Subject Matter Expert Report: Ice. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population

Prepared for:

Teck Coal Limited
421 Pine Avenue
Sparwood, BC, V0B 2G0

March 15, 2021

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:

Hatfield T. and C. Whelan. 2021. Subject Matter Expert Report: Ice. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population. Report prepared for Teck Coal Ltd. Report Prepared by Ecofish Research Ltd. March 15, 2021.

Certification: *stamped version on file.*

Senior Reviewer:

Todd Hatfield, Ph.D., R.P.Bio. No. 927

Director, Senior Environmental Scientist

Technical Lead:

Todd Hatfield, Ph.D., R.P.Bio. No. 927

Director, Senior Environmental Scientist

Disclaimer:

EXECUTIVE SUMMARY

Abundances of both juvenile and adult life stages of Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) (WCT) in the upper Fording River (UFR) were substantively lower in 2019 than 2017 (the Westslope Cutthroat Trout Population Decline Window, also referred to as the Decline Window). Teck Coal Limited (Teck Coal) initiated the "Evaluation of Cause" (EoC) to determine whether and to what extent various stressors and conditions played a role in the decline. One of multiple potential stressors that has been identified is the formation and presence of ice during the winters in the Decline Window, which could cause mortality of fish through effects to fish and fish habitat.

The impact hypothesis evaluated was:

- Did ice formation cause or contribute to the observed WCT population decline?

To support the evaluation of ice as a stressor, a literature review was first conducted to describe generally how ice formation occurs in streams and identify potential effects on WCT. This information was then used to evaluate whether conditions in the UFR overwintering areas during the Decline Window may have caused or contributed to the observed WCT decline.

Detailed and specific data for ice formation in the UFR during and before the Decline Window were not available; thus sources of data used to evaluate this impact hypothesis included weather and climate data (air temperature, snow accumulation), hydrometric data (stage, discharge), water temperature, photographs of river conditions, qualitative observations of ice conditions, and modelling of habitat availability in relation to surface ice. The findings of our analyses were used to determine if the weather conditions were anomalous during the Decline Window compared to historical conditions, and could have caused excessive surface ice formation, frazil and anchor ice accumulation, or ice jams, which may have caused or contributed to the observed WCT population decline. The broadest estimate of the Westslope Cutthroat Trout Population Decline Window (Decline Window) includes the winters of 2017/18 and 2018/19. Using historical data as context, we examined the Decline Window data for anomalies.

Plots of air and water temperature, snowpack and discharge were examined for periods where instability or conditions that favoured ice formation would have occurred. Downward swings in air and water temperature, and prolonged extreme cold events were considered more likely to lead to frazil or anchor ice development that would affect suitability of WCT overwintering habitats. Water level (stage) was examined to corroborate the effects of ice formation on streamflow. Snow can accumulate on surface ice or envelop narrow streams and act as a buffer from cold air temperatures for overwintering fish, so snow accumulation and snow-water equivalents were examined to determine if snow conditions were abnormally low in the winters examined.

Based on the observed weather conditions and supporting information, ice formation in winter 2017/18 was likely fairly typical, whereas ice formation in winter 2018/19 would have been more severe than in 2017/18. Effects of ice were likely minimal in some key overwintering areas such as

Henretta Lake or the Multi-plate pool where depths would have provided abundant refuge from surface ice or inflowing frazil ice; whereas, other areas like river segments S1 to S9 were likely more directly affected by dynamic and static ice. We draw special attention to the period of early February 2019 through early March 2019. Air temperature during this period was exceptionally cold but were preceded by unseasonably warm air temperatures. We suggest the ice conditions related to a sudden air temperature drop at the beginning of February (coincident with other conditions such as low snow cover) could have negatively affected suitability of several key overwintering habitats. Overall, an increase in detrimental ice conditions in the UFR may have caused mortality of WCT through several pathways. Direct pathways include crushing, stranding or freezing. Indirect pathways include increased physiological demands or increased exposure to predation, pollutants or other factors as habitat is reduced in area or in suitability and individuals are forced into denser congregations or less suitable habitats.

The available evidence for ice formation and related effects suggest that overwintering conditions were severe in 2018/19 and could have caused or contributed to the observed WCT decline in the UFR. All of the requisite conditions were met for causing or contributing to the observed decline for this winter; however, there is considerable uncertainty with respect to the magnitude of effect. Data were insufficient to provide explicit evidence of a direct linkage between fish mortality and the severe winter conditions, and there were no detailed direct observations of ice conditions, particularly dynamic ice conditions. Nevertheless, a range of effects (physiological, behavioural, occlusion, direct freezing, etc.) are possible, alone or in combination, and may have acted in concert with other stressors like water quality, predation, short-term and long-term habitat trends, and other factors. The conclusions offered here are based on effects inferred from data collected at weather and hydrometric stations, and predicted effects from the scientific literature, rather than from direct observations of ice conditions and fish mortalities in the UFR.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

LIST OF APPENDICES

ACRONYMNS AND ABBREVIATIONS

EoC	Evaluation of Cause
FRO	Fording River Operations
LAEMP	Local Aquatic Effects Monitoring Program
RKm	River Kilometer
SME	Subject Matter Expert
SWE	Snow Water Equivalent
UFR	Upper Fording River
WCT	Westslope Cutthroat Trout
WUA	Weighted Usable Area
WUW	Weighted Usable Width

READER'S NOTE

What is the Evaluation of Cause and what is its purpose?

The Evaluation of Cause is the process used to investigate, evaluate and report on the reasons the Westslope Cutthroat Trout population declined in the upper Fording River between fall 2017 and fall 2019.

Background

The Elk Valley is located in the southeast corner of British Columbia (BC), Canada. It contains the main stem of the Elk River (220 km long) and many tributaries, including the Fording River (70 km long). This report focuses on the upper Fording River, which starts 20 km upstream from its confluence with the Elk River at Josephine Falls. The Ktunaxa First Nation has occupied lands in the region for more than 10,000 years. Rivers and streams of the region provide culturally important sources of fish and plants.

The upper Fording River watershed is at a high elevation and is occupied by only one fish species, a genetically pure population of Westslope Cutthroat Trout *(Oncorhynchus clarkii lewisi)* — an iconic fish species that is highly valued in the area. This population is physically isolated because Josephine Falls is a natural barrier to fish movement. The species is protected under the federal Fisheries Act and the Species at Risk Act. In BC, the Conservation Data Center categorized Westslope Cutthroat Trout as *"imperiled or of special concern, vulnerable to extirpation or extinction."* Finally, it has been identified as a priority sport fish species by the Province of BC.

Evaluation of Cause

Following identification of the decline in the Westslope Cutthroat Trout population, Teck Coal initiated an Evaluation of Cause process. The overall results of this process are reported in a separate document (Evaluation of Cause Team, 2021) and are supported by a series of Subject Matter Expert reports.

The report that follows this Reader's Note is one of those Subject Matter Expert Reports.

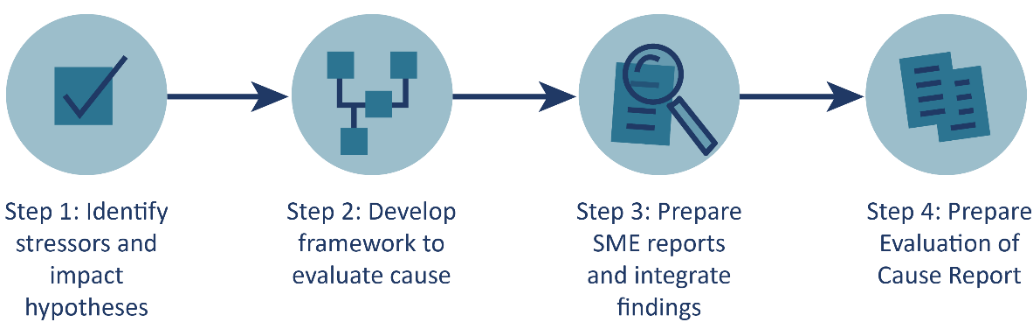
The upper Fording River watershed is influenced by various human-caused disturbances including roads, a railway, a natural gas pipeline, forest harvesting and coal mining. Teck Coal Limited (Teck Coal) operates the three surface coal mines within the upper Fording River watershed, upstream of Josephine Falls: Fording River Operations, Greenhills Operations and Line Creek Operations.

Monitoring conducted for Teck Coal in the fall of 2019 found that the abundance of Westslope Cutthroat Trout adults and sub-adults in the upper Fording River had declined significantly since previous sampling in fall 2017. In addition, there was evidence that juvenile fish density had decreased. Teck Coal initiated an *Evaluation of Cause* process. The overall results of this process are reported separately (Evaluation of Cause Team, 2021) and are supported by a series of Subject Matter Expert reports such as this one. The full list of SME reports follows at the end of this Reader's Note.

Building on and in addition to the Evaluation of Cause, there are ongoing efforts to support fish population recovery and implement environmental improvements in the upper Fording River.

How the Evaluation of Cause was approached

When the fish decline was identified, Teck Coal established an *Evaluation of Cause Team* (the Team), composed of *Subject Matter Experts* and coordinated by an Evaluation of Cause *Team Lead.* Further details about the Team are provided in the Evaluation of Cause report. The Team developed a systematic and objective approach (see figure below) that included developing a Framework for Subject Matter Experts to apply in their specific work. All work was subjected to rigorous peer review.



Conceptual approach to the Evaluation of Cause for the decline in the upper Fording River Westslope Cutthroat Trout population.

With input from representatives of various regulatory agencies and the Ktunaxa Nation Council, the Team initially identified potential stressors and impact hypotheses that might explain the cause(s) of the population decline. Two overarching hypotheses (essentially, questions for the Team to evaluate) were used:

- Overarching Hypothesis #1: The significant decline in the upper Fording River Westslope Cutthroat Trout population was a result of a single acute stressor[1] or a single chronic stressor[2].
- Overarching Hypothesis #2: The significant decline in the upper Fording River Westslope Cutthroat Trout population was a result of a combination of acute and/or chronic stressors, which individually may not account for reduced fish numbers, but cumulatively caused the decline.

The Evaluation of Cause examined numerous stressors in the UFR to determine if and to what extent those stressors and various conditions played a role in the Westslope Cutthroat Trout's decline. Given that the purpose was to evaluate the cause of the decline in abundance from 2017 to 2019[3], it was important to identify stressors or conditions that changed or were different during that period. It was equally important to identify the potential stressors or conditions that did not change during the decline window but may, nevertheless, have been important constraints on the population with respect to their ability to respond to or recover from the stressors. Finally, interactions between stressors and conditions had to be considered in an integrated fashion. Where an *impact hypothesis* depended on or may have been exacerbated by interactions among stressors or conditions, the interaction mechanisms were also considered.

The Evaluation of Cause process produced two types of deliverables:

1. **Individual Subject Matter Expert (SME) reports** (such as the one that follows this Note): These reports mostly focus on impact hypotheses under Overarching Hypothesis #1 (see list, following). A Framework was used to align SME work for all the potential stressors, and, for consistency, most SME reports have the same overall format. The format covers: (1) rationale for impact hypotheses, (2) methods, (3) analysis and (4) findings, particularly

[1] Implies September 2017 to September 2019.

[2] Implies a chronic, slow change in the stressor (using 2012–2019 timeframe, data dependent).

[3] Abundance estimates for adults/sub-adults are based on surveys in September of each year, while estimates for juveniles are based on surveys in August.

whether the requisite conditions[4] were met for the stressor(s) to be the sole cause of the fish population decline, or a contributor to it. In addition to the report, each SME provided a summary table of findings, generated according to the Framework. These summaries were used to integrate information for the Evaluation of Cause report. Note that some SME reports did not investigate specific stressors; instead, they evaluated other information considered potentially useful for supporting SME reports and the overall Evaluation of Cause, or added context (such as in the SME report that describes climate (Wright et al., 2021).

2. **The Evaluation of Cause report** (prepared by a subset of the Team, with input from SMEs): This overall report summarizes the findings of the SME reports and further considers interactions between stressors (Overarching Hypothesis #2). It describes the reasons that most likely account for the decline in the Westslope Cutthroat Trout population in the upper Fording River.

Participation, Engagement & Transparency

To support transparency, the Team engaged frequently throughout the Evaluation of Cause process. Participants in the Evaluation of Cause process, through various committees, included:

Ktunaxa Nation Council

BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development

BC Ministry Environment & Climate Change Strategy

Ministry of Energy, Mines and Low Carbon Innovation

Environmental Assessment Office

[4] These are the conditions that would need to have occurred for the impact hypothesis to have resulted in the observed decline of Westslope Cutthroat Trout population in the upper Fording River.

Citation for the Evaluation of Cause Report

When citing the Evaluation of Cause Report use:

Evaluation of Cause Team, (2021). *Evaluation of Cause — Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Evaluation of Cause Team.

Citations for Subject Matter Expert Reports

Focus	Citation for Subject Matter Expert Reports
Climate, temperature, and streamflow	Wright, N., Greenacre, D., & Hatfield, T. (2021). *Subject Matter Expert Report: Climate, Water Temperature, Streamflow and Water Use Trends. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Ice	Hatfield, T., & Whelan, C. (2021). *Subject Matter Expert Report: Ice. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. Report Prepared by Ecofish Research Ltd.
Habitat availability (instream flow)	Healey, K., Little, P., & Hatfield, T. (2021). *Subject Matter Expert Report: Habitat availability. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Ecofish Research Ltd.
Stranding – ramping	Faulkner, S., Carter, J., Sparling, M., Hatfield, T., & Nicholl, S. (2021). *Subject Matter Expert Report: Ramping and stranding. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Ecofish Research Ltd.

Focus	Citation for Subject Matter Expert Reports
Stranding – channel dewatering	Hatfield, T., Ammerlaan, J., Regehr, H., Carter, J., & Faulkner, S. (2021). *Subject Matter Expert Report: Channel dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited by Ecofish Research Ltd.
Stranding – mainstem dewatering	Hocking M., Ammerlaan, J., Healey, K., Akaoka, K., & Hatfield T. (2021). *Subject Matter Expert Report: Mainstem dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. and Lotic Environmental Ltd. Zathey, N., & Robinson, M.D. (2021). *Summary of ephemeral conditions in the upper Fording River Watershed. In Hocking et al. (2021). Subject Matter Expert Report: Mainstem dewatering. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. and Lotic Environmental Ltd.
Calcite	Hocking, M., Tamminga, A., Arnett, T., Robinson M., Larratt, H., & Hatfield, T. (2021). *Subject Matter Expert Report: Calcite. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd., Lotic Environmental Ltd., and Larratt Aquatic Consulting Ltd.
Total suspended solids	Durston, D., Greenacre, D., Ganshorn, K & Hatfield, T. (2021). *Subject Matter Expert Report: Total suspended solids. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Fish passage (habitat connectivity)	Harwood, A., Suzanne, C., Whelan, C., & Hatfield, T. (2021). *Subject Matter Expert Report: Fish passage. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Ltd. by Ecofish Research Ltd. Akaoka, K., & Hatfield, T. (2021). Telemetry Movement Analysis. In Harwood et al. (2021). *Subject Matter Expert Report: Fish passage. Evaluation of Cause – Decline in upper*

Focus	Citation for Subject Matter Expert Reports
	Fording River Westslope Cutthroat Trout population. Report prepared for Teck Coal Ltd. by Ecofish Research Ltd.
Cyanobacteria	Larratt, H., & Self, J. (2021). *Subject Matter Expert Report: Cyanobacteria, periphyton and aquatic macrophytes. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Larratt Aquatic Consulting Ltd.
Algae / macrophytes	
Water quality (all parameters except water temperature and TSS [Ecofish])	Costa, EJ., & de Bruyn, A. (2021). *Subject Matter Expert Report: Water quality. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd. Healey, K., & Hatfield, T. (2021). *Calculator to assess Potential for cryoconcentration in upper Fording River.* In Costa, EJ., & de Bruyn, A. (2021). *Subject Matter Expert Report: Water quality. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd.
Industrial chemicals, spills and unauthorized releases	Van Geest, J., Hart, V., Costa, EJ., & de Bruyn, A. (2021). *Subject Matter Expert Report: Industrial chemicals, spills and unauthorized releases. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd. Branton, M., & Power, B. (2021). *Stressor Evaluation – Sewage.* In Van Geest et al. (2021). *Industrial chemicals, spills and unauthorized releases. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd.
Wildlife predators	Dean, D. (2021). *Subject Matter Expert Report: Wildlife predation. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by VAST Resource Solutions Inc.

Focus	Citation for Subject Matter Expert Reports
Poaching	Dean, D. (2021). *Subject Matter Expert Report: Poaching. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by VAST Resource Solutions Inc.
Food availability	Orr, P., & Ings, J. (2021). *Subject Matter Expert Report: Food availability. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Minnow Environmental Inc.
Fish handling	Cope, S. (2020). *Subject Matter Expert Report: Fish handling. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Westslope Fisheries Ltd.
	Korman, J., & Branton, M. (2021). *Effects of capture and handling on Westslope Cutthroat Trout in the upper Fording River: A brief review of Cope (2020) and additional calculations.* Report prepared for Teck Coal Limited. Prepared by Ecometric Research and Azimuth Consulting Group.
Infectious disease	Bollinger, T. (2021). *Subject Matter Expert Report: Infectious disease. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by TKB Ecosystem Health Services Ltd.
Pathophysiology	Bollinger, T. (2021). *Subject Matter Expert Report: Pathophysiology of stressors on fish. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by TKB Ecosystem Health Services Ltd.
Coal dust and sediment quality	DiMauro, M., Branton, M., & Franz, E. (2021). *Subject Matter Expert Report: Coal dust and sediment quality. Evaluation of Cause – Decline in upper Fording River Westslope Cutthroat Trout population.* Report prepared for Teck Coal Limited. Prepared by Azimuth Consulting Group Inc.

Focus	Citation for Subject Matter Expert Reports
Groundwater quality and quantity	Henry, C., & Humphries, S. (2021). *Subject Matter Expert Report: Hydrogeological stressors. Evaluation of Cause - Decline in upper Fording River Westslope Cutthroat Trout population.* Report Prepared for Teck Coal Limited. Prepared by SNC-Lavalin Inc.

1. INTRODUCTION

Abundances of adult and juvenile life stages of Westslope Cutthroat Trout (WCT) in the upper Fording River (UFR) have been estimated since 2012 through high-effort snorkel and electrofishing surveys, supported by radio-telemetry and redd surveys (Cope *et al.* 2016). Surveys using similar methods were conducted in the summer/fall of 2012-2014, 2017, and 2019. Abundances of both juvenile and adult life stages were substantively lower in 2019 than 2017, indicating that a large decline occurred during that two-year period between 2017 and 2019[5] (hereafter referred to as the Westslope Cutthroat Trout Population Decline Window, also Decline Window; Cope 2020). The magnitude of the decline as well as refinements in the timing of decline are reviewed in detail by Cope (2020) and Evaluation of Cause Team (2021).

Teck Coal Ltd. (Teck Coal) initiated the "Evaluation of Cause" (EoC) to assess factors responsible for the population decline. The EoC evaluates numerous impact hypotheses, to determine whether and to what extent various stressors and conditions played a role in the decline of WCT. Given that the primary objective is to evaluate the cause of the sudden decline over a short time period (from 2017 to 2019), it is important to identify stressors or conditions that changed or were different during the Decline Window. However, it is equally important to identify all potential stressors or conditions that did not change during the Decline Window but nevertheless may be important constraints on the population. Finally, interactions among stressors are also considered in the EoC. Where an impact hypothesis depends on interactions among stressors or conditions, or may be exacerbated by particular interactions, the mechanisms of interaction are considered as specific impact hypotheses.

