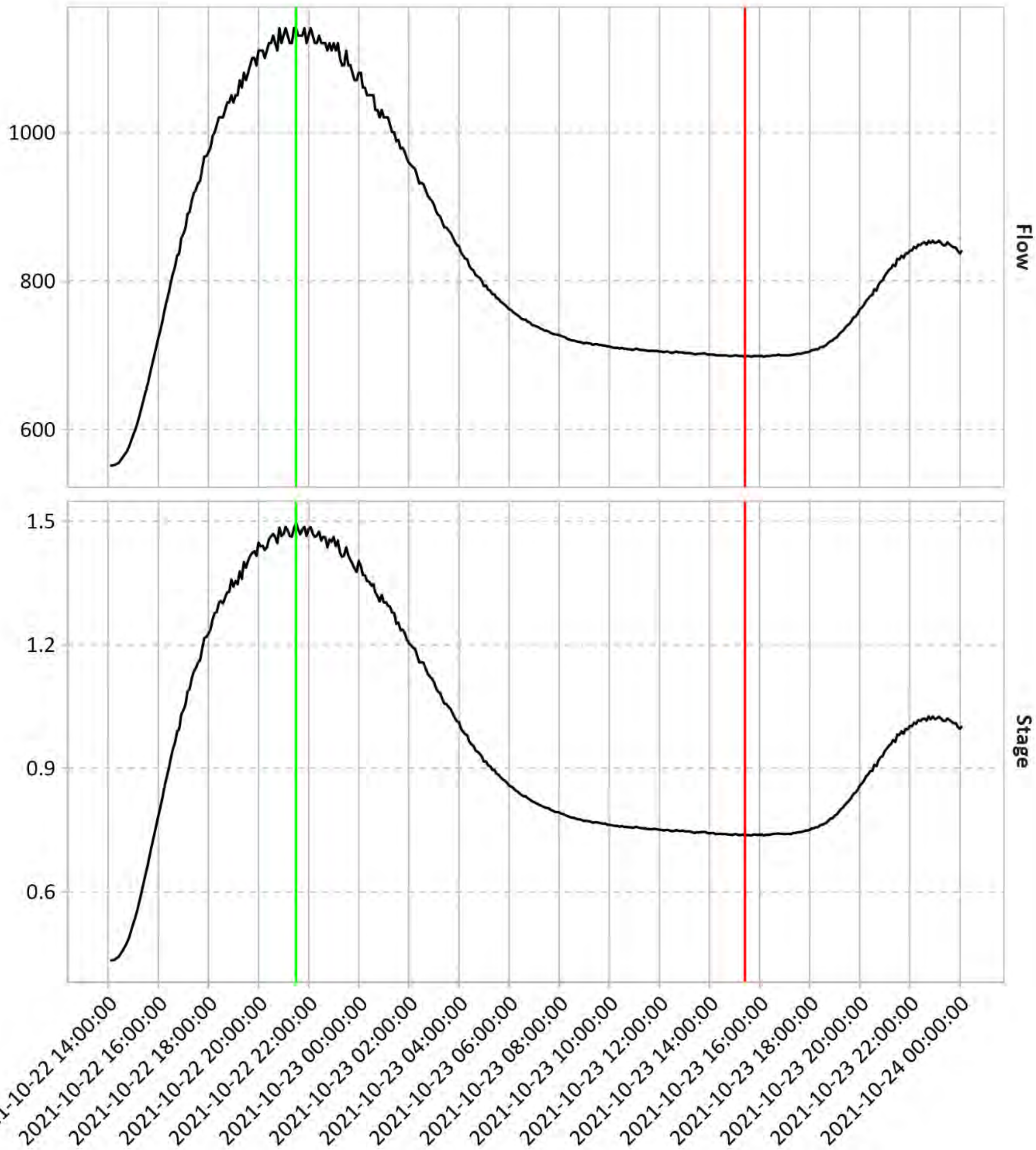


Figure 11. Discharge of Peace River at Pine for October 24 - 25, 2021 (Trip 8, Day 3).