A project team is evaluating the cause of decline and is investigating two "Overarching" Hypotheses:

- Overarching Hypothesis #1: The significant decline in the UFR WCT population was a result of a single acute stressor[6] or a single chronic stressor[7].
- Overarching Hypothesis #2: The significant decline in the UFR WCT population was a result of a combination of acute and/or chronic stressors, which individually may not account for reduced WCT numbers, but cumulatively caused the decline.

Ecofish Research Ltd. (Ecofish) was asked to provide support as subject matter expert (SME) to evaluate some of the stressors. This report investigates direct and indirect effects of ice formation as stressors on WCT in the UFR. Where identified, anomalies compared to historical data are presented and discussed.

[5]Abundance estimates for adults / sub-adults are based on surveys in September of each year, whereas estimates for juveniles are based on surveys in August.

[6]Implies the single acute stressor acted between September 2017 to September 2019.

[7]Implies a chronic slow change in the stressor (using 2011-2019 timeframe, data dependent).

1.1. Background

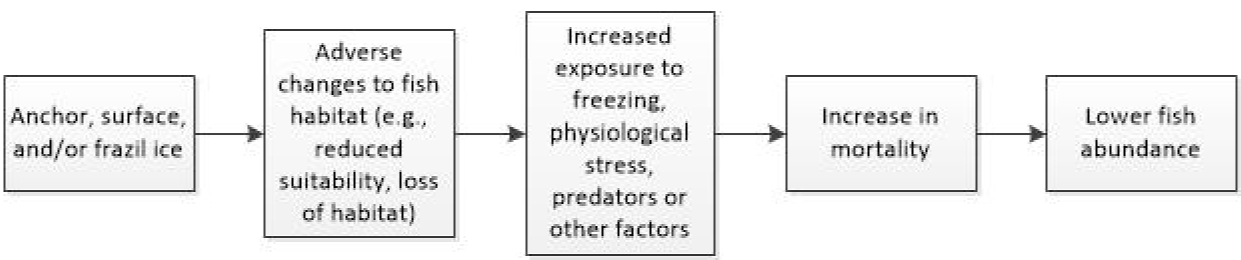
1.1.1. Overall Background

This document is one of a series of SME reports that supports the overall EoC of the UFR WCT population decline (Evaluation of Cause Team 2021). For general information, see the preceding Reader's Note.

1.1.2. Report-Specific Background

Winter in high elevation, cold water streams presents several challenges to fish survival. Generally, WCT in the UFR migrate to habitat that protects them from the harshest winter conditions (Cope *et al.* 2016). However, fish need to access overwintering habitat, and once there, suitability can vary and is dependent on several factors. Those factors include the timing of ice and snow accumulation, ice type, and access to hydraulically and thermally suitable areas within the overwintering habitat. As described in detail in Section 3.1, ice formation can cause increased risk to fish due to adverse changes to habitat (e.g., reduced suitability of flow and cover, loss of habitat or valuable habitat features, displacement from habitat) and this may result in direct effects to fish, potentially because they become concentrated within smaller habitat areas or suboptimal habitat where they may become vulnerable to effects such as freezing, physiological stress, or other risk (e.g., predation). Figure 1 provides a pathway of effect conceptual model for the cause-effect linkages between ice formation and reduced fish abundance considered in this investigation.

Figure 1. Effect pathway diagram linking ice formation to WCT population decline in the UFR.



1.1.3. Author Qualifications

Todd Hatfield, Ph.D., R.P.Bio.

This project is being led by Todd Hatfield, Ph.D., a registered Professional Biologist and Principal at Ecofish Research Ltd. Todd has been a practising biological consultant since 1996 and he has focused his professional career on three core areas: environmental impact assessment of aquatic resources, environmental assessment of flow regime changes in regulated rivers, and conservation biology of freshwater fishes. Since 2012, Todd has provided expertise to a wide array of projects for Teck Coal: third party review of reports and studies, instream flow studies, environmental flow needs assessments, aquatic technical input to structured decision making processes and other decision support, environmental impact assessments, water licensing support, fish community baseline studies, calcite effects studies, habitat offsetting review and prioritizations, aquatic habitat management plans, streamflow ramping assessments, development of effectiveness and biological response monitoring programs, population modelling, and environmental incident investigations.

Todd has facilitated technical committees as part of multi-stakeholder structured decision making processes for water allocation in the Lower Athabasca, Campbell, Quinsam, Salmon, Peace, Capilano, Seymour and Fording rivers; he has been involved in detailed studies and evaluation of environmental flows needs and effects of river regulation for Lois River, China Creek, Tamihi Creek, Fording River, Duck Creek, Chemainus River, Sooke River, Nicola valley streams, Okanagan valley streams, and Dry Creek. Todd was the lead author or co-author on guidelines related to water diversion and allocation for the BC provincial government and industry, particularly as related to the determination of instream flow for the protection of valued ecosystem components in BC. He has worked on numerous projects related to water management, fisheries conservation, and impact assessments, and developed management plans and guidelines for industry and government related to many different development types. Todd is currently in his third 4-year term with COSEWIC (Committee on the Status of Endangered Wildlife in Canada) on the Freshwater Fishes Subcommittee.

Colby Whelan, M.Sc., R.P.Bio

Colby Whelan is a fisheries biologist who obtained his Bachelor of Science from the University of Victoria and his Master of Science in Ecology at the University of Calgary. His graduate work studied the risk of Whirling Disease infection to threatened populations of Westslope Cutthroat Trout in Banff National Park. His study examined how variation in fish habitats in Banff could lead to differential risk of Whirling Disease establishment, and how this information could be used to design protective measures for threatened fish populations.

Colby has worked for Ecofish since 2019 and prior to that worked for the aquatics department of Parks Canada in Banff National Park. Through these positions he has participated in several projects that study factors that contribute to the decline of native trout populations, including Whirling Disease, climate change, invasive species, and habitat loss. Colby has direct experience with collecting data on WCT during winter in the Canadian Rockies, including in conditions similar to those discussed in this report.

1.2. Objective

The objective of this report is to review the available information to assess the potential for ice formation to have impacted WCT abundance during the Decline Window in the UFR through effects on overwintering fish and fish habitat. Ice formation within streams can directly and indirectly cause fish mortality, which can, in turn, lead to population decline if a large proportion of the population is impacted.

Thus, the specific impact hypothesis evaluated was:

- Did ice formation cause or contribute to the observed WCT population decline?

To address this objective, three questions related to potential effects of ice on WCT were investigated:

1. Did anchor, frazil or surface ice cause WCT mortality via freezing, crushing, or entrapment (direct effect)?
2. Did anchor, frazil or surface ice alter habitat availability or preclude WCT from using preferred overwintering habitat (indirect effect)?
3. Did anchor, frazil or surface ice result in behavioural or physiological response by WCT (direct effect)?

1.3. Approach

To support the evaluation of ice as a stressor, a literature review was first conducted to provide a summary of ice formation processes and potential effects on WCT (Section 2.1). The aim of the literature review was to describe generally how ice formation occurs in streams and how fish cope with different forms of ice. This information was then used to evaluate whether conditions in the UFR overwintering areas during the Decline Window may have caused or contributed to the observed WCT decline.

The Decline Window includes the winters (November to March) of 2017/18 and 2018/19 and we considered both of these winters relative to recent historical periods when reviewing climatic and hydrometric data (Section 2.2). However, additional lines of evidence suggest that the decline occurred during the second of these winters (Evaluation of Cause Team 2021); thus, we focused additional assessment on winter of 2018/19. Modelling of habitat availability that could potentially have been precluded by surface ice was conducted to evaluate to what extent surface ice could have influenced the availability of suitable overwintering fish habitat (Section 2.3).

Assessment of the potential effect of ice on WCT in the UFR during the Decline Window involved evaluation of requisite conditions. Requisite conditions are defined as the circumstances that would need to be met for ice to potentially cause or contribute to the WCT population decline. To be considered a primary cause of the WCT decline, ice formation needs to have been the primary factor affecting WCT survival during the Decline Window. Ice formation must therefore have affected key overwintering habitats and been moderate-to-high intensity (i.e., high magnitude and long duration) during the Decline Window (September 2017 to September 2019). For ice formation in overwintering conditions to be considered as contributing to the WCT decline, the effects are expected to have been of low-to-moderate magnitude within the Decline Window compared to pre-September 2017. Requisite conditions (Table 1) were based on spatial (extent and location) and temporal (timing and duration) aspects of ice and on the intensity (magnitude) of the events in relation to risks for fish associated with ice formation and presence.

Table 1. Requisite conditions for effects of ice formation to be the primary cause of WCT decline.

Spatial extent	Detrimental ice conditions occurred over an area sufficient to affect a large proportion of the fish population
Duration	Presence of frazil ice, anchor ice or surface ice was of sufficient duration to result in fish mortality
Location	Areas in the UFR occupied by fish were affected by detrimental ice conditions
Timing	Ice conditions and overwintering habitat availability were more severe during the Decline Window than before
Intensity	Ice conditions were more detrimental during the Decline Window than before, or acted in combination with other factors to cause higher mortality during the Decline Window

A difference in Intensity before vs. during the Decline Window was considered a key requisite condition because some degree of ice formation is expected in the UFR each year; however, only once it reaches a high intensity is detrimental ice considered severe enough to cause WCT mortality. Detailed and specific data for ice formation in the UFR during and before the Decline Window were not available, so we compiled and reviewed other data that could provide evidence of what ice conditions would likely have been during the two winters of the Decline Window. This information was reviewed to allow assessment of whether, and to what extent, ice may have played a role in WCT mortality. The requisite conditions were evaluated using the following information:

- Information from the scientific literature on ice formation and suitable overwintering fish habitat;
- Knowledge of key overwintering areas for the UFR WCT population (e.g., Cope *et al.* 2016);
- Weather (air temperature, snow accumulation and SWE), hydrology (discharge/stage and water temperature) and channel morphology data collected on the UFR mainstem and tributaries;
- Photo records from stationary camera stations in 2018 and 2019 and from LAEMP monitoring 2017-2020;
- Incidental field observations of ice in overwintering conditions on the UFR mainstem and tributaries in 2018 and 2019; and

- Habitat transect data (e.g., water depth and wetted width) collected on the UFR mainstem that was used to estimate available overwintering refuge habitat under varied assumptions of ice thickness.

The above information was used to assess the spatial extent and timing of ice cover and determine whether conditions during the Decline Window were markedly different than in previous years and may therefore have caused or contributed to the WCT population decline. The results of this analysis support evaluation of Overarching Hypothesis 1 (requisite condition to cause) and Hypothesis 2 (requisite condition to contribute) for the ice stressor.

2. METHODS

2.1. Literature Review

To support the evaluation of ice as a stressor on WCT during the Decline Window, a literature review was first conducted to summarize available information on ice formation processes in streams and potential effects of stream ice on overwintering fish and their habitat. The literature review summarized information on factors that affect ice formation in streams to allow evaluation of the ice conditions that may have been present during the two winters in the Decline Window, reviewed salmonid overwintering habitat preferences and potential impacts of ice on overwintering fish, and summarized knowledge on overwintering WCT habitats in the UFR. Implications for WCT overwintering survival in the UFR given potential changes to stream connectivity that may have been caused by ice were also considered in relation to previously identified barriers to movement (culverts), specific concerns related to fish passability at such locations, and information on fish movement patterns as determined from previous research. The information summarized during the literature review was then used to evaluate whether conditions in the UFR overwintering areas may have caused or contributed to the observed WCT decline.

2.2. Overwintering Conditions in the Upper Fording River

To evaluate whether ice formation directly or indirectly resulted in the observed WCT decline, we reviewed observations of conditions at key overwintering locations. There were few direct observations of ice conditions during the Decline Window, so examination of weather, water temperature, and hydrology data and other ancillary information provide the best insights into winter conditions. Available weather records were examined for instances of extreme cold or irregular patterns during the Decline Window relative to climatic normals to determine if conditions occurred that could lead to effects on fish from ice. Note that a broad treatment of climate data is provided in the Evaluation of Cause report on Climate (Wright *et al.* 2021).

Based on evidence that the WCT decline occurred during the second of the winters of the Decline Window (Evaluation of Cause Team 2021), as well as the anomalous weather conditions identified from data summaries (see Section 3.2), conditions in the 2018/19 winter were examined more closely. This was done through a compilation of weather and hydrometric observations, investigation of sudden and high magnitude air temperature changes during winters within the data record since 1970 in relation to the 2018/19 winter, reviewing photographic evidence of ice formation from photographs taken at 10 game cameras, and compiling qualitative observations of ice in the UFR during the 2018/19 winter.

2.2.1. Data Sources

We compiled and summarized available records of air and water temperature, snow accumulation and snow-water equivalents[8] (SWE) and stream stage/discharge data for the Decline Window, and the period prior to the Decline Window, from several sources.

Air temperature and snow accumulation are two drivers of river ice formation and data exist for several locations in the region. The primary source for air temperature data in this report is the EC Fording River Cominco station (Map 4) from which daily average air temperature was obtained. This station was selected because it is near the UFR, relatively central in the region, and had a long period of record (1970-2018). The Fording River Cominco station was decommissioned in 2018 and replaced with the nearby Fording River water treatment plant weather station (FR_WTT), which was operational through 2019. The two time series were combined to form a complete record.

Snow data from two stations were reviewed: FRO_CSP, which provides a local record of snow accumulation but has only operated since 2013; and the Morrissey Ridge Station, which is ~80 km away (Map 4) but provides a record of snow water equivalents (a measure of the mass of the snowpack and how much stored water it has) from 1983 to present and is considered indicative of general SWE for the region. Totals reported only consider November to March, as the primary concern in this report is snow accumulation on river ice.

Water temperature, stage, and flow data were obtained from are three hydrometric stations in the UFR (HC1, FRNTP, FRABCHF; Map 4). Stage and discharge data were also examined from Water Survey Canada records between 2010 and 2019 for two hydrological gauges: NK018 Fording River at the Mouth and NK002 Elk River at Fernie.

Photo time series were available from two sources. As part of an offsetting monitoring program Teck Coal maintained a series of game cameras that collected a photo at 13:00 each day; photos were examined for winters of 2017/18 and 2018/19. Once monthly photos were also taken at GH_FR3, FR_CP1SW and FR_FRABCH (Map 3) as part of Teck Coal's Local Aquatic Effects Monitoring Program (FRO LAEMP 2016 - 2020; Minnow and Lotic 2019).

To interpret the patterns in air temperature plots, several statistical analyses were carried out. We tested the statistical significance of the difference between the mean January and February 2019 air temperatures vs. historical median air temperatures for those months. Additionally, an analysis was conducted to determine the return interval for sudden high to low air temperature shifts in the UFR

[8] The amount of liquid water contained in the snowpack

area. Methods for the analyses that tested difference from historical median, and the return interval, are presented alongside the corresponding results in Section 3.3.2.

2.3. Habitat Availability in Relation to Surface Ice

Ice formation has the potential to affect the availability of suitable overwintering fish habitat. The question of whether surface ice could influence the availability of suitable overwintering fish habitat was investigated by modelling the amount of usable habitat that would be precluded by surface ice; we also investigated the amount of usable habitat that may be lost when ice formation puts water into hydraulic storage (ice storage effect; see Section 3.1.1).

We used simple exploratory models to predict weighted usable area (WUA) in the presence of different surface ice thicknesses. These models are intended as simple explorations of the amount of usable habitat under open water conditions that could be consumed by surface ice, rather than modelled predictions of hydraulically suitable habitat under ice. WUA is a measure of the area of a stream section that has suitable depth, velocity and substrate for a specified fish species and life stage; since it is a measure of suitable habitat, WUA is usually much less than the total wetted area. Habitat modelling was completed for the UFR from the Henretta Creek confluence to the Chauncey Creek confluence in two separate zones (one from the Henretta Creek confluence to the Kilmarnock confluence, and one from the Kilmarnock confluence to the Chauncey confluence). Details on transects and habitat modelling are provided in the Evaluation of Cause report on habitat availability (Healey *et al.* 2021) and the FRO OEMP instream flow study of the UFR upstream of Chauncey Creek (Healey *et al.* 2020).

The ice modelling assumed build up of surface ice uniformly across the transects, and that fish require >5 cm of water between the bottom of the ice sheet and the streambed for habitat to remain usable. Model results are provided for 5, 10 and 15 cm buffers. The models are used to illustrate in a general sense the degree that habitat can be reduced by ice.

A similar exploration was carried out to assess whether a discharge reduction due to ice formation (discharge depression; see Section 3.1.1) could substantively influence WUA. This model used the average discharge of FR_FRNTP for February 2019 (0.36 m^3/s) as a baseline and then modelled WUA reduction at several assumed levels of discharge depression due to the ice storage effect.

3. RESULTS

3.1. Literature Review

3.1.1. Ice Formation in Streams

3.1.1.1. Factors That Affect Stream Ice formation

Many factors influence the formation of stream ice in winter. Key factors that can affect amount of ice, type of ice, and the timing and speed of ice formation include flow characteristics (e.g., velocity and turbulence), channel characteristics (e.g., size and shape), and weather conditions. Air temperature is instrumental in determining ice formation initiation and rate, and once surface ice formation begins, snow accumulation can insulate the water below and prevent further ice accumulation. Water depth is also an important factor; given similar temperatures and flows, shallow streams cool faster than deep streams, and therefore have more rapid ice formation. Likewise, ice formation would be expected to occur faster when flows are comparatively low.

The velocity and turbulence of flow is a critical factor in the freezing process. Low velocity, such as occurs in low gradient sections of streams (e.g., pools) and along stream margins, is associated with static ice formation, occurring at the surface of the stream (Ashton 1986). A surface velocity of <0.6 m/s (Ashton 1986) is generally accepted as the threshold for static ice formation (Stickler *et al.* 2010). When velocity is below this threshold, ice will stay on the surface because vertical turbulence is insufficient to overcome the rise velocity (due to buoyancy) of an ice particle that forms at the surface (Figure 2). In general, calm stream sections with low gradients and velocities have stable ice cover with consistent thickness.

High velocities and turbulent flows, which are typical of steep streams or certain mesohabitat types, can lead to super-cooling conditions (water temperatures less than 0 °C) and dynamic ice formation processes (Tesaker 1994, Stickler and Alfredsen 2009; Figure 2). Super-cooling occurs when the entire water column cools to below 0 °C (i.e., there is no temperature stratification) because turbulent mixing is sufficient to produce a uniform water temperature within the stream (Brown *et al.* 2011). Thus, super-cooling occurs when the air temperature is sub-freezing, little or no surface ice is present, and water flow is sufficiently turbulent to overcome temperature stratification. Super-cooled conditions typically lead to the formation of frazil ice, anchor ice, and frazil slush.

Figure 2. **Examples of anchor ice (top; from Brown *et al.* 2011) and extreme frazil slush (bottom; from http://www.lifeinyosemite.com/2009/04/15/frazil-ice-in-yosemite-creek/).**

Frazil ice (loose ice crystals or clusters of few to many crystals) may adhere to submerged objects and can accumulate in large quantities. When accumulation occurs on the stream bed, this is referred to as anchor ice. Anchor ice typically consists of small, fluffy ice crystals that have a milky appearance and may form extensive, porous blankets over the streambed (Huusko *et al.* 2007, Brown *et al.* 2011; Figure 1). In riffles with a fast current, anchor ice can become thick and can create anchor ice dams. Hanging dams, which form when frazil ice is deposited on the underside of surface ice in areas with reduced water velocity (e.g., pools), can sometimes become large (e.g., extending to the riverbed and across the channel of large rivers) and can persist for extended periods (e.g., until spring; Brown *et al.* 2000). Frazil slush is composed of anchor ice lifted from the bottom, and frazil ice crystals, either singly or flocculated together. It is common to see frazil slush on the surface of streams or rivers after a period of frazil ice production. Frazil slush is buoyant and can consolidate on the water surface and can pack or clump together into large floes (Brown *et al.* 2011). Although ice production in small, steep rivers is typically dynamic due to higher water velocities and turbulent flow, ice production in large rivers is generally more static (Huusko *et al.* 2007; Table 2), both dynamic and static ice can form in mesohabitats within any system depending on flow and channel conditions at a smaller spatial scale. Similarly, although anchor ice is typically found in turbulent shallow rapids with rough substrates, it can also occur in deep areas or relatively large and slow rivers during very cold temperatures, especially if there is no ice/snow cover (Butler 1979). Timing and amount of snow accumulation, which depends on elevation, and weather, affects ice formation because snow cover over surface ice provides insulation and moderates effects of rapid changes in air temperature.

Figure 3. A schematic illustration of ice formation in rivers from Huusko *et al.* (2007).

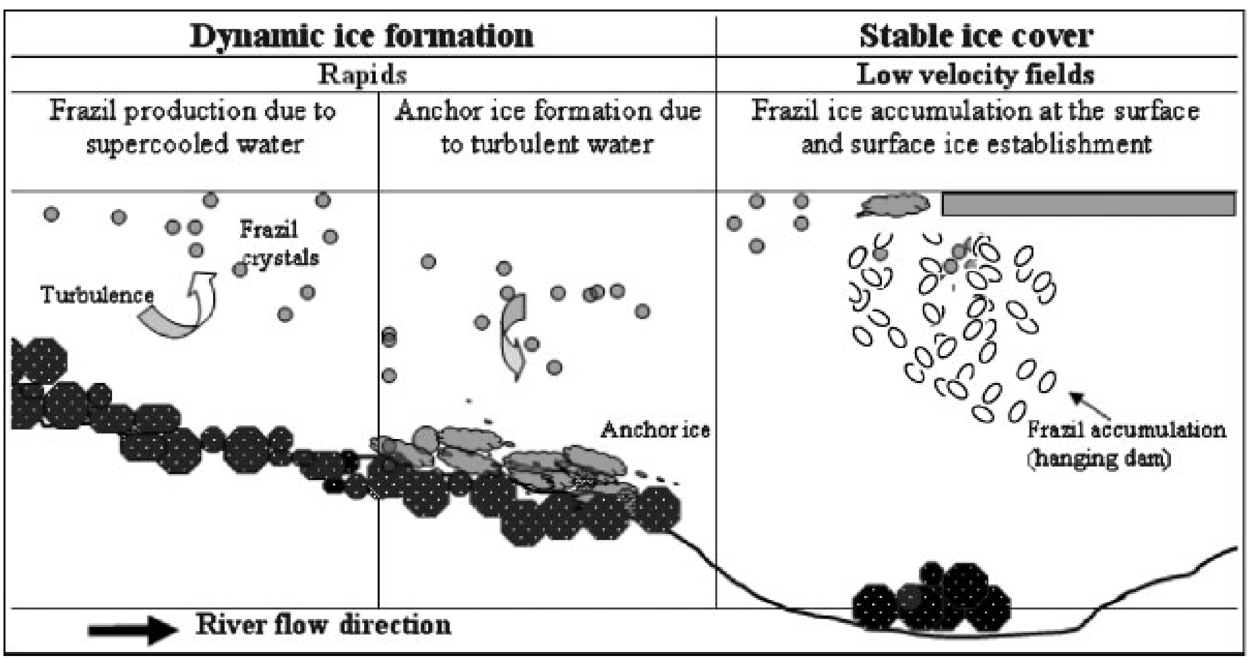


Table 2. Generalized ice processes over the course of winter in three types of rivers (from Huusko *et al.* 2007).

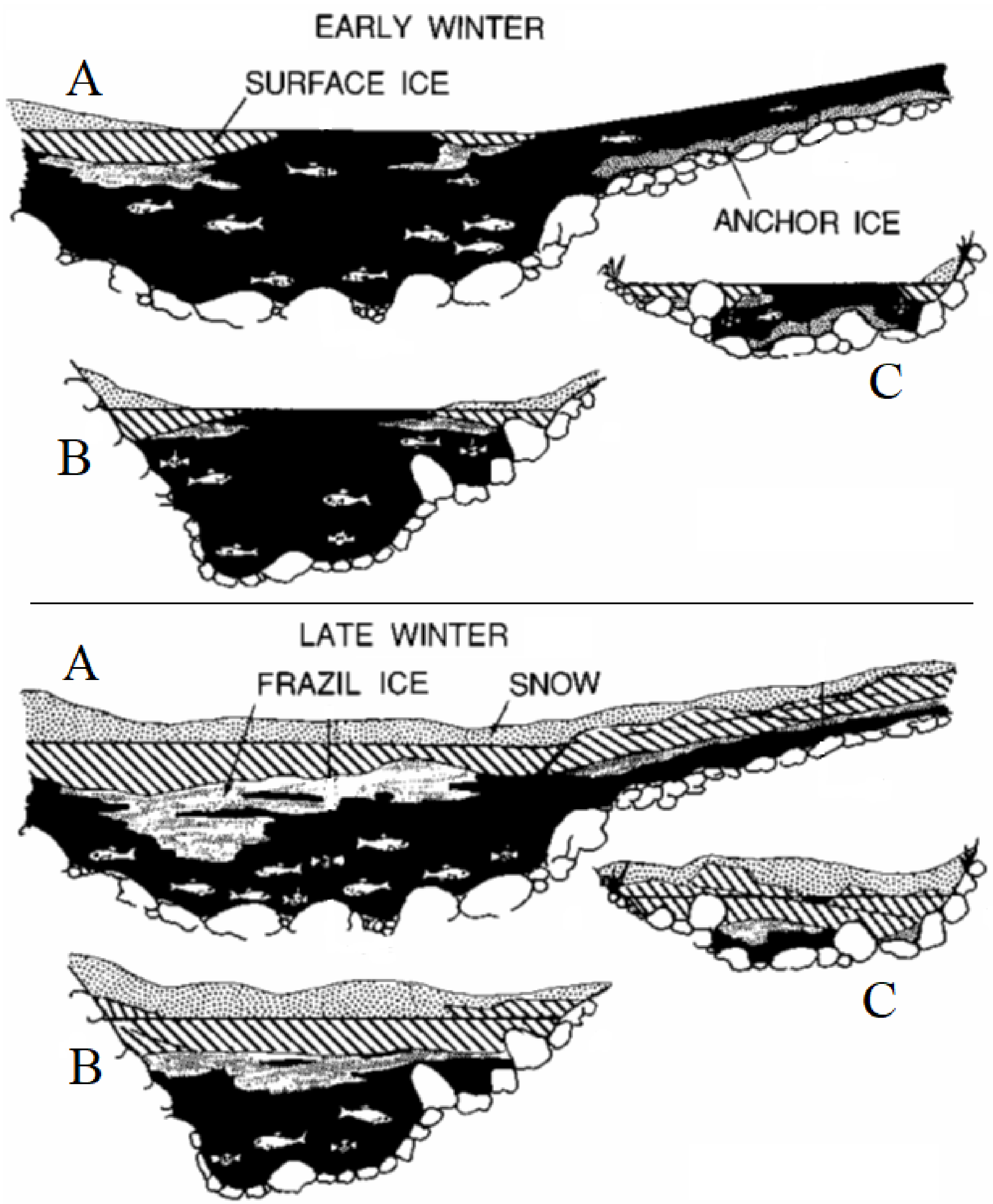
Ice regimes	River Type		
	Small, steep rivers	**Large rivers**	**Regulated rivers**
Early Winter Freeze-up	Border and skim ice Dynamic ice formation	Border and skim ice Ice over formation	Border ice Dynamic ice formation
Mid-Winter	Extended dynamic ice formation Anchor ice dams Local ice runs	Stable ice cover Dynamic ice formation in open riffles	Less surface ice Local ice runs Increased dynamic ice formation
Late Winter Ice break-up	Thermal ice break-up	Thermal ice break-up	Repeated mechanical ice break-ups throughout winter

3.1.1.2. Seasonal Changes in Stream Ice

Ice formation in streams typically begins in late fall when low air temperatures cool water to the freezing point. At this time, border ice forms along the stream margins and skim ice forms in areas with low velocity (Huusko *et al.* 2007). Typically, in large, low gradient rivers, static ice formation continues until the river is completely covered. In high gradient streams and river sections, dynamic ice formation occurs due to super-cooling and turbulence; thus, frazil ice, anchor ice, and frazil slush are common (Brown *et al.* 2011; Table 1, Figure 3). As winter progresses, icing conditions continue to be influenced by topography, weather conditions, and individual stream characteristics. Large, low gradient streams and rivers typically reach a stable state in mid-winter, with ice-covered surfaces and ice-free openings in riffles (Table 1, Figure 3). Small, high gradient streams may undergo an extended period of dynamic ice formation before reaching stable winter conditions (Huusko *et al.* 2007). The insulating effect of an early and deep snow cover on a stream will have a large bearing on surface ice formation during mid-winter for all stream types, including high elevation streams (Chisholm *et al.* 1987). Although, surface ice formation is normally prevented in turbulent, high velocity stream sections, partial or full ice cover may still form due to frazil ice accumulations. If snow accumulates on surface ice, the insulating effects may reduce the presence of anchor and frazil ice (Needham and Jones 1959). In streams where stable ice formation does not occur (e.g., high gradient, low to mid elevation streams, regulated rivers, or groundwater dominated reaches), ice may form and thaw repeatedly in response to variable air temperatures. In narrow, high elevation tributaries, snow can envelop the stream to form an insulated environment where no ice cover forms.

Ice break-up in spring is one of the most significant hydrological events of the year, though its effects can vary based on latitude and stream type (Prowse 1994; Prowse and Culp 2004). Ice break-up can be categorized as thermal or mechanical, but typically, both processes occur to some extent (Huusko *et al.* 2007; Brown *et al.* 2011). During thermal break-up, ice cover deteriorates with increasing temperatures and melts in place, and there may be no notable increase in discharge and little or no movement of ice. During mechanical break-up, an increase in stream discharge fragments the ice cover, which is then transported downstream by the current. In some cases, this can cause considerable scouring of the streambed and an increase in sediment transport (Cunjak *et al.* 1998; Prowse and Culp 2004), and ice jams may occur where ice fragments accumulate.

Figure 4. Representation of the change in habitat availability in a temperate A) large stream, B) small stream pool, and C) small stream riffle as a standard winter progresses and ice accumulates (from Cunjak 1996).

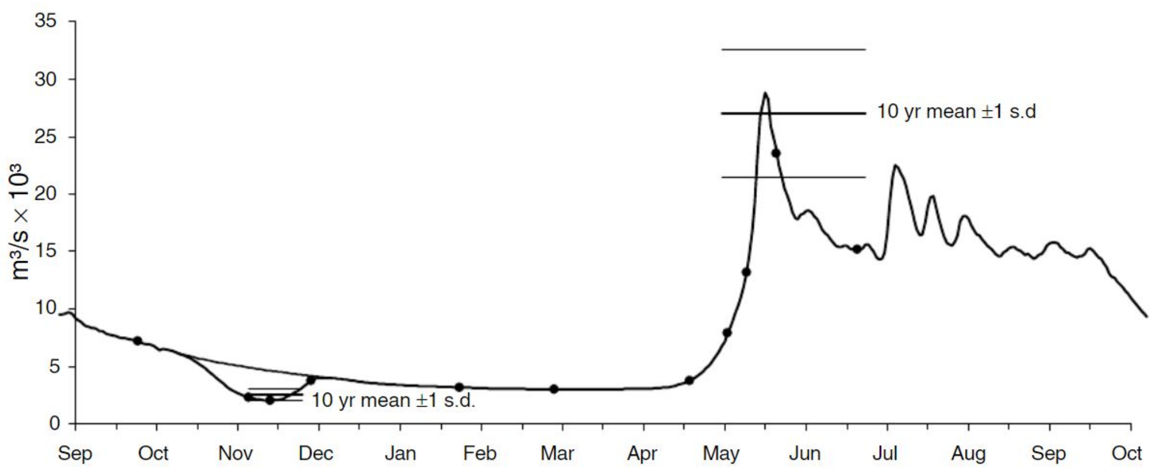


3.1.1.3. Hydrological Response to Ice Formation

A dynamic and interactive relationship exists between ice and stream hydrology. The ice formation processes are dependent on flow and channel characteristics (Section 3.1.1.1); conversely, stream hydraulics, such as discharge and stage, are affected by ice formation, presence, and break-up. Given the large number of factors involved, the relationship between ice and stream hydrology is complex and highly variable. Ice formation is known to produce many extremes in hydrological conditions, such as low flows and floods, and can substantially modify other geomorphic and chemical processes important in the aquatic ecosystem, such as the erosion and deposition of sediment and production and transport of oxygen (Prowse 2001). Similarly, seasonal trends in ice formation processes and discharge may be highly variable in accordance with multiple interacting factors, including rates of temperature change and precipitation patterns.

One well-documented relationship between ice and discharge is the discharge reduction (discharge depression) that can result downstream of ice formation (Hamilton and Moore 1997, Prowse 2001, Moore *et al.* 2002, Morse and Hicks 2005). The formation of ice puts water into hydraulic storage, meaning that the water transformed to ice is removed from the discharge. Also, ice build up and related constrictions in the channel cause increased resistance to flow (i.e., friction), which can alter streamflow characteristics (Prowse and Carter 2002, Morse and Hicks 2005). The timing, duration, and magnitude of the discharge depression is a function of multiple factors including discharge at freeze-up, air temperature (affecting speed of ice formation), and hydraulic channel characteristics. The discharge depression caused by ice formation can become exaggerated if groundwater input to the stream becomes blocked by ice formation. Such an effect can cause a discharge depression that cannot be accounted for by instream hydraulic storage alone (Hamilton and Moore 1996). Even when discharge depression does not occur, fluctuations in discharge may occur due to the dynamic nature of ice formation processes, such as backwatering and release of water behind ice dams (Moore *et al.* 2002). In contrast, discharge may dramatically increase during ice break-up. At this time, not only is water released from hydrologic storage and moves, along with ice, downstream, but the loss of ice concurrently reduces resistance to flow (Morse and Hicks 2005).

Figure 5. Mackenzie River at Arctic Red, 1995-1996 hydrograph with data from Environment Canada, 1996 (from Prowse *et al.* 2007). Mean annual fall low flow and spring high flow periods are indicated. Circles indicate the date of discharge measurements. The discharge depression in November is attributed to ice formation storing water locally, an effect similar to withdrawal of water.



Effects of ice on discharge can be particularly complex during freeze-up and break-up because discontinuous ice cover, and dynamic ice formation or break-up processes, result in complex flow physics (Morse and Hicks 2005). Alterations to discharge may also cause considerable changes to the aquatic environment. For example, accumulations of frazil or anchor ice can substantially alter discharge characteristics by raising the riverbed and smoothing out irregularities on the river bottom (Huusko *et al.* 2007). These changes can affect water levels and alter mesohabitat characteristics (Kerr *et al.* 2002, Stickler *et al.* 2007). If anchor ice dams or hanging dams form, they can have a dramatic effect on discharge and hydraulics. Ice dams can create blockages in the channel (Maciolek and Needham 1952, Stickler *et al.* 2008), which may cause flow to become constricted in some areas (e.g., increased velocities through pools; Cunjak and Caissie 1994, Brown *et al.* 2000). For example, ice dams can temporarily block discharge causing fluctuations in water levels, which can create backwatered areas that may then freeze over (Huusko *et al.* 2007). During spring break-up, severe and sudden flooding can occur upstream of ice jams, leaving downstream segments dewatered, and flooding can also occur downstream when ice jams release (Brown *et al.* 2011).

The impact of river ice on discharge and stage is even greater for extreme events than for average flow conditions (Beltaos 2000). Due to the potential for discharge depression, ice formation can cause a shift in the timing of low flow events, and this can be exacerbated by unusual weather conditions. For example, if unusually cold conditions occur early or late in the winter causing freeze-up at an unusual time, the resultant low flow period can shift from the more typical seasonal pattern (Conly and Prowse 1995). Thus, a discharge depression could be exacerbated if it coincides with the natural low flow period or if onset of unusually cold conditions occurs rapidly following warm temperatures when no surface ice or snow cover has accumulated. Extreme low flows can occur if a discharge depression caused by ice formation occurs at the time of minimum winter low flow. Extreme low flow events tend to be relatively short-lived: once ice cover is formed normal flow tends to resume (see Figure 5). Despite short durations, discharge depressions can have substantial effects on the aquatic environment and may have implications for water diversion or use (e.g., effective effluent dilution; Prowse 2001). For example, Maciolek and Needham (1952) observed diurnal isolation of side channels of a high-elevation stream during exceptionally cold conditions that caused hydrological responses from ice formation at night. However, short-lived extreme low-flow events are rarely documented due to difficulties in reliable data collection during dynamic flow periods and because the interpolation of infrequently measured (e.g., once a week or less is a common measurement interval in winter conditions) flows can mask extreme values (Prowse 1994).

3.1.2. Salmonid Overwinter Habitat Preferences

As water temperature decreases in autumn, conservation of energy becomes a priority for fish and they move into overwintering areas that favour reduced energy use (Cunjak 1996). This may require small-scale shifts, movements to different mesohabitat types, or relatively long-distance migration if suitable habitats are not available near the rearing location (Bjornn 1971, Huusko *et al.* 2007). In the UFR, some WCT occupy the same stream segment throughout the year; whereas, other individuals migrate between stream segments and may move up to 30 km between spawning and overwintering areas (Cope *et al.* 2016). Such movements generally coincide with a decline of water temperature below a critical temperature (Hillman *et al.* 1987, Jakober *et al.* 1998, Bramblet *et al.* 2002), although other cues may also be important in triggering movements. For example, changes in discharge, and possibly even changes in day length or prey availability, are thought to play a role in the timing of autumnal habitat shifts (Peterson 1982; Huusko *et al.* 2007).

The use of specific habitats during winter is an adaptation that salmonids in cold climates have developed to mitigate the negative effects of ice formation and the need to conserve energy during winter. Salmonids, including WCT, tend to move to habitat that provides cover and lower water velocities (Cunjak 1996, Hiscock *et al.* 2002, Huusko *et al.* 2007, Brown *et al.* 2011). Slow velocity areas used for overwintering may include bend pools (as opposed to step or plunge pools where frazil ice may be produced), backwater areas, off-channel ponds, logjams, swamps, side channels, beaver ponds, and tributaries, and the amount of available cover influences the number of fish that overwinter in an area (Tschaplinski and Hartman 1983, Bustard 1986, Swales *et al.* 1986, Meyer and Griffith 1997). Areas with these types of habitats are often limited in streams and rivers, so it is common for fish to be found in groups or aggregations where these habitats do occur (Huusko *et al.* 2007). Although fish generally move to lower velocity areas in winter, where hydraulically suitable water provides shelter from ice and predators, small individuals may also seek cover in interstitial spaces in the stream substrate (McMahon and Hartman 1989, Lindstrom and Hubert 2004). Mean water column velocity and depth used by *Oncorhynchus* spp. in winter is <0.3 m/s, and >0.4 m, respectively (Huusko *et al.* 2007, Baltz *et al.* 1991, Harper and Farag 2004).