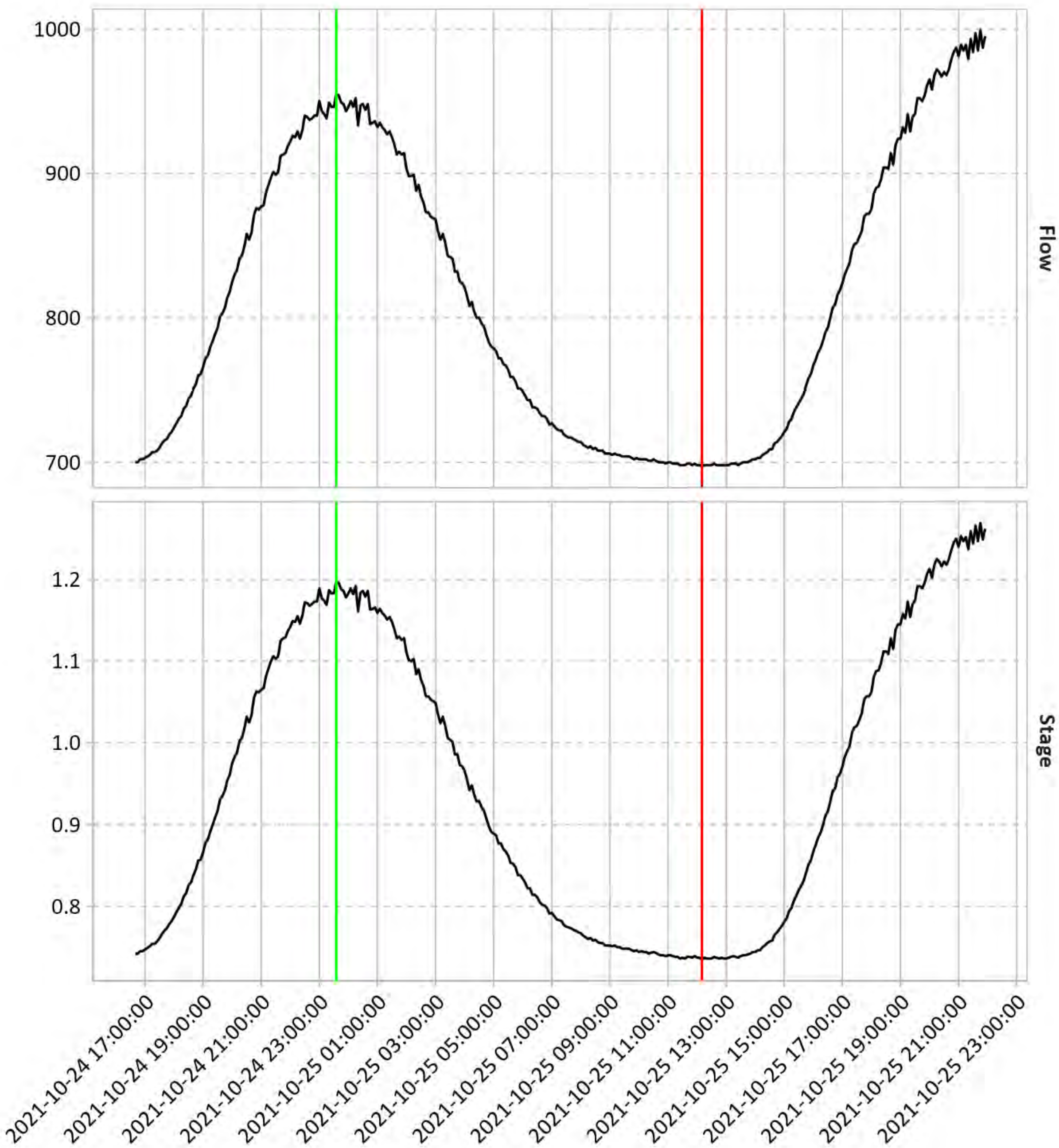


Figure 12. Discharge of Peace River at Pine for October 25 - 26, 2021 (Trip 8, Day 4).