Fish winter movement patterns can be complex and may be related to the stability of winter conditions (Huusko *et al.* 2007). Movement of fish in winter has been found to be greater in the presence of frazil and anchor ice than stable ice (Jakober *et al.* 1998, Brown *et al.* 1993, 2000, Simpkins *et al.* 2000), and more extensive movements occur in streams with frequent freezing and thawing events (Jakober *et al.* 1998). However, even static ice formation can cause channel constrictions that increase velocities, which may also reduce habitat usability and lead to movements and redistributions of salmonids (Whalen *et al.* 1999).

3.1.3. Effects of Ice on Overwintering Fish

The availability, quality, quantity and distribution of overwintering habitat is frequently limited in habitats occupied by WCT and, therefore, is disproportionately important habitat (Cleator *et al.* 2009). Winterkill can be a frequent and dramatic occurrence in northern productive lakes resulting in visible fish kills and carcasses (e.g., Greenbank 1945). Mortality of fish during winter in streams is usually less conspicuous and is not well-studied, but existing studies indicate that mortality during winter in streams is a substantial source of total mortality (Simpkins *et al.* 2000, Hoffsten 2003, Alexiades *et al.* 2012, Cope *et al.* 2016). Fish that do not reach suitable overwintering habitat in streams can suffer high mortality in winter. Even fish that do reach suitable habitats can experience high mortality under unusual winter conditions. Hoffsten (2003) measured a 77% reduction in trout density following an especially harsh winter with low temperatures and thin snow cover, demonstrating that winter mortalities in streams can reach extreme levels under some circumstances. Maciolek and Needham (1952) noted 50% mortality of trout in a high-elevation stream during a winter with low snow cover, yet very few carcasses were observed.

Winter mortality in stream habitat may be exacerbated by dynamic ice formation, which may cause increased flow velocity and displacement from, or loss of, optimal habitat or habitat features. Frazil or anchor ice accumulation can create constrictions and increase local water velocity to levels that are unsuitable for fish (Brown and Mackay 1995, Jakober *et al.* 1998, Whalen *et al.* 1999, Prowse *et al.* 2007). Frazil, anchor, or entrained pieces of surface ice can accumulate in fish habitat resulting in occlusion for short or long periods in winter (Chisholm *et al.* 1987, Brown and Mackay 1995, Jakober *et al.* 1998, Lindstrom and Hubert 2004). Frazil ice can also displace fish from their habitat by forming hanging dams or other accumulations (Brown *et al.* 2011). For example, hanging dams have been observed to fill more than 80% of the volume of pools (Cunjak and Caissie 1994) and contribute to locally high-water velocities (Brown *et al.* 2000). The formation of anchor ice can be extensive enough to limit access to important interstitial cover in coarse substrate and woody debris (Huusko *et al.* 2007, Brown *et al.* 2011).

Due to the potentially deleterious effects of dynamic ice formation, ice cover that forms in autumn or early winter can be important for subsequent overwinter survival (Jakober *et al.* 1998). Specifically, the development of a layer of stable surface ice is important for several reasons. Surface ice provides a platform on which snow can accumulate (Lindstrom and Hubert 2004). Snow cover acts as a thermal insulator, which stabilizes water temperature (Jakober *et al.* 1998). This prevents water from becoming super-cooled during bouts of cold, thus reducing the extent to which frazil and anchor ice form. Due to its insulative properties, snow cover also slows the thickening of surface ice and thereby prevents the reduction of habitat area for fish (Lindstrom and Hubert 2004). Surface ice can also provide cover that protects fish from bird or mammal predation, and Rainbow Trout have been observed to leave cover to feed and aggregate more readily in areas where ice cover exists than where it does not (Huusko *et al.* 2007). In addition, surface ice formation can offset anchor ice cover of interstices by providing additional complex habitat for small fish to hide in (Brown and Mackay 1995, Simpkins *et al.* 2000). The influence of groundwater can prevent surface ice from forming, which may allow for greater production of frazil or anchor ice (Brown 1999). Although snow cover has important insulative properties that protect overwintering habitat from deleterious ice formations, large amounts of snow cover over surface ice, especially wet snow, can also have deleterious effects by depressing surface ice, thereby reducing habitat availability.

Variable weather can be more detrimental to fish than consistently sub-zero air temperatures. Surface ice thickening and ice jam formation, which can reduce fish habitat area and/or occlude fish habitat, is more common during a prolonged freeze-up with repeated warm/cold cycles than during a stable freeze-up with constant sub-zero temperatures. Periodic warm spells can cause snow cover consolidation which reduces its insulative properties. Some reports document large portions of overwintering habitat becoming consumed by surface ice thickening (Chisholm *et al.* 1987, Brown *et al.* 2011). Consequently, in streams with substantial surface ice thickness (i.e., low gradient streams or pool sections) fish must reside in the deepest locations or in areas influenced by groundwater, which is typically warmer than surface water in winter (West *et al.* 1992, Brown *et al.* 2011).

In addition to coping with the physical effects of winter conditions, streams with variable temperatures and ice cover can be physiologically stressful for fish (Jakober *et al.* 1998). Thermal stress, which can impair swimming capacity and ability to fight infections (Huusko *et al.* 2007), occurs if fish cannot find habitats that provide stable temperature conditions (e.g., insulating surface ice, groundwater inflow, deep pools). Physiological stress from winter can be compounded by other stressors (e.g., heavy metals, synthetic organic compounds, pesticides, siltation, total suspended solids) and lead to an increase in energy demand, which may be lethal if there is a shortfall in metabolic energy reserves (Lemly 1996). Physiological effects of cold and ice are discussed and evaluated for the EoC in Bollinger (2021).

Dissolved oxygen depletion is another potential physiological stressor that may occur in lentic waterbodies due to compounding factors that may exist at freeze-up. Macrophyte and phytoplankton growth accumulates during the summer, but once water begins to cool these organisms die. Decomposition begins and is an oxygen-consuming process that can deplete dissolved oxygen in the water. Dissolved oxygen in lakes is replenished by exchange with the air and surface turbulence or from inflow streams; however, ice cover during winter prevents gas exchange and interior streams tend to be at their lowest flows. These conditions can result in a decline in oxygen, which can affect fish overwintering survival through hypoxia (Meding and Jackson 2003). Hypoxia is more common in productive shallow lakes that have and insufficient volume to buffer the effects of dissolved oxygen consumption from decomposition (Greenbank 1945; Magnuson *et al.* 1985). However, the literature review found few documented cases of winter hypoxia induced winterkill among trout, and none among Cutthroat Trout.

Fish mortality coincident with ice formation may be due to one or many mechanisms and determining cause can be difficult. In addition to effects on fish habitat and physiology discussed above, fish may be killed directly by ice through freezing, crushing, or entrapment. Fish may also be killed indirectly if ice increases their vulnerability to predators (potentially because they aggregate within a reduced habitat area or are physiologically stressed) or places unsustainable demands on energy reserves. Fish mortalities have been attributed to frazil ice (Simpkins *et al.* 2000; Cope *et al.* 2016; Maciolek and Needham 1952); however, this is poorly documented in the literature despite widespread acceptance of the effect. Fish populations are generally not regularly monitored, especially during winter, so there can be considerable uncertainty with respect to specific effects of winter conditions on a population.

3.1.4. Overwintering Habitats in the Upper Fording River

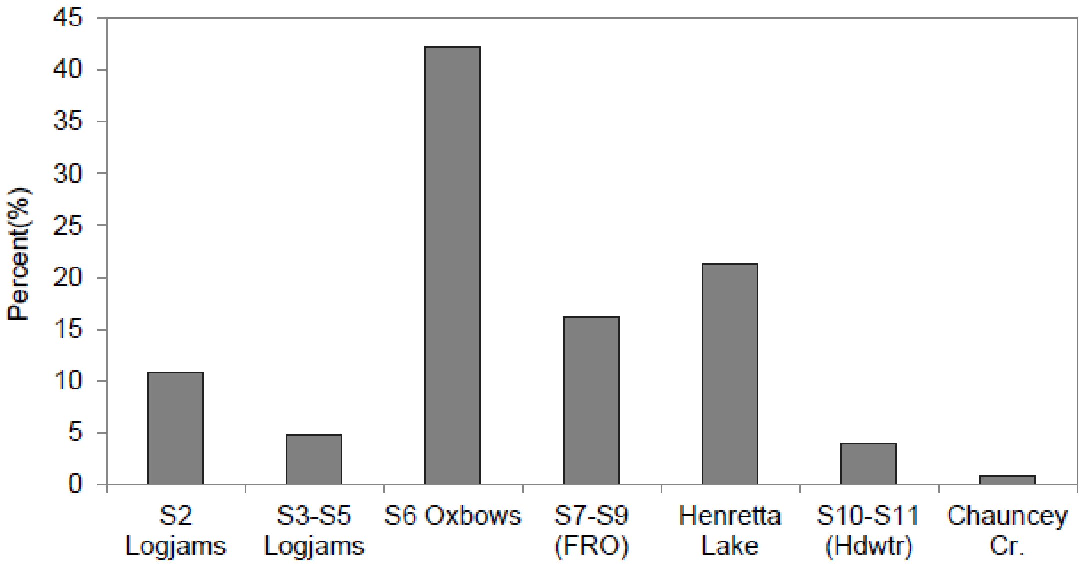
Each year WCT leave their preferred summer habitat to seek areas that provide shelter from the cold conditions that occur during winter. These movements typically occur from September 1 to October 15, before ice-forming cold weather begins; periodicities for key activities of WCT in the UFR are provided in Table 3. Selection of overwintering habitat types differs by life stage (Cope *et al.* 2016). In the UFR, larger-bodied WCT (>200 mm) tend to favour deep, slow-velocity pools and logjams, and areas downstream of groundwater influx where there is no anchor ice (Cope *et al.* 2016). Overwintering WCT juveniles prefer riffles (gradient of 1-3%) associated with substantial overhead cover (e.g., LWD) and coarse substrate, but also use deeper holding habitat (Cope *et al.* 2016). Juvenile salmonids studied in other systems are known to make use of interstices within coarse substrate where they can hide below the surface of the stream bed (Jakober *et al* 1998, Cleator *et al.* 2009). Therefore, low embeddedness, is considered a necessary substrate characteristic for juvenile overwintering habitat (Cope *et al.* 2018). In the UFR, the accumulation of mineral calcite on substrate contributes to embeddedness of substrate (Cope *et al.* 2016) and may therefore restrict use of interstices as cover for juveniles.

Table 3. Periodicity of Westslope Cutthroat Trout in the upper Fording River watershed.

Life Stage	Jan				Feb				Mar				Apr				May				Jun				Jul				Aug				Sep				Oct				Nov				Dec			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Spawning migration													■	■	■	■	■	■	■	■																												
Spawning																			■	■	■	■	■	■	■	■																						
Incubation (egg & alevin)																			■	■	■	■	■	■	■	■	■	■	■	■	■	■																
Summer Rearing (≥7° C)																											■	■	■	■	■	■	■	■	■	■												
Over-wintering migration																																	■	■	■	■	■	■										
Over-wintering	■	■	■	■	■	■	■	■	■	■	■	■																											■	■	■	■	■	■	■	■	■	■
Juvenile migration[1]																																																

[1] No defined periodicity

Figure 6. Frequency (%) of over-wintering radio tagged Westslope Cutthroat Trout within watershed features for the upper Fording River 2012-2015. From Cope *et al.* (2016).



Cope *et al.* (2016) identified temporal and spatial patterns of overwintering WCT adults in the UFR from 2013-2015 (Figure 6). Radio-tagged fish were monitored with telemetry over a three-year period and tracked in ~250 overwintering detection locations (where a radio-tagged fish was located during overwintering monitoring). Cope *et al.* (2016) grouped these locations into four areas, which make up roughly 20% of the total available habitat in the UFR. The areas in downstream order are: 1) Henretta Pit Lake; 2) river segments S7, S8 and S9 in the Clode Flats area, including the Multi-plate culvert pool; 3) river segment S6 oxbows; and 4) logjams and bedrock pools of upper segment S1 through lower segment S3 (Map 1). Brown and Mackay (1995) found WCT in the Ram River, Alberta, were not observed to overwinter immediately adjacent to major sources of groundwater inflow, but rather downstream several kilometers where groundwater had become better mixed with surface water. The same phenomenon has been observed in the groundwater-influenced sections of S6 (Cope pers. comm, 2020).

Within the four areas identified above, seven finer-scale sites were identified as important overwintering habitat (Cope *et al.* 2016). Portions of S6 known as the S6 oxbow pools (river km (rkm) 42-44) were used by the greatest percentage of tagged fish (~42% of tagged population). This area is defined by low-gradient sections with slow velocity, abundant cover, and is several kilometers downstream of groundwater influence (rkm 49). Old growth forest at this location provides bank stability and sections of deep channel incision where large woody debris or logjams are common. Henretta Lake is a common overwintering location (~22%), approximately 1 hectare in size;

it provides lentic habitat and a maximum depth of over 5 m. Sections S7-S9 are moderately utilized (~15%); these sections feature groundwater influence but are also within the FRO mine site and physical habitat has been influenced by the development. This stretch contains the Multi-plate plunge pool, the only deep habitat aside from Henretta Lake and the only deep pool in a six kilometer stretch of the Fording River; however, it has little cover, no groundwater inflow, and suitability is limited. The S2 logjams (10%) are also important and are composed of several large, deep pools with abundant cover provided by large woody debris. Other finer-scale sites identified during the three-year study period were documented to provide overwintering habitat for roughly 11% of the radio-tagged WCT: the S3-S5 logjams, S10-S11 sections, and Chauncey Creek.

In 2013, a large flood occurred that affected channel morphology of a number of streams in the region. The flood disturbed riparian areas, moved large woody debris, and formed new stream channels. Overall, the deep, slow-velocity pools preferred by WCT for overwintering in the UFR appeared to remain largely intact. Henretta Lake was affected by some infilling; however, this area was subsequently targeted with habitat improvements that backwatered the lake and enhanced the area following the effects of the flood. Thus, despite the flood, the S6 pools, Henretta Lake, and other important overwintering habitats in the UFR appeared to remain largely intact and functional (Cope *et al.* 2016).

3.1.5. Effects of Connectivity on Overwintering WCT in the UFR

Interruptions to access of suitable overwintering locations have been previously identified as a potential problem for WCT in the UFR by Cope *et al.* (2016) and in other EoC reports, (Harwood *et al.* 2021, Healey *et al.* 2021) and may have implications for WCT overwintering survival. Culverts on the mainstem and in tributaries have been identified as barriers to movement and there are specific concerns related to passability on the mainstem at Henretta and Multi-plate culverts (Map 1, Map 3). Portions of the UFR mainstem become dewatered in the fall, or have been observed freezing solid (Minnow and Lotic 2018); these drying reaches will also act as barriers to upstream and downstream movement when depths become too shallow for passage.

Within the UFR, migratory individuals may travel up to 30 km from overwintering areas to spawning locations, and then return to the overwintering areas between late August and October. Resident individuals travel less than the migratory fish, but can still move up to 5 km annually (Cope *et al.* 2016). If a loss of connectivity occurs while fish have moved to their summer rearing locations then access to the usual overwintering location could be blocked. We assume that individuals that cannot access their preferred overwintering area would seek another suitable overwinter habitat. Given the uncertainty in realized migrations, we have considered both the possibility that WCT had access to suitable overwintering locations and the possibility that connectivity was interrupted and forced WCT to overwinter in less-than-ideal locations.

3.2. Overwintering Weather Conditions in the Upper Fording River During the Decline Window

3.2.1. Air Temperature

The UFR is a moderately high elevation watershed in the Canadian Rockies and regularly experiences cold weather from November through March. The coldest months are typically December and January, which averaged -11.2 ºC and -10.2 ºC, respectively, during the period of record (1970-2018). In contrast, February and March were warmer and averaged -7.9 ºC and -4.1 ºC (EC Cominco, 1970-2018). Average daily temperatures can often reach below -20 ºC and warm temperatures above 0 ºC can occur for short periods.

Winter 2017/18 had average air temperatures that did not greatly depart from normal. Late November had a warm period and sustained cold did not begin until December. There were three occasions where air temperature went below -20 ºC (minimum daily average: -27 ºC); however, in each case the temperature drop was not sudden, and was preceded by conditions below -5 ºC (Figure 7). The pattern of alternating between moderately warm and moderately cold persisted until April.

Air temperature in 2018/19 was not typical of average conditions. The winter began with mild conditions; from early November until late January daily average air temperature often reached above 0 ºC and only twice dropped below -15 ºC. Analysis of differences between 2019 temperatures and the preceding historical record were conducted by fitting general linear models in the R package lme4 (Bates *et al.* 2015) of the form:

$$Temperature \sim Period$$

Where *Period* divides daily water temperature data between 2019 and all preceding years (1970-2018). Models were fitted for each of the two months in question and statistical significance (p-value) of differences in *Temperature* between 2019 and preceding years was then calculated. Because of issues with heteroscedasticity due to the high variability of temperature conditions, we obtained p-values through permutation tests (10,000 permutation), which do not rely on theoretical distributions and therefore do not have the parametric assumption of homoscedasticity. January 2019 was warmer than the historical median (Table 4) ($p < 0.047$), and temperatures repeatedly reached the 95th percentile of the historical record. However, a sudden and large change in air temperature occurred from February 2 to 3 when the average air temperature dropped from 0 ºC to -22 ºC (maximum to minimum of 2 ºC to -25 ºC; Figure 8). The cold weather persisted through the remainder of February, with minimum daily lows below -20 ºC occurring 19 out of 28 days in February. February was significantly colder than the average February since 1970 (p=0.0001). The cold air temperatures persisted until early March, and the coldest day of the year occurred on March 2 (-24 ºC). By mid-March, average daily air temperature began to climb steadily, and reached 5 ºC by late March.

Figure 7. Air temperatures at the Fording River EC Cominco (elev. 1587 m)/ FRO_WWT (elev. 1579 m), for the years of 1970-2019.

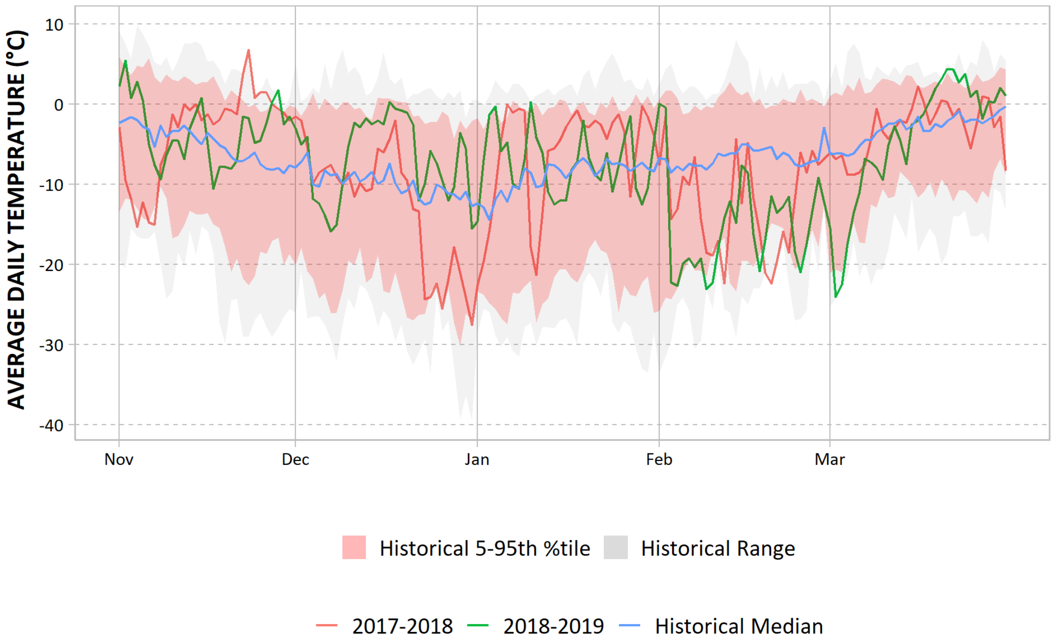


Figure 8. Range of daily minimum and maximum air temperatures (1970-2019) and daily minimum and maximum for winter of 2018/19 at Fording River EC Cominco (elev. 1587 m)/ FRO_WWT (elev. 1579 m).

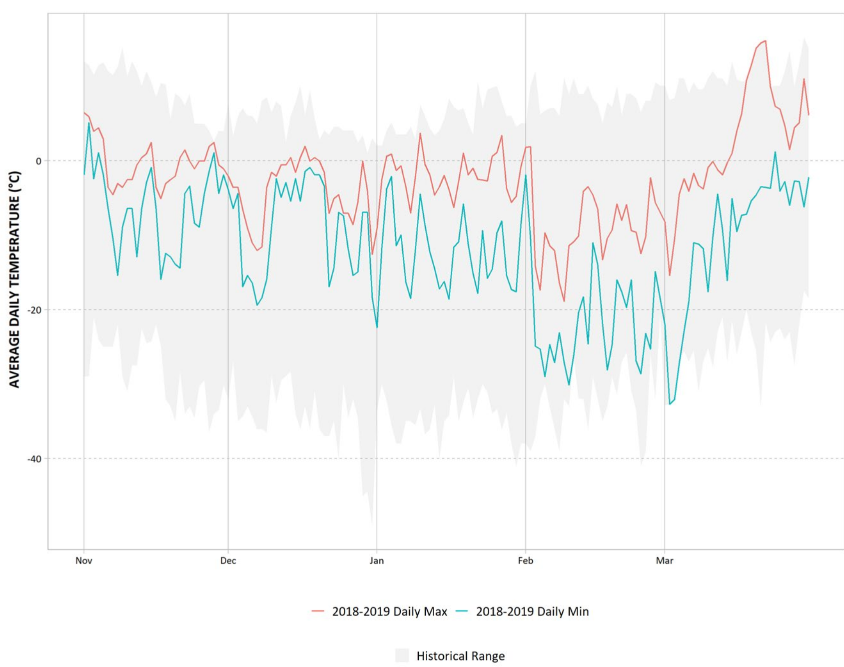


Table 4. Permutation testing results for comparison of mean temperature in January and February 2019 in relation to historical means (1970-2018).

Period	Mean value (ºC)	Std Error	P-value
Jan-19	-7.4	1.33	0.047
Jan-Historical	-10.0		
Feb-19	-15.3	1.21	0.0001
Feb-Historical	-7.7		

3.2.2. Snow Accumulation and Snow Water Equivalents

Snow in the UFR can occur from September to May, although accumulation typically occurs between November and April. Snow accumulation in 2017/18 at FRO_CSP was the second highest of the six winters recorded and totaled 373.6 cm, which is 126% the period measured (the average for 2013-2019 was 297 cm) (Table 5). Snow began in November when there was above average (2013-19) snow accumulation. December had lower than average snow accumulation (2013-19), but January, February and March were all above average (2013-19). The Morrissey Ridge station recorded a similar pattern in SWE: an early spike occurred in November, SWE was then below average through December and early January, and SWE returned to normal for the rest of the winter (Figure 9).

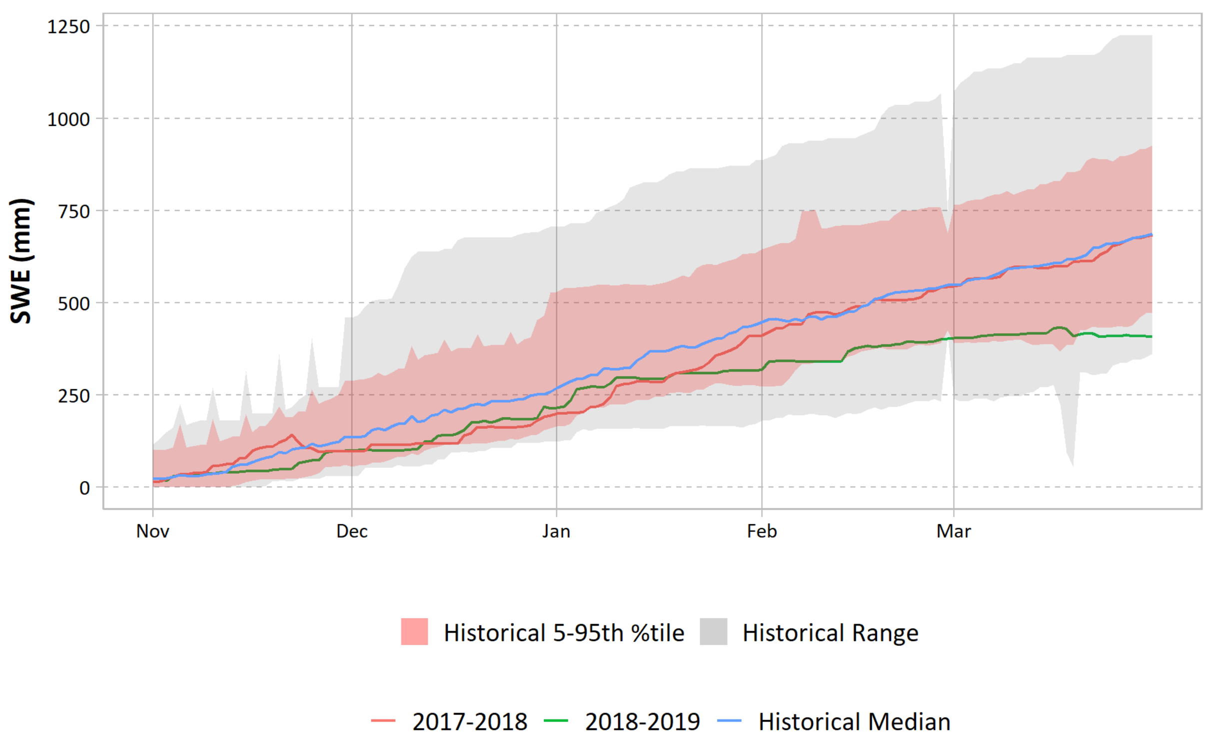
The winter of 2018/19 had less snow accumulation than in average years (2013-19). At FRO_CSP, November is usually the month with greatest snowfall with an average of 85.7 cm of snow, but in 2018/19 only 25.8 cm fell. December of the 2018/19 winter had greatest snow accumulation among the years reviewed, but the rest of the winter (Nov-Mar) was dry and the total snow accumulation for these months was far below normal (2013-19). The total snow accumulation for the year was 185.8 cm, or 62.4 % of the average (2013-19). At Morrissey Ridge, 2018/19 was a below-average year for SWE. SWE accumulated more slowly than normal and remained near the 25th percentile until mid January. By February, the SWE was well below the 25th percentile and remained below it for the rest of the winter.

Table 5. Total monthly and annual snow accumulation at FRO_CSP (Elev. 1690 m) from 2013-2019 (Nov-Mar).

Total Snowfall (mm) at FRO_CSP						
Year	November	December	January	February	March	Total
2013-2014	96.7	32.8	71.5	64.1	**112.0**	**377.1**
2014-2015	**108.6**	28.2	59.5	54.5	47.3	298.1
2015-2016	**128.9**	54.2	31.2	31.3	40.3	285.9
2016-2017	40.0	46.4	20.1	**84.0**	73.6	264.1
2017-2018	**115.0**	20.4	83.7	68.3	86.2	373.6
2018-2019	25.8	**71.2**	29.2	44.2	15.4	185.8
Average	85.8	42.2	49.2	57.7	62.5	297.4

Notes: Shaded values denote maximum for each month, and bolded values denote annual maximum (Nov-Mar)

Figure 9. Winter (Nov-Mar) snow water equivalents at the Morrissey Ridge weather station (elev. 1860 m).



3.2.3. Water Temperature

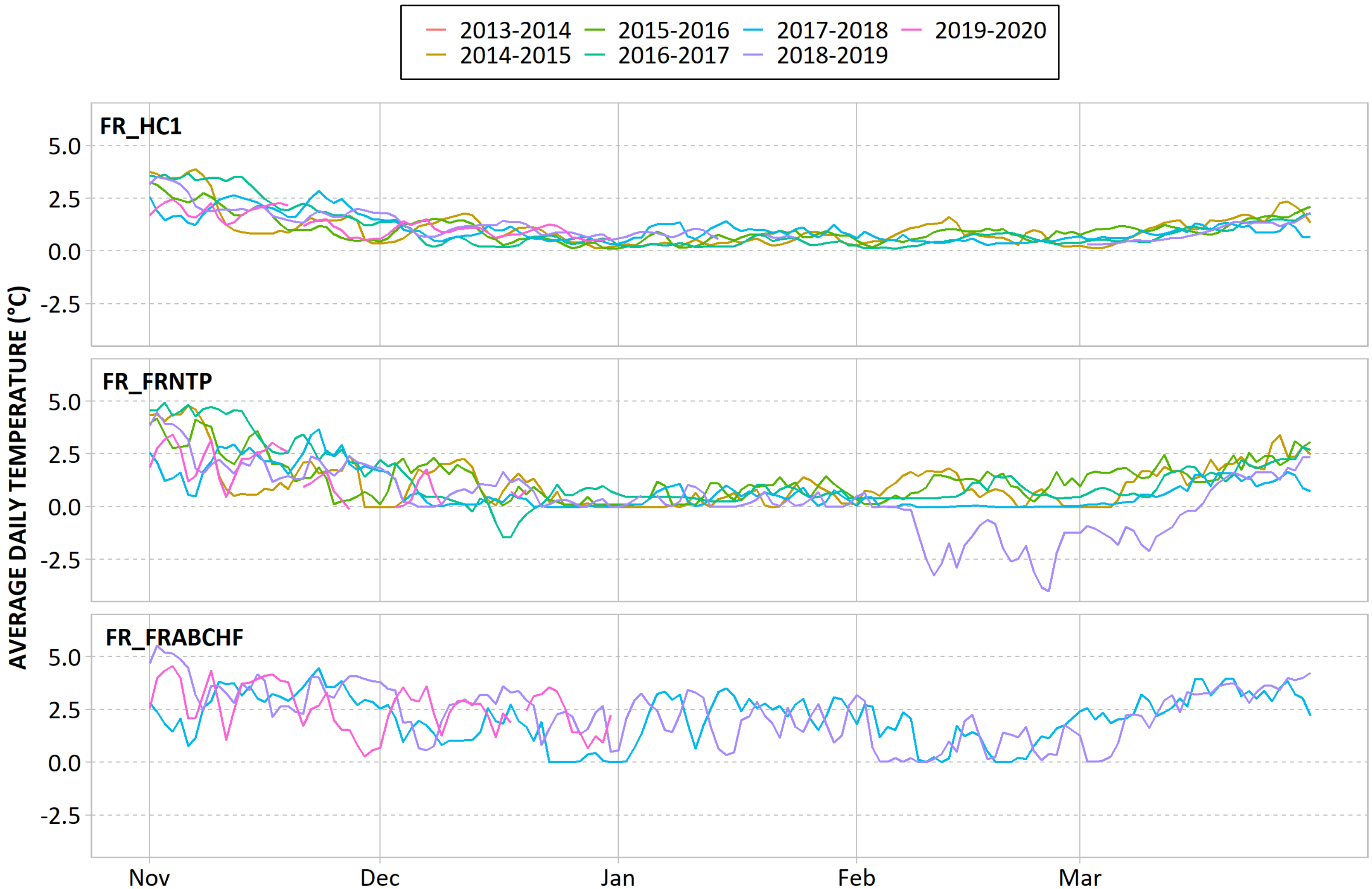
For the period of record, water temperature in the UFR generally hovered between 0 and 2 ºC (Figure 10); however, cold air temperatures can cause the water temperature to sink below 0 ºC at which point it is possible for ice formation to occur. Water temperature is generally correlated with air temperature, but there are several factors that can decouple this relationship, including surface ice accumulation, snowpack, duration of cold air temperatures, streamflow (width, depth, velocity) and groundwater inputs (groundwater tends to be warmer than surface water in winter).

The UFR is a complex system that contains multiple tributaries and has groundwater inputs and inputs from lakes, mining pits and ponds. It is logical to expect that the stream would warm as it drops in elevation; however, for both years examined, the coldest temperatures occurred at the FR_FRNTP gauge, which is mid elevation in the UFR. Next warmest and least variable was FR_HC1, which is immediately below Henretta Lake. FR_FRABCHF records were notably warmer in winter, and is known to receive groundwater input (Map 4).

Water temperatures from all three gauges (FR_HC1, FR_FRNTP, FR_FRABCHF) for 2017/18 fell to between 4 ºC and 2 ºC near mid-November and by early December stabilized to between 1 ºC and 0 ºC. An exception was at FR_FRABCHF, where temperature varied from nearly 3 ºC to 1 ºC, before dropping to 0 ºC for a sustained period. At FR_HC1 water temperature varied between 2 ºC and 0 ºC by January and remained below 2 ºC into April. The water temperature at FR_FRNTP remained between 1 ºC and 0 ºC from January until mid-March. At FR_FRABCHF there was variation in water temperature through January, with swings from 3.5 to 1 ºC, and in February water temperature dropped to 0 ºC twice before warming to 4 ºC in March.

Water temperature patterns were different in 2018/19. At FR_HC1 and FR_FRNTP mild temperatures were recorded at the beginning of the winter, but there was a steep dip to near 0 ºC in early December and after which temperature varied between 0 and 1 ºC. At the same time as the February 2019 drop in air temperature was recorded (described in Section 3.2.1) water temperature abruptly dropped below 0 ºC and reached -4 ºC at FR_FRNTP (this could indicate slush or ice around the water temperature sensor). Water temperature at FR_FRABCHF was notably variable from mid-November until early January with regular swings from 3 ºC to 0.5 ºC; however, during February the water temperature dropped to zero for roughly half the days until early March. We speculate the large magnitude of variation at this location was due to the complex interaction of warmer groundwater and colder surface water, both of which may vary over time.

Figure 10. Water temperature records from 2017/18 and 2018/19 at FR_HC1 (top, elevation 1712 m), FR_FRNTP (middle, elevation 1640 m), and at FR_FRABCHF (top, elevation 1555 m).



3.2.4. Discharge and Stage

The UFR follows a seasonal discharge pattern of low flows in the winter when precipitation is stored as snowpack, followed by peak flows in the late spring and early summer as snowmelt occurs, and then a lengthy decline in discharge from late summer through winter (Wright *et al.* 2021). During winter months it can be difficult to accurately measure stage at hydrometric gauges and transform the stage data to discharge estimates because stage-discharge curves are error prone in the presence of ice (RISC 2018). Because discharge at continuous hydrometric stations is calculated from measured stage and is often "adjusted" during the hydrometric QA processes, we examined the seasonal discharge trend, but close examination focused on variation of stage rather than stage per se. We examined winter hydrological data to determine: 1) whether the winters of 2017/18 and 2018/19 had abnormally low discharge; 2) the magnitude and timing of storage depletion effects; and 3) whether periods exist of highly variable stage, which may indicate ice effects on stage readings.

Water Survey Canada records from the Fording River at the Mouth (NK018) and Elk River at Fernie (NK002) hydrological gauges between 2010 and 2019 indicated that large swings in stage are common at gauges in the winter (defined for this report as November through March) during the years examined (2010-2019), and nearly all winters in the years reviewed had spikes in stage and discharge. The winter of 2017/18 was no exception. During this year, discharge at NK018 gauge was slightly low relative to other years while discharge at NK002 appeared normal. For the remaining winter months (Dec-Mar), extreme variation was present for both stage and discharge, beyond what could be expected based on the little melt water that should have occurred at this time. Data from the NK002 showed a similar pattern with a small, brief decline in discharge in November and a spike during cold weather in late December; however, winter 2017/18 was notable for a prolonged high stage from January through March. Such a prolonged high stage was only present in such magnitude one other year (2011/12) and was likely due to backwatering from ice at the gauge location.

The winter of 2018/19 generally had average discharge at both gauges through the winter, with large variations in stage over short periods. There was a stable flow in November but this was followed by a dip in stage and discharge in early December (at both gauges) that was possibly caused by the occurrence of a storage effect. A period with little variation in discharge occurred from mid-December until late January. Concurrent with the cold air temperatures in February (Section 3.2.1) rapid large-magnitude variations in stage were recorded at NK002, with an initial dip that resulted in the lowest discharges of the year. This was followed by a large spike where the stage reading increased from 1.75 m to 2.75 m in a matter of days. NK018 did not show an initial dip but had variable stage readings with four spikes that varied between 1.5 m and 1.9 m and persisted until the end of March. Given the spikes in stage recorded at both gauges, it is likely that ice formation was affecting the entire UFR region. These large variations in stage are not unusual in comparison to the historical data; however, in almost all previous cases examined between 2010 and 2019, the extreme variation in discharge and stage began in December or early January.

There are additional hydrology gauges within the UFR at FR_HC1, FR_FRNTP and FR_FRABCHF; however, data from these gauges were not reviewed because periods with abnormal stage/discharge patterns had been already been removed during the QA process.

Figure 11. Maximum daily discharge and stage from the WSC hydrometric station located at the Fording River mouth (NK018, elevation 1227 m) for November - March of each winter from 2010/11 through 2018/19.