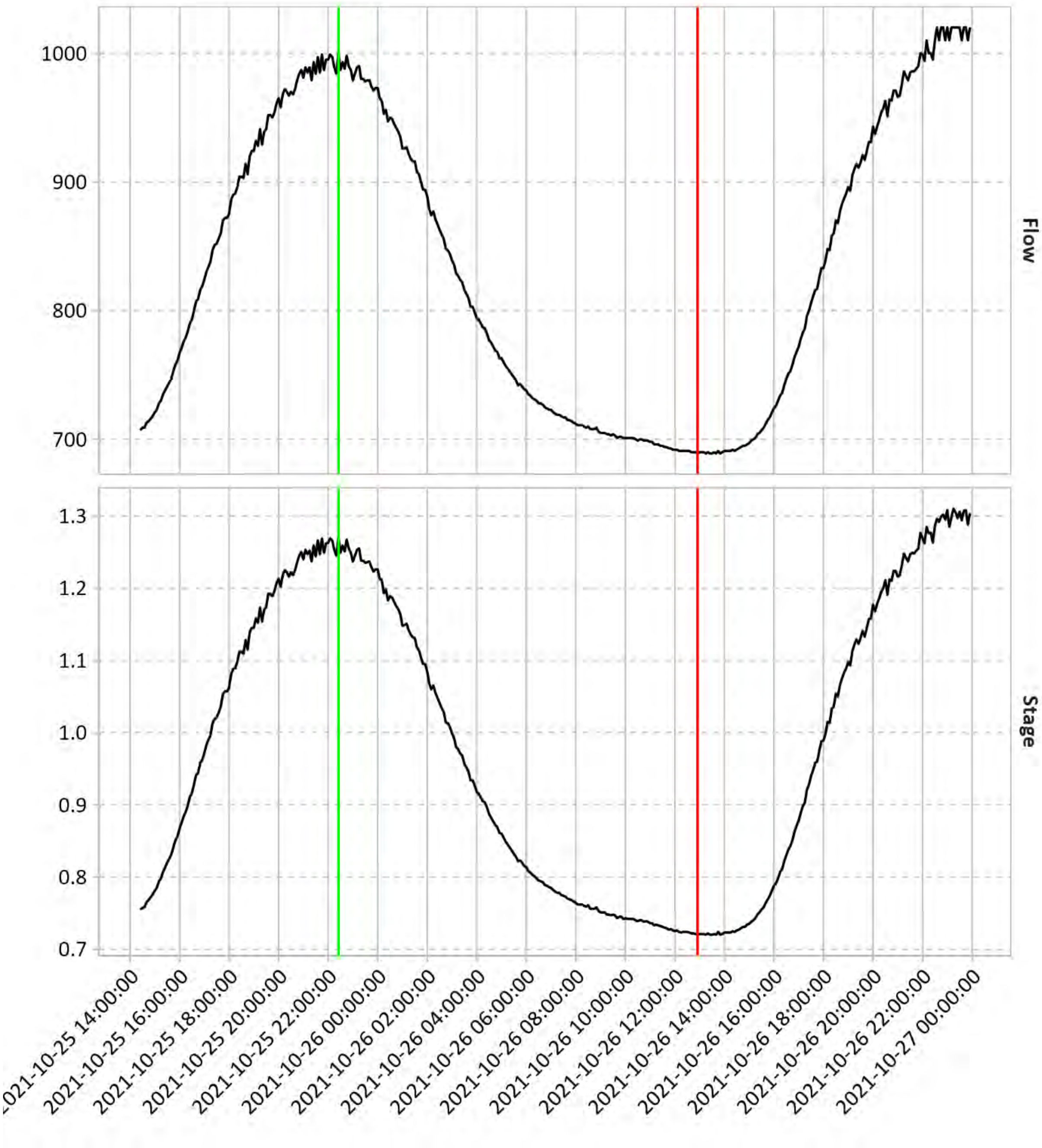


Figure 13. Discharge of Peace River at Pine for November 5 - 6, 2021 (Trip 9, Day 1).