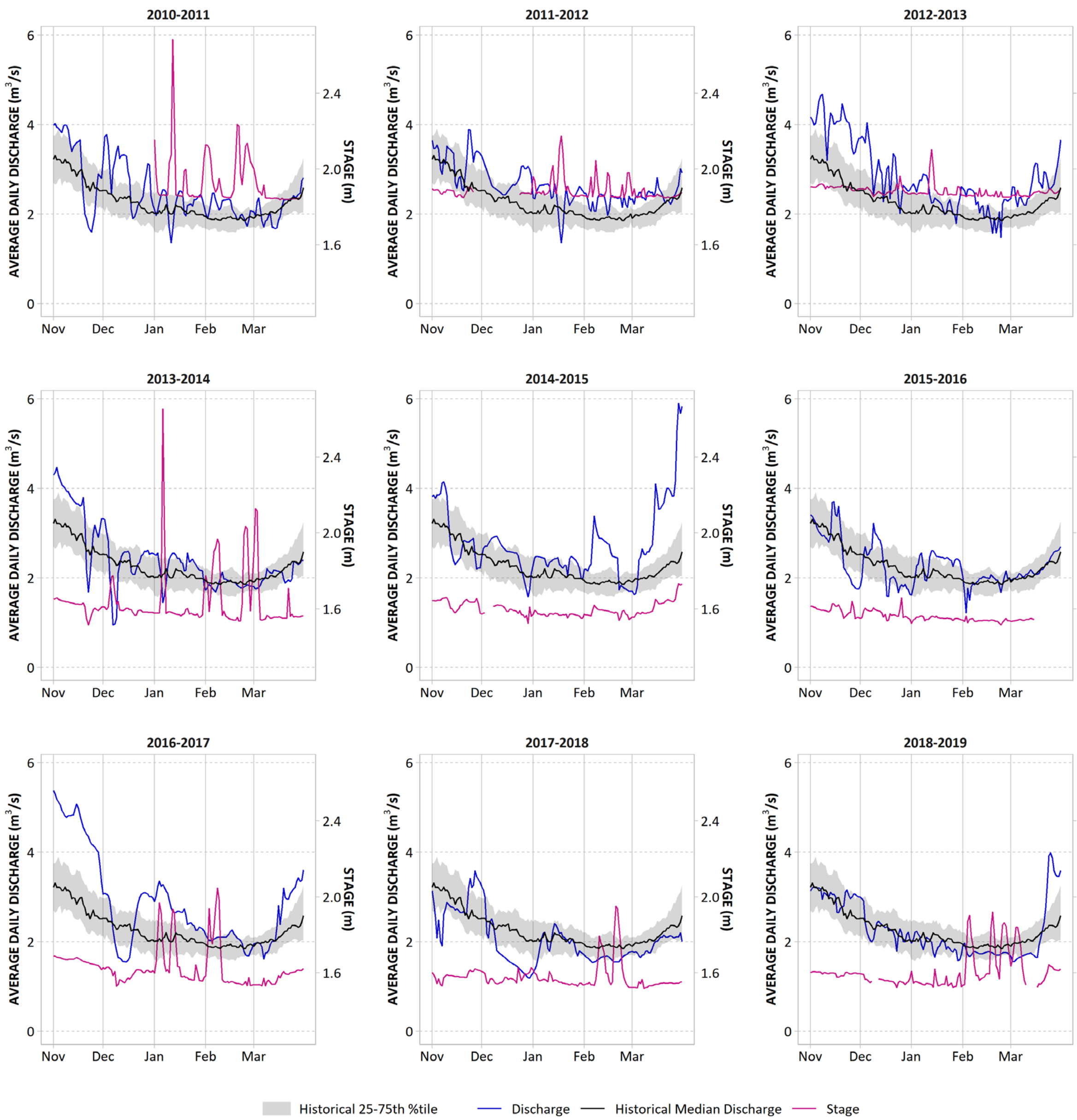
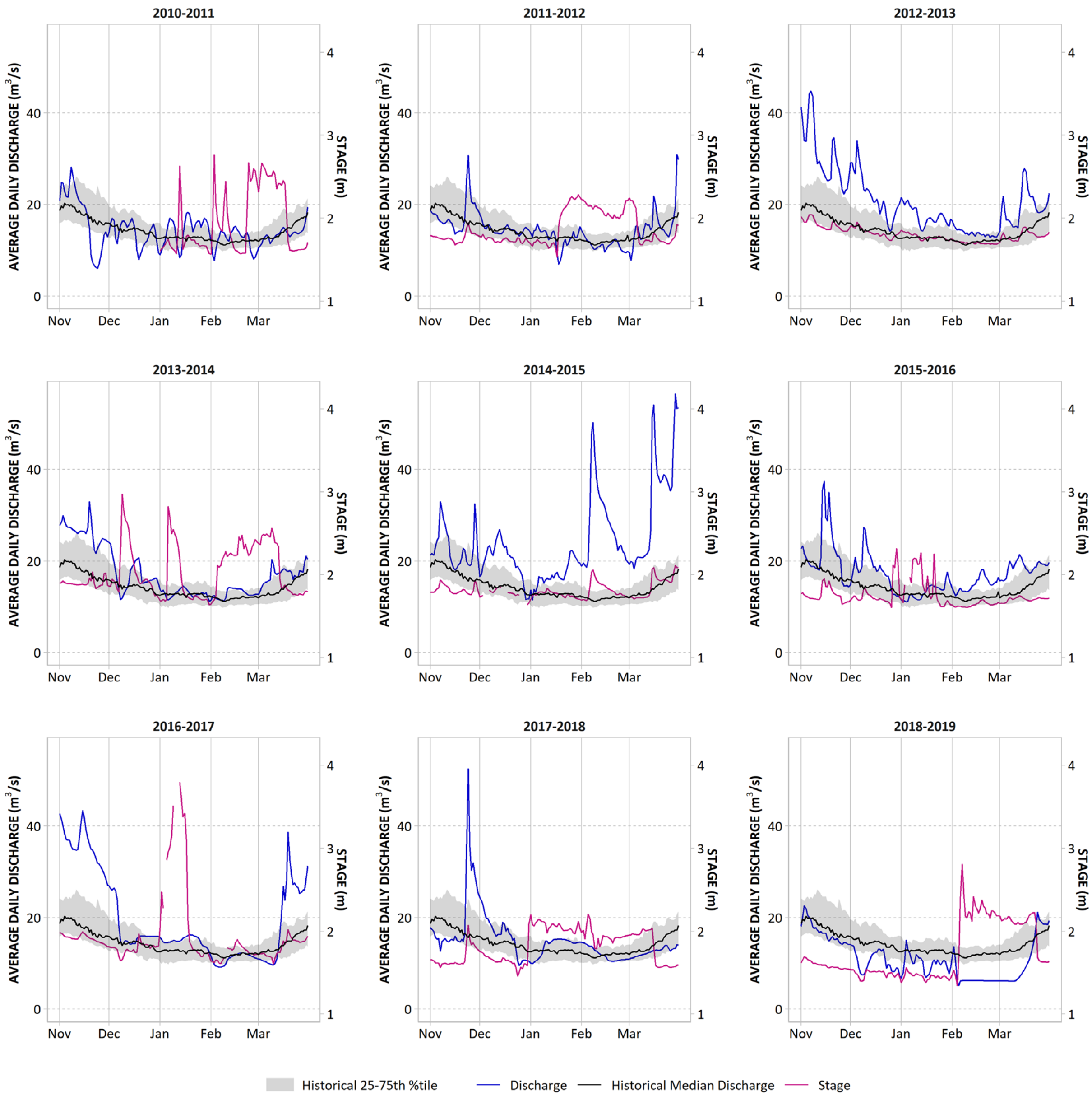


Figure 12. Maximum daily discharge and stage from the WSC hydrometric station located on the Elk River at Fernie (NK002, elevation 974 m) for November - March of each winter from 2010/11 through 2018/19.



3.3. Winter Conditions in the Upper Fording River in 2018/19

3.3.1. Weather and Hydrologic Observations

Air temperature records in the winter of 2018/19 indicate that conditions may have favoured more rapid and greater amounts of ice formation than usual and that ice formed later within the typical overwintering period than normal. A large magnitude air temperature drop occurred in early February in this winter. The extreme air temperature drop was recorded in the daily air temperature extremes record at the EC Fording River Cominco weather station as a 27 ºC temperature drop between February 2 and 3 (Figure 8).

To determine the rarity of a change in average daily temperature of this magnitude during the winter (Nov-Mar), the return period was calculated using the following formula $Tr = \frac{1}{p} = \frac{n+1}{m}$ where *Tr* is the return period, *p* is the probability, *n* is the sample size, and *m* is the rank number of the temperature change in the period examined. Both an empirical and Gumbel distribution were modelled, based on differences in daily average temperature across a three-day moving window. While the early February temperature drop was substantial, changes of this magnitude occurred roughly once every 8.5 years (empirical model; 8.7 years for Gumbel model) in this region, for the period from 1970 to 2019. Since 1970 there have been five changes of greater magnitude, all of which occurred prior to 2000. There have been two recent years where slightly smaller changes occurred (2013 and in 2014).

The effects of large swings in air temperature seem to be reflected in the water temperature and discharge/stage records. In the four years examined (2014/15 to 2018/19) the water temperature at FR_FRNTP went below zero only twice, once for a short period with the extreme cold in December 2017 and once for a prolonged period during the cold weather in February and March 2019. In February 2019, the stage readings at both NK018 and NK002 gauges became highly variable with large spikes in stage. It is difficult to determine from the temperature and stage records exactly what was occurring during this time period, particularly in high-use habitats in the UFR; however, we speculate that substantial ice formation was occurring at the hydrometric gauges.

There are several conditions that could contribute to making the effect of the air temperature drop in 2018/19 more dramatic than usual for ice formation in the UFR. First, the air temperature leading up to the drop in February was unusually warm (Figure 8). This would likely have prevented surface ice formation that insulates the stream against extreme weather. Second, streamflow in the UFR is variable and in some places dewaters (Map 3) during low flow periods, and this may have occurred as early as September in 2018 (Minnow and Lotic, 2019). Thus, any isolated pockets of water that remained in the drying reach would be exposed to freezing conditions and make poor overwintering habitat. Third, groundwater input is known to occur in the UFR around S6. Since groundwater is typically warmer than surface water in winter, groundwater inflows can reduce initial ice formation and keep a stream open. Downstream from groundwater inputs the stream will cool, but exposure to extreme cold air temperatures may allow supercooling of surface water and formation of frazil ice (see Section 3.1.1.1). Thus, the presence of groundwater could lead to increased dynamic ice formation during extreme air temperatures drops by preventing more typical surface ice formation that would otherwise help to moderate water temperatures when extreme air temperature drops occur.

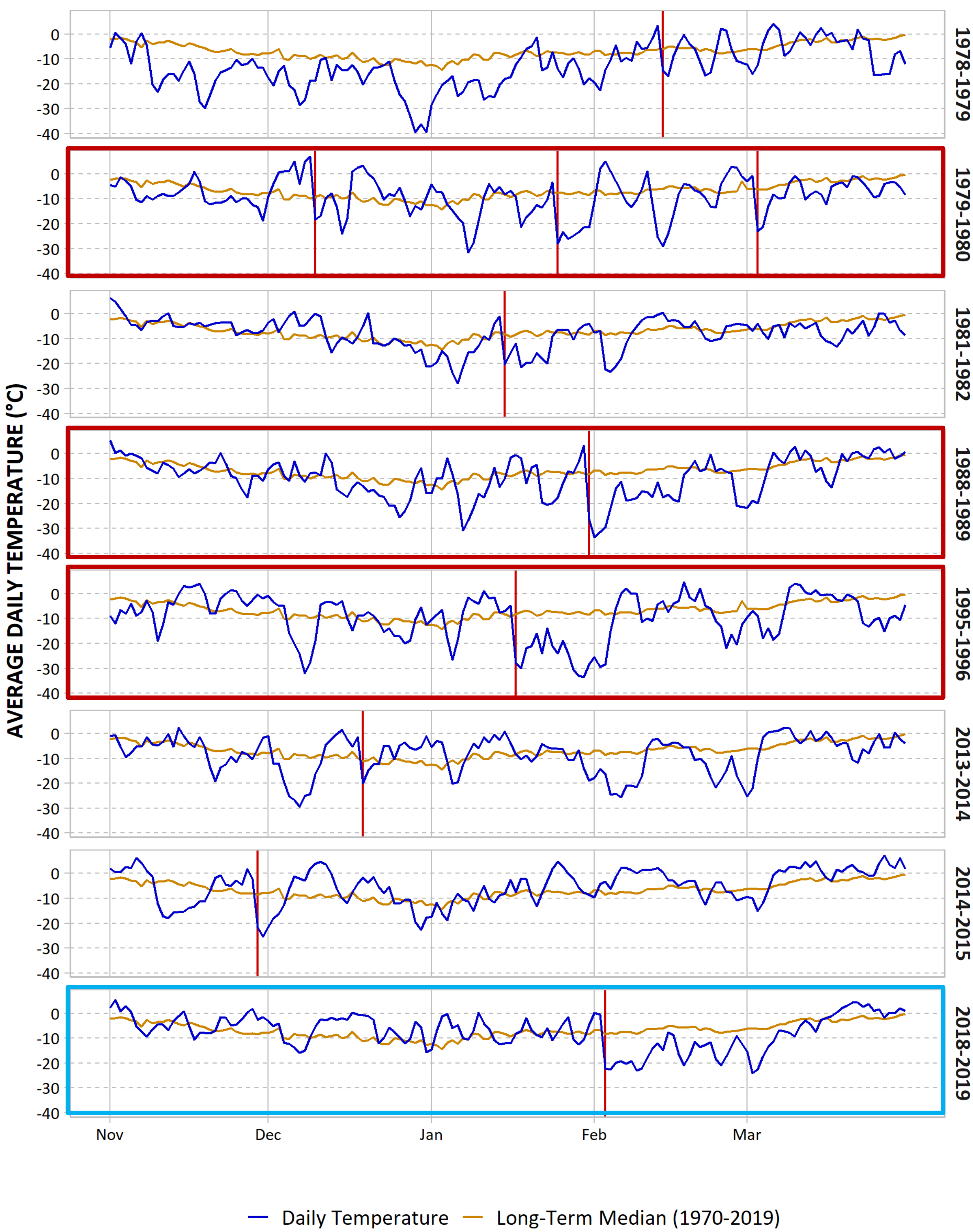
3.3.2. Air Temperature Changes of Note (1970-2019)

During the available record (1970-2019), there were five rapid air temperature changes that exceeded the magnitude of the drop in early February 2019 (Figure 13). These took place once each in the winters of 1988/89 and 1995/96, and on three separate occasions in the winter of 1979/80. In

January 1989 a 39 ºC drop (maximum to minimum) occurred over three days and was the greatest of the 49 years examined.

Three unique features related to air temperature were observed for the 2018/19 winter in relation to the other winters in which temperature drops of a large magnitude occurred. First, the winter of 2018/19 was the only winter during which air temperature reaching below -20 ºC did not occur prior to the sudden temperature drop events (sub -20 ºC occurred multiple times in the other winters prior to the high magnitude drop). Second, the drop in 2018/19 occurred later in the year than for most other winters (all except in 1978/79 and 1979/80); in general, stream discharge is lower later in the winter, which could allow ice formation to occupy more of the available habitat than at higher flows. Third, when examined in relation to the historical median, air temperature in 2018/19 began with a sustained period of above median temperatures. After the February transition, the air temperature was consistently much lower than the median. This contrasts with other years, where variation was often greater.

Figure 13. Average daily air temperature (blue line) at Fording River EC Cominco/ FRO-WTT for the top 10 -drops in air temperature (vertical red line) over a three-day period. Years with drops greater in magnitude than 2018/19 are outlined in red, and 2018/19 is outlined in blue.



3.3.3. Photographic Evidence of Ice Formation in 2018/19

As part of Teck Coal's monitoring efforts of effectiveness of offsetting habitat, 10 game cameras were installed in spring 2017 that were set to take one daily photo at 13:00 and recorded the instantaneous air temperature. All of the cameras were located in a stretch of stream between Henretta Lake and the FRO offices. Six of the cameras were functioning and were not obscured during the February 2019 temperature drop. Of the six cameras, five appeared to show substantial ice formation in the days that immediately followed the temperature drop on February 3 (cameras 1,3,6,7,8). One (camera 4) shows some surface ice formation but less ice is evident than that recorded by the other cameras. Representative views were compiled and are shown in (Figure 14) and although the photos taken may not be representative of conditions in stretches of river downstream of the cameras, the photos nevertheless provide a good indication of surface ice conditions in this area. The photos indicate rapid surface ice formation occurred within 24 hours; they cannot provide evidence of frazil ice or anchor ice. Several of the cameras that are directed towards riffle mesohabitats appear to show a noticeable reduction in streamflow in February 2019. For comparison, conditions on the same date in 2018 are also provided.

Photographic evidence of ice conditions is contained in a record of photos taken approximately once monthly (2017-2020) at set photo points for FRO LAEMP monitoring (Minnow and Lotic 2019). Three sites were photographed: GH_FR3, FR_CP1SW and FR_FRABCH (Map 2), and the photos taken during the winters of the decline period are compiled in Appendix A (winter 2019-20 was included for context). The photo records show an apparent pattern of ice formation in 2018/19 that exceeds that in winter 2017/18 or 2019/20, and in some instances in February/March 2019 drying of the entire streambed occurs. The drying evidenced in the photo record is at the southern end of the normal southern drying reach (Figure 16) documented in the 2019 LAEMP report (Minnow and Lotic 2020).

Photos were also collected during invertebrate sampling in the UFR from February 12-14, 2019. The photos show a variety of conditions where most riffle habitats appeared open (Figure 17), but pool habitats were ice covered (Figure 18). In some cases, the entire water column was frozen to the substrate (Figure 18). Instances of entrained frazil ice or anchor ice were visible in some photos (Figure 19).

Figure 14. **FRO offsetting cameras 1 (below Henretta Lake), the left column depicts the cold period from Dec 19 – 26, 2017 and the right column from Jan 31 - Feb 6, 2019 (the blue line denotes the overnight air temperature transition in 2019). The photos illustrate the overnight onset of ice in 2019 compared to the more gradual onset in 2017. For exact locations see Map 4.**

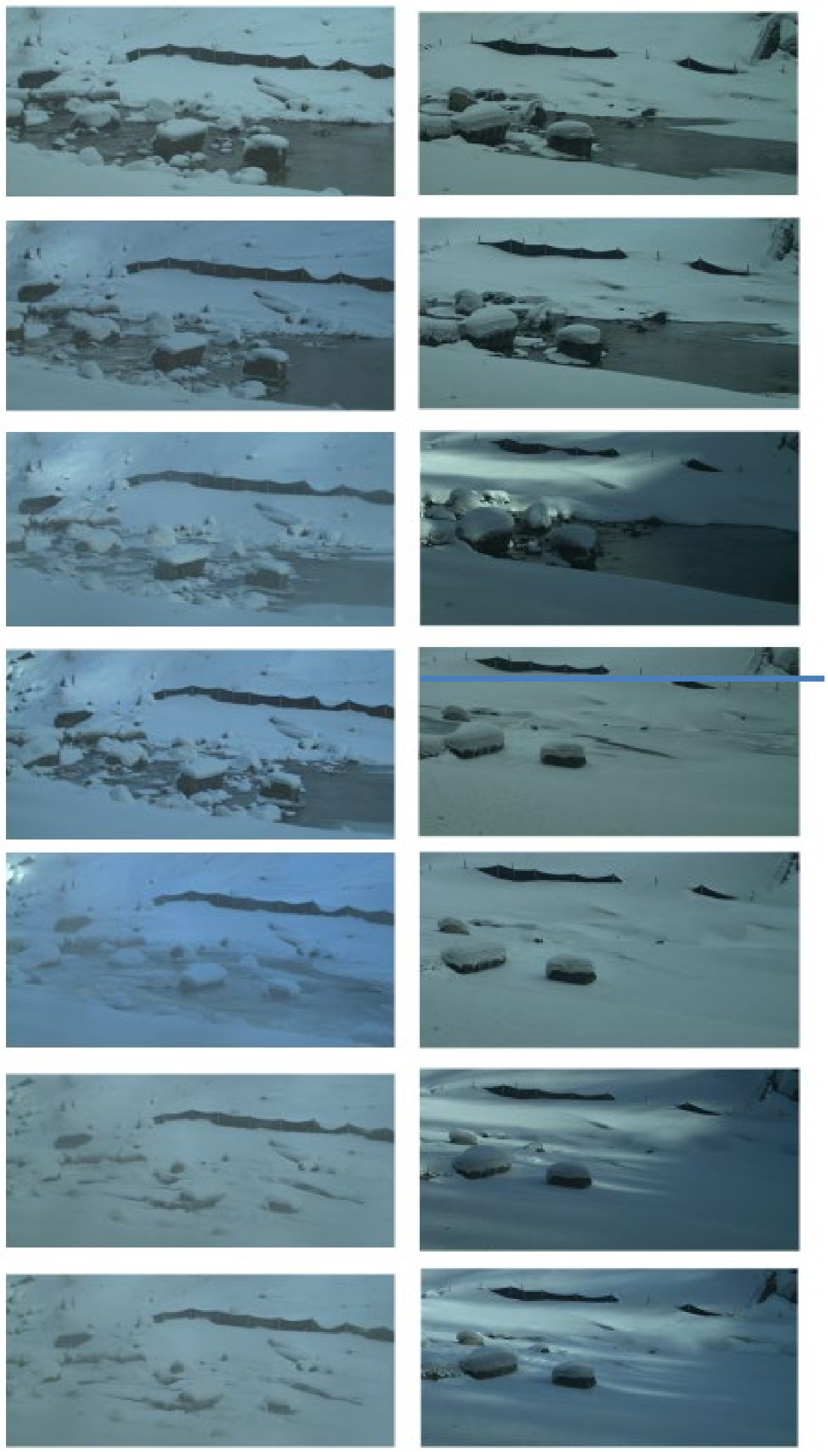


Figure 15. FRO Offsetting cameras 8, the left column shows ice progression during a cold snap that occurred December 19-26, 2017, and the right column from Jan 31 - Feb 6, 2019 (the blue line denotes the overnight air temperature transition in 2019). In this series the onset of ice is more similar between the two years. For exact locations see Map 4.

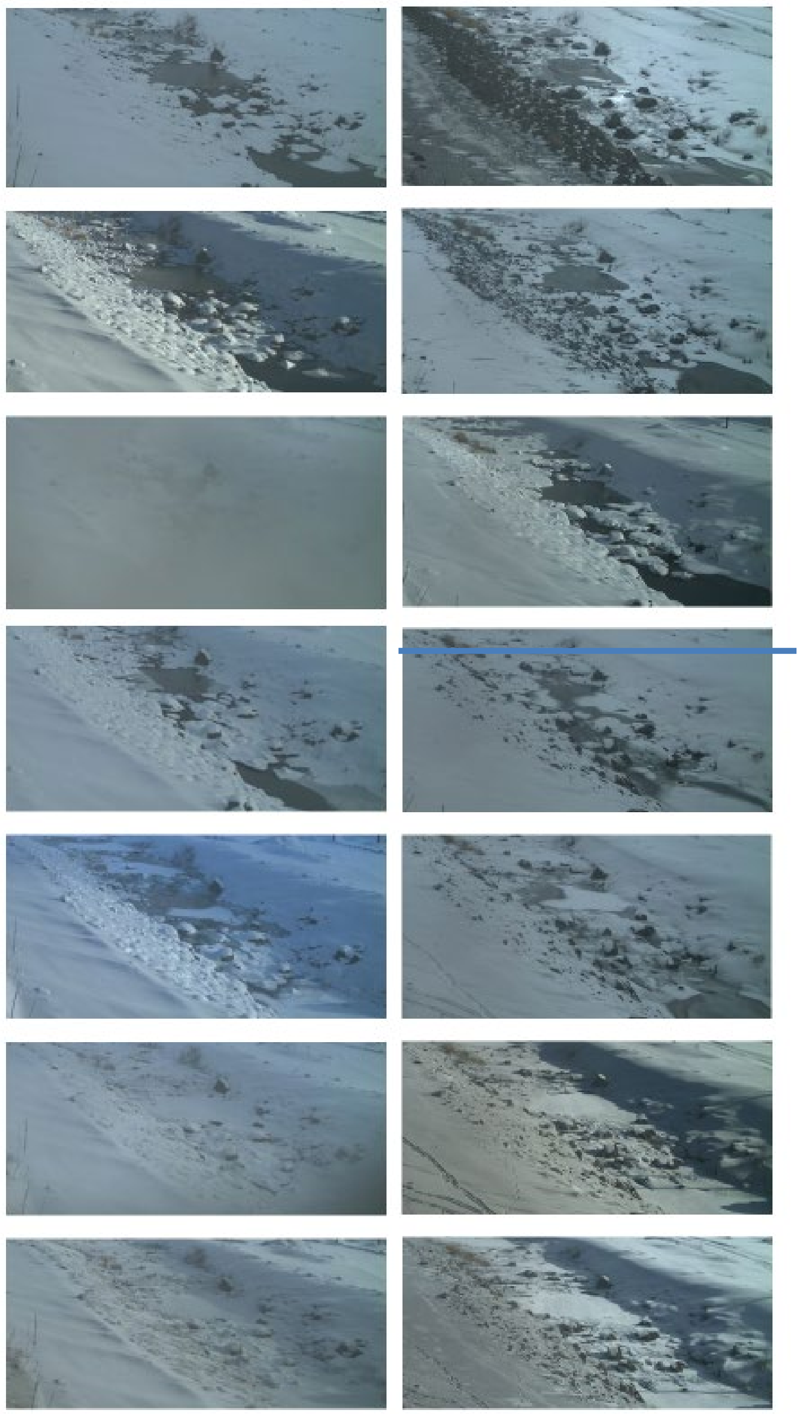


Figure 16. Photo taken at designated photo point for LAEMP sampling at FR_CP1SW on November 6, 2018, showing complete interruption of connectivity.

Figure 17. Upstream photo angle of an open water riffle at FR_FODPO taken during invertebrate sampling, February 14, 2019.

Figure 18. Downstream perspective of the UFR taken at FR_FODNGD on February 12, 2019. Evidence of substatial ice buildup is visible on right side of the photo.

Figure 19. Photo of ice bore hole from FR_FOBCP (left) and FR_FODHE (right) taken on February 11 and 13, 2019, demonstrating freezing of the entire water column.

Figure 20. Photo of the substrate taken at FR_FO22 on February 14, 2019, the sections that are blurry appear to be entrained frazil ice or anchor ice on the substrate.

3.3.4. Qualitative Observations of Ice in the UFR

Records of snow and ice in the UFR have mostly been occasional incidental observations taken to characterize winter habitat conditions for benthic invertebrates or to characterize conditions in the southern drying reach (Minnow and Lotic 2018, 2019) rather than systematic surveys of ice conditions. General ice cover and ice types were provided by Cope (pers. comm. 2020) (Table 7) to summarize observations of typical winter conditions in different river segments of the UFR. These provide a point of reference for comparing with anomalous conditions such as those in February 2019. Ice cover information was compiled to provide context for discussions of winter conditions (Map 2). General information was also collected by Minnow Environmental at 12-17 locations in the UFR during winter sampling in December 2018, February 2019 and December 2019.

The incidental observations indicate high spatial variation in distribution and type of ice cover in the UFR mainstem (Table 6). Unfortunately, the qualitative nature of the data and the schedule of its collection means that only broad comparisons can be made. There was only one location with ice observations on all three sampling dates (RG_FOBCP), and the observations for this location do not indicate drastic differences in conditions among the dates. The remainder of the observations indicate that February 2019 had substantial ice conditions; however, there were no observations from February of other years to determine if the amount and conditions of ice were unusual. The data are nevertheless useful for bounding expectations for surface ice thickness, which is relevant to calculations provided in Section 3.4

Table 6. Observations of ice cover in the UFR mainstem made during FRO-LAEMP data collection for December 2018, February 2019, and December 2019 by Minnow Environmental.

Station ID	River Segment[1]	UTMs, Zone 11		Comments		
		Easting	Northing	Dec-18	Feb-19	Dec-19
RG_FODHE	S9	651337	5565428	Frozen, no moving water under ice, some slush.	n/s	n/c
RG_FOUCL	S9	650787	5564445	n/c	n/c	No ice on river.
RG_FOUNGD	S8	650857	5563530	No ice	n/c	No ice present.
RG_FODNGD	S8	650973	5563162	n/c	Fractures in ice.	No ice on river.
RG_MP1	S8	651157	5562443	n/c	Some open areas in ice.	n/c
RG_FOUSH	S8	650859	5561151	Lots of ice, not anchored.	Fractures in ice; not anchored.	n/c
RG_FOBKS	S7	652085	5558650	n/c	Ice 1 ft thick.	n/c
RG_FOBSC	S7	652371	5558151	n/c	Anchored ice in riffle; 2 ft of ice, 1 in of slush water in pool.	Only one riffle open, all others frozen down to substrate - layer of ice over cobble with water flowing over.
RG_FOBCP	S7	652921	5556990	Water gone to ground. 30 cm of ice on top of 16 cm of open pocket over substrate.	Most of river frozen solid. Broke open two holes that were not frozen to the bottom.	River frozen with some water flowing over. Ice down to substrate with no open riffles to sample.
RG_FRCP1SW	S7	653387	5556201	n/s	n/s	Frozen to the bottom with anchor ice.
RG_FRUPO	S6	653892	5555951	No ice on creek.	Relatively open.	n/c

n/s = not sampled; n/c = no comment

[1]as per Cope et al. 2016

Table 7. General observations of typical winter conditions in the UFR (2012-2015, 2019; Cope pers. comm. 2020).

UFR Stream Segment	Snow Cover	Ice Cover	Ice Cover			Groundwater Moderated	Water Temperature (°C)
			Surface	Anchor	Frazil		
Headwaters to bottom of S7	95% cover	frozen	n/c	n/c	n/c	n/c	n/c
Bottom of S7 to top half of S6	n/c	ice free	none	none	none	yes	4-5
Lower S6	n/c	sometimes	none	none	none	yes	1-2
Below S6 (Chauncey)	n/c	variable[1]	yes	yes	yes	n/c	n/c
Further downstream to Greenhills	n/c	dynamic	yes	ice dams	yes	n/c	n/c

[1] depends on weather patterns

n/c = no comment provided

3.4. Habitat Availability in Relation to Surface Ice

Details on transects and habitat modelling are provided in the Evaluation of Cause report on habitat availability (Healey *et al.,* 2021) and the FRO OEMP instream flow study of the UFR upstream of Chauncey Creek (Healey *et al.* 2020). The results indicated that surface ice formation can substantially reduce the amount of suitable overwintering habitat (Table 8). For example, a surface ice cover of 50 cm thickness within the Henretta to Kilmarnock zone was predicted to reduce open-water WUA by 41%, when assuming that fish need a minimum of 5cm buffer under the ice for the space to be usable. When a 10 cm or a 15 cm buffer is used, the WUA is reduced by 49% and 60% respectively. At 50 cm ice thickness, habitat loss is predicted to be even higher in the Kilmarnock to Chauncey zone; WUA loss for 5 cm, 10 cm, and 15 cm buffers were 56%, 63% and 70% respectively. This model does not account for frazil ice and its possible effects, and relies on an open-water hydraulics model.

Modelling of WUA at several assumed levels of discharge depression due to the ice storage effect indicated that the amount of habitat loss due to the discharge depression depended greatly on the assumed discharge reduction (Table 9). The effect was considerably more pronounced at the highest assumed discharge reduction (50%). The habitat reduction during a discharge depression was modest: maximum 10% in the Henretta to Kilmarnock section and maximum 11% in the Kilmarnock to Chauncey section. The habitat reduction would be transient and occur only during the discharge depression, but would nevertheless add to the total effect of ice.

Results from both models should be treated with caution and they are meant to be primarily illustrative rather than predictive. Both models are simple and are based on assumed discharges that are lower than the lowest discharges recorded in the field. Considerably more complex models would be required to assess the combined habitat effects of surface ice and discharge depression, or to assess dynamic ice formation, dewatering due to ice jams, or water flowing overtop of surface ice. Nevertheless, since the effects would co-occur, the results indicate that habitat availability can be notably affected by surface ice formation.

Table 8. Habitat availability following formation of surface ice of varying thickness, expressed as a) weighted usable area (WUA) and b) change in WUA relative to ice free conditions.

a) WUA remaining following surface ice formation

Zone	Buffer Thickness	WUA (1000 m²) for Ice Thickness					
		0 cm	10 cm	20 cm	30 cm	40 cm	50 cm
Henretta to Kilmarnock	5 cm	4.3	3.9	3.6	3.3	3.0	2.6
	10 cm	4.3	3.7	3.4	3.1	2.8	2.2
	15 cm	4.3	3.6	3.3	3.0	2.6	1.7
Kilmarnock to Chauncey	5 cm	4.9	4.6	3.8	3.3	2.9	2.2
	10 cm	4.9	4.2	3.5	3.2	2.5	1.8
	15 cm	4.9	3.8	3.3	2.9	2.2	1.5

b) Change in WUA (%) relative to ice-free conditions

Zone	Buffer Thickness	Δ WUA (%) for Ice Thickness					
		0 cm	10 cm	20 cm	30 cm	40 cm	50 cm
Henretta to Kilmarnock	5 cm	0%	-10%	-17%	-24%	-31%	-41%
	10 cm	0%	-15%	-21%	-28%	-36%	-49%
	15 cm	0%	-17%	-24%	-31%	-41%	-60%
Kilmarnock to Chauncey	5 cm	0%	-7%	-24%	-34%	-41%	-56%
	10 cm	0%	-15%	-29%	-35%	-49%	-63%
	15 cm	0%	-24%	-34%	-41%	-56%	-70%

Table 9. Habitat availability (WUA) in relation to assumed discharge declines during ice formation (storage effect), based on discharges at FR_FRNTP.

Flow Reduction	Discharge (m³/s)	WUA (1000 m²)		Storage Effect	
		Henretta to Kilmarnock	Kilmarnock to Chauncey	Henretta to Kilmarnock	Kilmarnock to Chauncey
0%	0.36	4.95	4.35	0%	0%
5%	0.34	4.94	4.32	0%	-1%
10%	0.32	4.92	4.28	-1%	-2%
25%	0.27	4.83	4.17	-2%	-4%
50%	0.18	4.51	3.92	-10%	-11%

4. DISCUSSION

In this report we investigated the causal pathway between ice conditions in the UFR and the observed decline in WCT abundance. Data are inadequate for a precise description of conditions throughout the UFR mainstem during the Decline Window. Nevertheless, we were able to compile several data sources to investigate whether conditions were anomalous and, based on the scientific literature and photo evidence, to consider the implications of the conditions during the Decline Window. There were two winters within the Decline Window; we investigated conditions during both, and placed this information in historical context to understand anomalies. The winter of 2018/19 was especially cold and had unique features that may have played a role in causing the WCT decline.

4.1. Winter 2017/18

Conditions in the winter of 2017/18 (November to March) were consistent with the period of record for air temperature, snow accumulation and SWE. Daily average air temperature dropped to the coldest point of the Decline Window in late December 2017 (Figure 7); however, the lead up to this cold was gradual and would likely have allowed for stable surface ice to form in many or most parts of the river, and thereby prevented further formation of frazil and anchor ice. Another drop in air temperature occurred in February, but was also gradual and air temperatures did not decrease to the same extent as during the first drop. Daily average air temperatures below -25 °C occur regularly in the UFR, and were common in the winters examined more closely (Figure 13). Snow accumulation and SWE in the region in 2017/18 were above normal for the period observed, and began with heavy snow in November, though SWE slowed through December (Figure 9; Table 5). We expect that the gradual onset of cold air temperatures would have allowed for additional surface ice thickness and extent. Despite lower than normal snow accumulation/SWE for the observed period, at the time of the December cold weather the snow that did accumulate likely still provided a greater buffer than no ice or snow and therefore likely moderated water temperatures and further ice formation.

Despite the prolonged stretch of cold weather that occurred in December 2017, water temperature recorded during this period did not drop below 0 ºC at any station (Figure 10), which indicated that the sensors were not frozen or affected by frazil ice. The water temperature data suggest that the river was protected from extreme cold by previous ice build-up and snow accumulation. The stage record at the Fording at Mouth gauge indicates some degree of stage fluctuation (indicative of backwatering and ice jams; Figure 11). Discharge was slightly lower than normal. There were two large spikes in stage in February during the period of cold air temperatures; however, one or two spikes in stage were visible in the data for eight of nine winters examined, so this was not considered abnormal. Discharge at the Elk at Fernie gauge (NK002) was normal; however, the stage was variable and showed a period of elevation higher than any other in the ten years examined. This may be due to prolonged backwatering at the gauge location for most of the winter; such stage fluctuations are apparent in more than half of the winters shown in Figure 11. At both WSC stations, observation of the storage effect (discharge depression, see Section 3.1.1.3) is difficult to discern due to the repeated variation in stage throughout the winter season.

Based on weather and hydrology time series for 2017/18, we do not believe that conditions were unusual for the region. To meet the requisite conditions (Table 1) the intensity of ice formation effects needed to have been greater during the Decline Window than for the years prior. In the case of 2017/18, the timing of cold weather onset, lack of a sudden drop to cold air temperature, the high snow accumulation, and the consistent water temperatures above 0 ºC all imply stable ice formation conditions, which are unlikely to have substantively influenced WCT overwintering habitats. Based on this evidence, in 2017/18 the requisite conditions to cause the observed WCT decline were not met; likewise, we conclude that in 2017/18 the requisite conditions were not met to contribute substantively to the observed WCT decline (except as an ongoing typical stressor as in most winters).

4.2. Winter 2018/19

4.2.1. Ice formation in the UFR in the Winter 2018/19

The weather in winter 2018/19 (November to March) was anomalous. The air temperature record for this period shows that until February, air temperatures were relatively warm (Figure 7). Early cold weather with a gradual onset is considered ideal for surface ice formation that would create stable aquatic conditions for the rest of winter, particularly if early formation of surface ice is accompanied by snow accumulation. This pattern did not occur in 2018/19. The drop in temperature that occurred in February 2019 was remarkable for its magnitude and suddenness. Similar temperature drops have occurred only in three other winters since 1970, and each of those were preceded by prolonged cold conditions that were greater than the one in 2018/19 (Figure 13). Following the temperature drop in February 2019 there was a period of sustained cold that lasted until early March. This period was notable for the stability of very cold air temperatures and daily maximum temperatures did not exceed 0 °C until mid-March. SWE and accumulation in the winter of 2018/19 were well below average and may not have acted to buffer streams from the sudden drop to cold air temperature.

The air temperature and snow data indicate a period later in winter 2018/19 when dynamic ice formation may have occurred. The warm weather preceding the cold snap is expected to have promoted open water conditions through the early winter, particularly in areas with groundwater inflow, and the water temperature records at all three hydrometric stations support this conclusion. Once the drop in air temperature occurred, we expect that a rapid change in stream conditions also occurred. Water temperatures at all three stations dropped to freezing or even below freezing (FR_FRNTP) for all of February and early March. Following the Feb 2-3 air temperature drop both FR_FRNTP and FR_HC1 had delays of roughly two days before water temperature began to drop. The water temperature decline at FR_FRABCHF occurred immediately after air temperature dropped. The period following the air temperature drop was the only occasion where air temperature at any gauge was below 0 ºC for a sustained period since 2013 (Figure 10).

An examination of the hydrometric data during winter 2018/19 indicates rapid stage variation at WSC stations (Figure 12). Water inputs from meltwater, groundwater and precipitation are expected to be stable in winter and at their lowest point for the year, so the massive spikes in stage recorded are likely due to direct effects of ice at the gauges. The Fording at the Mouth gauge (NK018) shows spikes in stage in all years examined, but the duration of extreme spikes during the temperature drop in February 2019 exceeds all except 2015/16. We interpret this as a sustained period when widespread ice is jamming and then releasing, creating short duration changes in stage. These large variations in stage would make it difficult for stable surface ice to form, and instead could mimic conditions during rapid breakup, when changes in stage can cause surface ice to break up and become entrained in the stream flow. The discharge depression is difficult to discern and quantify due in part to its likely co-occurrence with the ice jams; it is reasonable to expect it occurred during this period, though magnitude cannot be estimated. A discharge and stage decline appears to have been underway at the Elk at Fernie gauge (NK002) immediately prior to the large stage increase in early February (Figure 12). The discharge decline in response to ice formation would have reduced available habitat beyond already low winter discharges. Evidence of severe ice formation is apparent in daily photos captured by cameras during the Decline Window. In nearly all locations a sudden change of conditions is evident as rapid ice formation, and in some locations there appears to be concurrent reduction in discharge (Appendix A, Figure 15.)