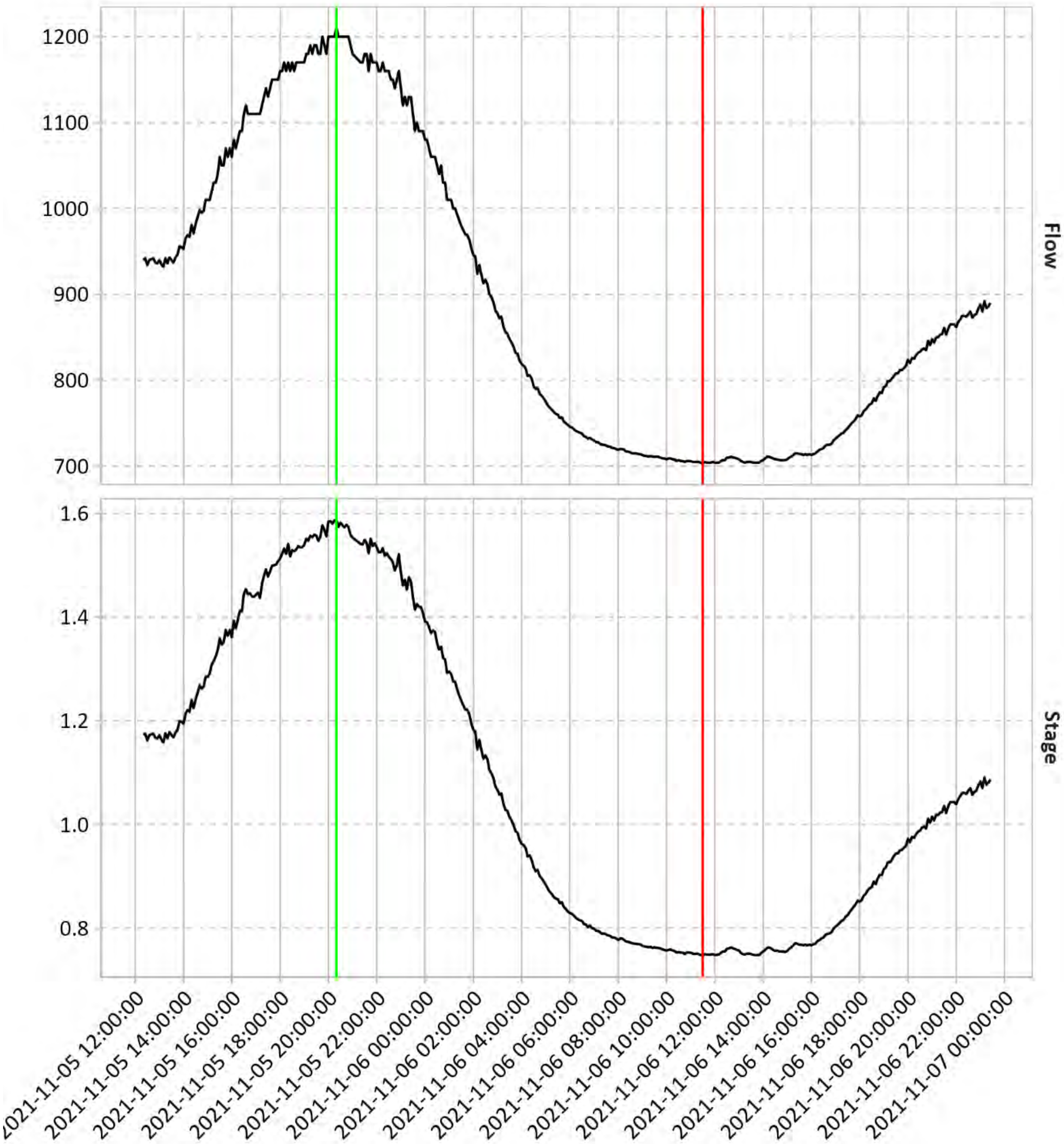
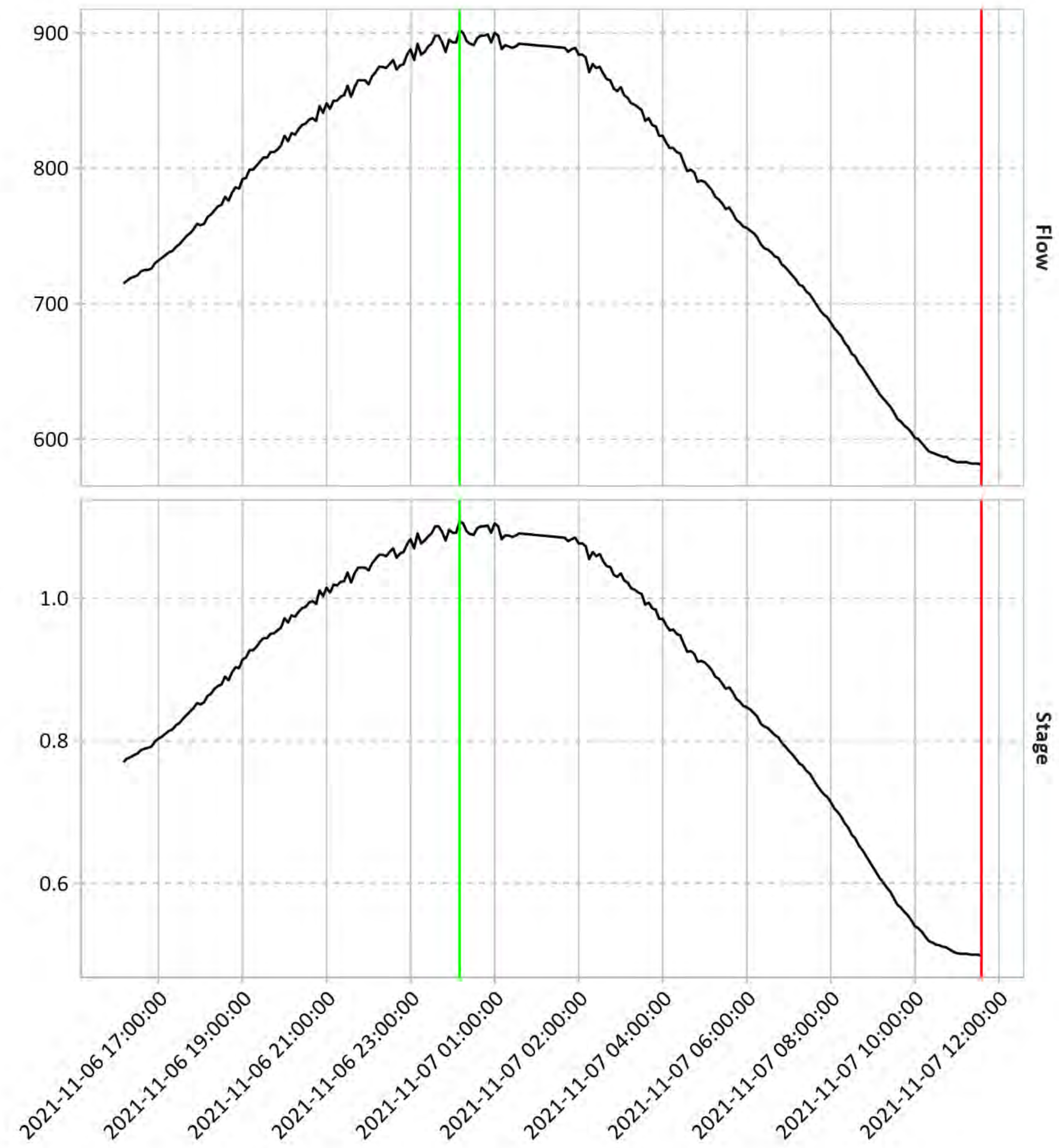


Figure 14. Discharge of Peace River at Pine for November 7, 2021 (Trip 9, Day 2).



Appendix C. Site Photos

TABLE OF CONTENTS

LIST OF FIGURES