Based on the weather and hydrometric time series and the few direct observations available, we conclude that the duration, timing and intensity of ice formation were anomalous compared to historical conditions and likely were severe for overwintering WCT throughout the UFR. We believe patterns of surface ice formation and breakup, frazil and anchor ice accumulation, and ice jam blockages may have occurred in many areas of the UFR, and for a sustained period from early February to mid March 2019. Shallow streams cool rapidly and the change to cold temperatures occurred at a time when the UFR is typically at its lowest annual level, which would promote rapid ice formation and the coincident effects on aquatic habitat and organisms. Evidence of this phenomenon can be seen in the FRO offsetting camera photo records and photo records collected during LAEMP monitoring. During the period of extreme cold in 2018/19 several cameras recorded stream levels dropping notably or to nil, or to a point where the remaining water appears to freeze solid . These instances of drying or freezing would present barriers to fish passage or represent reductions in habitat availability during periods of extreme cold. This could have ramifications for fish survival because one of the main behavioural responses to frazil ice is to move in search of appropriate habitat (Brown *et al.* 2011).

4.2.2. Effects of Ice Formation on WCT in the UFR in the Winter 2018/19

In the absence of direct observations of conditions within key overwintering habitats of the UFR it is not possible to be definitive in determining effects to WCT or to attribute mortality to a specific cause. Nevertheless, sufficient information exists that, when combined with evidence from the literature, allow supportable inferences. It has been previously identified that WCT suffered winter mortality in past winters (Cope *et al.* 2016), though data are insufficient to relate mortalities to timing of specific weather events. Based on our conclusion that winter 2018/19 was colder and more severe for ice formation than normal, we expect that mortality of fish both within and outside of the key overwintering habitats would be higher than normal. Issues with connectivity in the UFR have been previously identified (e.g., seasonal drying reaches, icing and culvert passability; Harwood *et al.* 2021, Healey *et al.* 2021, Cope *et al.* 2016), and it is possible that poor fish passage conditions in autumn 2018 may have prevented some fish from returning to their preferred overwintering areas. Some of these fish may have been forced into less suitable overwintering areas where they were more exposed to the effects of severe ice conditions in winter 2018/19. In habitats outside of key overwintering areas WCT may have been exposed to both direct and indirect effects of ice, including trauma, occlusion, forced movements and physiological effects. The habitats outside of key overwintering areas are of poorer suitability, so effects are expected to be greater in such locations, with higher mortality rates than in locations of high suitability. Nevertheless, total number of WCT within these poorer suitability habitats is expected to be less than those in the key overwintering areas.

Effects of ice and cold water conditions on the physiology of WCT are considered in other EoC reports. Topics covered include the effects of cold on the pathophysiology of WCT (Bollinger 2021) and the effects of low dissolved oxygen on WCT (Evaluation of Cause Team 2021). Interpretation of conditions in the key overwintering areas (e.g., Henretta Lake, Multi-plate pool, S6 pools, and S1-S3 log jams) is more complex. Cope *et al.* (2016) estimates these key areas are used by up to 90% of WCT in the UFR (Figure 5). The areas identified as preferred for overwintering tend to be deep with slow water velocity, which would generally favour surface ice rather than dynamic ice formation. We speculate that ice formation upstream of these areas was sufficient to infill portions of overwintering areas with frazil ice or entrained surface ice; although, the extent of this infilling is difficult to predict. Similar effects have occurred in other locations and can cause direct mortality due to trauma or occlusion from suitable habitat (Brown *et al.* 2011) or may cause fish to seek other areas (Jakober *et al.* 1998). In northern regions, prolonged cold can cause surface ice to increase in thickness to the point that it substantially reduces pool depth, and makes fish habitat unsuitable. We applied a simple model to assess this effect and found that surface ice formation alone would be unlikely to eliminate a substantial portion of available overwintering habitat because these habitats are considerably deeper than expected surface ice thickness (see Section 3.4). However, the results should be treated as indicative only, and beyond 50 cm ice thickness the model is very uncertain. Also, the model does not incorporate accumulation of surface and anchor ice due to build up from frazil ice (see for example Figure 3 and Figure 4 and Section 3.1.1).

4.2.3. Possible Interactions with Extreme Cold at Key Overwintering Areas

Cope *et al.* (2016) described four areas of the UFR that were used by the majority of WCT for overwintering. Quantitative observations of ice conditions are not available; however, we attempt to draw inferences on what the ice conditions may have been like at these locations based on the weather and hydrology observations described above. We also note that the degree of fish use of these areas in winter 2018/19 are not known.

4.2.3.1. Henretta Lake

Henretta Lake is typically a stable overwintering habitat in the UFR because it is a relatively large area of deep still water, with a maximum depth of over 5m. It is likely that Henretta Lake was largely unaffected by conditions in winter 2019. Even if frazil ice was produced upstream and flowed into the lake the large waterbody would likely still offer abundant refuge. It is possible that lack of deep snow cover encouraged thicker surface ice than normal, but the depth of the lake would still allow abundant refuge. There is no *a priori* reason to think that DO levels would be substantially different than during a normal winter, especially given the large volume of the lake. Passage conditions in the fall may have precluded some fish from reaching Henretta Lake for overwintering (Harwood *et al.* 2021).

4.2.3.2. Segments S7-S9

Segments S7-S9 are located within the FRO mine-site and are noted for being degraded and having little cover from LWD or other sources (Cope *et al.* 2016). Observations of photos (see Section 3.3.3,Figure 14) from cameras shows that some locations in this area had rapid, substantial ice formation in the days following the temperature drop in February 2019. There is photo evidence that portions of the river in this area underwent substantial ice formation, including areas where the entire water column froze (Figure 19). In comparison, the ice formation during a cold event in December 2017 has a slower onset (Figure 15). Based on the change in ice cover, and the general lack of available deep habitat, these river segments were likely mostly unsuitable for WCT overwintering in February and early March 2019. Relative distribution and abundance of fish in different portions of these river segments during the fall of 2018 and winter of 2018/19 is not known, though it may have been similar to that described in Cope *et al.* (2016).

An exception in this area is the Multi-plate pool, which is deep enough to provide adequate protection from surface ice. We do not know whether inflows of frazil ice may have been sufficient to affect the amount of suitable overwintering habitat or cause the formation of hanging dams, but the depth and size of the pool suggest it would continue to act as an overwintering refuge.

4.2.3.3. S6 Oxbows

During the cold weather in February 2019 it is possible that the S6 oxbows were subjected to frazil ice or other dynamic ice processes. This area has groundwater inputs immediately upstream, which may have prevented surface ice formation. The stream morphology in the S6 oxbows is not conducive to frazil ice production (predominately very low gradient low turbulence); however, the sections upstream (S7-S9) are more turbulent and frazil ice produced in these areas may have been transported downstream into the S6 oxbows. Photos collected during invertebrate sampling appear to show entrained frazil ice in the downstream portion of the oxbows at FR_FO22 (Figure 20). The oxbows also have numerous deadfall and logjams that may act as initiation points for anchor ice. Given the unusually cold weather for a sustained period, this area may have experienced much greater ice concentration than normal, and made it less suitable as overwintering habitat than normal. We assume the relative distribution and abundance of fish in this river segment during the fall of 2018 and winter of 2018/19 was similar to that described in Cope *et al.* (2016), and therefore contained a substantial part of the UFR population.

4.2.3.4. S1-5 Logjam Pools

Cope *et al.* (2016) describe large log jam pool complexes that provide overwintering habitat in river segments S1-5. These sites were described as having dynamic ice conditions and fish tended to move among pools during winter. Frazil and anchor ice along with ice dams are known to regularly occur in these river segments (Table 7). We speculate that since dynamic ice conditions are relatively common in this stretch of river that conditions would have been at least as severe and likely more severe during winter 2018/19. Dynamic ice is known to provide poor overwintering conditions and may have forced or encouraged fish to seek other areas of overwintering refuge. Presumably, any fish moving into this area from upstream (e.g., from the S6 segment) would have had trouble finding suitable overwintering habitat.

4.2.4. Evaluation of Requisite Conditions

The available data do not provide a clear understanding of the extent to which abnormal ice dynamics in overwintering habitat would affect WCT survivorship in the UFR, or the relative importance of different mechanisms of effect (i.e., physiological, behavioural, occlusion, direct freezing, etc.). WCT have been shown to substantively reduce movements during winter (Brown *et al.* 2011; Brown 1999; Cope *et al.* 2016); however, if necessary, individuals will move in response to severe conditions (e.g., Jakober *et al.* 1998; Simpkins *et al.* 2000; Alexiades *et al.* 2012). Overwintering locations in the UFR are notably few and limited in extent, and the best locations tend to be highly utilized each year. In a worst-case scenario, if ice began to infill key WCT overwintering habitat (conceptually shown in Figure 2 and Figure 3), the affected fish may have had little or no suitable habitat nearby to move to; we speculate that movements under severe conditions would have been more likely to occur in a downstream direction.

Abnormal ice conditions in overwintering habitat is expected to negatively affect WCT physiology and potentially increase mortality during winter (Bollinger 2021). We suggest there is good evidence that conditions were favourable for extreme frazil and anchor ice formation and the entrainment of broken surface ice. February is the period of lowest discharge and ice would be most concentrated in the stream at this time. Research suggests overwintering WCT have reduced swimming speeds and metabolic capacity to respond to unstable habitats that occur during severe ice formation periods (Huusko *et al.* 2007). Starvation has been documented in some populations, especially among juveniles (Brown *et al.* 2011), and the effect of food availability as a stressor of WCT in the UFR is assessed in detail in Orr and Ings (2021). These are considered indirect effects of ice, that could either result in mortality or increase the chances of mortality by other causes. The occurrence of severe conditions later in the winter would exacerbate the physiological effects of cold, when body condition tends to be the lowest (Lemly 1996). There is a phenomenon (cryo-concentration) that can result during ice formation in static water where chemical constituents can become hyper-concentrated. The potential implications of cryo-concentration are discussed in a separate SME report (Costa and de Bruyn, 2021).

Other streams near the UFR that were in the same climatic regime may have had similar ice conditions, yet apparently did not experience a similar WCT abundance decline during the Decline Window

(Cope *et al.* 2020). A more in-depth comparison of these systems may be useful, particularly with respect to availability of suitable overwintering habitats and potential ice effects on those habitats. Also, it is possible that the level of WCT biological and physical monitoring intensity in those systems is not sufficient to support a robust analysis of the magnitude of response to the weather anomalies of 2018/19.

In conclusion, the available evidence for ice formation and related effects suggest that overwintering conditions were severe in 2018/19 and may have caused or contributed to the observed WCT decline in the UFR. All of the requisite conditions were met for causing or contributing to the observed decline; however, there is considerable uncertainty with respect to the magnitude of effect. Data were insufficient to provide direct evidence for mortality associated with the severe winter and there were no detailed direct observations of ice conditions, particularly dynamic ice conditions. Nevertheless, a range of effects (physiological, behavioural, occlusion, direct freezing, etc.) are possible, alone or in combination, and these may have acted in concert with other stressors such as water quality, predation, and short-term and long-term habitat trends. The conclusions offered here are based on effects inferred from weather and hydrometric data and predicted effects from the scientific literature, rather than from direct observations of ice conditions and fish mortalities.

REFERENCES

Alexiades, A.V., M.M. Peacock, R. Al-Chokhachy. 2012. Movement patterns, habitat use, and survival of Lahontan Cutthroat Trout in the Truckee River. North American Journal of Fisheries Management 32: 974-983.

Ashton, G. (editor). 1986. River and lake ice engineering. Water Resources Publications, Highlands Ranch, Colorado.

Baltz D.M., B. Vondracek, L.R. Brown, and P.B. Moyle. 1991. Seasonal changes in microhabitat selection by rainbow trout in a small stream. Transactions of the American Fisheries Society 120: 166–176.

Bates, D., M. Mächler, B.M. Bolker, and S.C. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67(1): 1-48.

Beltaos S. 2000. Advances in river ice hydrology. Hydrological Processes 14: 1613–1625.

Bjornn T.C. 1971. Trout and salmon movements in two Idaho steams as related to temperature, food, stream flow, cover, and population density. Transactions of the American Fisheries Society 100: 423–428.

Bollinger, T. 2021. Subject Matter Expert Report: Pathophysiology of Stressors on Fish. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population. Report prepared for Teck Coal Limited

Bramblet R.G, M.D. Bryant, B.E. Wright, and R.G. White. 2002. Seasonal use of small tributary and main-stem habitats by juvenile Steelhead, Coho salmon, and Dolly Varden in a southeastern Alaska drainage basin. Transactions of the American Fisheries Society 131: 498–506.

Brown, R.S., S.S. Stanislawski, and W.C. Mackay. 1993. Effects of frazil ice on fish. Proceedings of the Workshop on Environmental Aspects of River (Editor), National Hydrology Research Institute. Saskatoon, SK. NHRI Symposium Series 12: 261-278.

Brown, R.S. and W.C. Mackay. 1995. Fall and winter movements of and habitat use by cutthroat trout in the Ram River, Alberta. Trans. Am. Fish. Soc. 124: 873-885.

Brown, R. S. 1999. Fall and early winter movements of cutthroat trout, *Oncorhynchus clarki*, in relation to water temperature and ice conditions in Dutch Creek, Alberta. Environmental Biology of Fishes 55:359–368.

Brown, R.S., G. Power, S. Beltaos, and T.A. Beddow. 2000. Effects of hanging ice dams on winter movements and swimming activity of fish. Journal of Fish Biology. 57: 1150-1159

Brown, R.S., W.A. Hubert and S.F. Daly. 2011. A primer on winter, ice, and fish: what fisheries biologists should know about winter ice processes and stream-dwelling fish. Fisheries 36:1, 8-26.

Bustard, D. 1986. Some Differences Between Coastal and Interior Stream Ecosystems and the Implications to Juvenile Fish Production. Canadian Technical Report of Fisheries and Aquatic Sciences. 1483.

Butler, R.L. 1979. Anchor ice, its formation and effects on aquatic life. Science in Agriculture, Vol. XXVI, Number 2, Winter, 2979.

Chisholm, I. M., W. A. Hubert, and T. A. Wesche. 1987. Winter stream conditions and use of habitat by brook trout in high-elevation Wyoming streams. Transactions of the American Fisheries Society 116:176-184.

Cleator, H., J. Earle, L. Fitch, S. Humphries, M. Koops, K. Martin, D. Mayhood, S. Petry, C. Pacas, J. Stelfox, and D. Wig. 2009. Information relevant to a recovery potential assessment of pure native Westslope Cutthroat Trout, Alberta population. Canadian Science Advisory Secretariat:1–26.

Conly, F. M., and T. D. Prowse. 1995. Hydrologic response to freeze-up on large northern rivers (Case Study). Pages 23–42 Winter Environments of Regulated Rivers, Proceedings of the 8th Workshop on the Hydraulics of Ice Covered Rivers.

Cope, S., C.J. Schwarz, A. Prince, and J. Bisset. 2016. Upper Fording River Westslope Cutthroat Trout Population Assessment and Telemetry Project: Final Report. Report Prepared for Teck Coal Limited, Sparwood, BC. Report Prepared by Westslope Fisheries Ltd., Cranbrook, BC. 266 p.

Cope, S. 2020. Upper Fording River Westslope Cutthroat Trout Population Monitoring Project: 2019. Report Prepared for Teck Coal Limited, Sparwood, BC. Report Prepared by Westslope Fisheries Ltd., Cranbrook, BC. 40 p + 1 app.

Costa, EJ., and de Bruyn, A. 2021. Subject Matter Expert Report: Water Quality. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population. Report prepared for Teck Coal Limited. Prepared by Golder Associates Ltd.

Cunjak, R. A., and D. Caissie. 1994. Frazil ice accumulation in a large salmon pool in the Miramachi River, New Brunswick: ecological implications for overwintering fish. Pages 279-295 in Ford, J. E., and D. G. Lonzarich. 2000. Over-winter survival and habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in two Lake Superior tributaries. Journal of Great Lakes Research 26:94-101.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Science 53: 267-282.

Cunjak R.A., T.D. Prowse, and D.L. Parrish. 1998. Atlantic salmon (Salmo salar) in winter: 'the season of parr discontent'. Canadian Journal of Fisheries and Aquatic Sciences 55(Suppl. 1): 161–180.

Evaluation of Cause Team, 2021. Evaluation of Cause — Decline in Upper Fording River Westslope Cutthroat Trout Population. Report prepared for Teck Coal Limited by Evaluation of Cause Team.

Greenbank, J. 1945. Limnological conditions in ice-covered lakes, especially as related to winter kill of fish. Ecological Monographs 15: 343-392.

Hamilton, A. S., and R. D. Moore. 1996. Winter streamflow variability in two groundwater-fed sub-Arctic rivers, Yukon Territory, Canada. Canadian Journal of Civil Engineering 1996: 1249–1259.

Harper D.D., and A.M. Farag. 2004. Winter habitat use by cutthroat trout in the Snake River near Jackson, Wyoming. Transactions of the American Fisheries Society 133: 15–25.

Harwood, A., Suzanne, C., Whelan, C., and Hatfield, T. 2021. Subject Matter Expert Report: Fish Passage. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population. Report prepared for Teck Coal Ltd. by Ecofish Research Ltd.

Healey, K., P. Little, and T. Hatfield. 2020. Fording River Instream Flow Study. Consultant's report prepared by Ecofish Research Ltd. for Teck Coal Limited. July 30, 2020.

Healey, K., Little, P., and Hatfield, T. 2021. Subject Matter Expert Report: Habitat Availability. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population. Report prepared for Teck Coal Limited by Ecofish Research Ltd.

Hillman T.W., J.S. Griffith, and W.S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116: 185–195.

Hiscock, M.J. D.A. Scruton, J.A. Brown, and K.D. Clarke. 2002. Winter movement of radio-tagged juvenile Atlantic Salmon in northeast Brook, Newfoundland. Transactions of the American Fisheries Society 131: 577-581

Hoffsten, P.O. 2003. Effects of an extraordinarily harsh winter on macroinvertebrates and fish in boreal streams. Archiv fur Hydrobiologia 157: 505:523.

Huusko, A., L. Greenberg, M. Stickler, T. Linnansaari, M. Nykänen, T. Vehanen, S. Koljonen, P. Louhi, and K. Alfredsen. 2007. Life in the ice lane: the winter ecology of stream salmonids. River Research and Applications 23: 469-491.

Jakober, M.J., T.E. McMahon, and R.F. Thurow, and C.G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society 127: 223-235.

Kerr, D.J., H.T. Shen, and S.F. Daly. 2002. Evolution and hydraulic resistance of anchor ice on gravel bed. Cold Regions Science and Technology 35:101-114

Lemly, A. D. 1996. Winter Stress Syndrome: An important consideration for hazard assessment of aquatic pollutants. Ecotoxicology and Environmental Safety 34:223–227.

Lindstrom, J.W. and W.A. Hubert. 2004. Ice processes affect habitat use and movements of adult cutthroat trout and brook trout in a Wyoming foothills stream. North American Journal of Fisheries Management 24: 1341-1352.

Maciolek, J. A., and P. R. Needham. 1952. Ecological effects of winter conditions on trout and trout foods in Convict Creek, California, 1951. Transactions of the American Fisheries Society 81:202-217.

Magnuson, J.J., A.L. Beckel, K. Mills, S.B. Brandt. 1985. Surviving winter hypoxia: Behavioral adaptations of fishes in a northern Wisconsin winterkill lake. Environmental Biology of Fishes 14: 241-250.

McMahon T.E., and G.F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 46: 1551–1557.

Meding, M. E., and L. J. Jackson. 2003. Biotic, chemical, and morphometric factors contributing to winter anoxia in prairie lakes. Limnology and Oceanography 48:1633–1642.

Meyer K.A., and J.S. Griffith. 1997. Effects of cobble-boulder substrate configuration on winter residency of juvenile rainbow trout. North American Journal of Fisheries Management 17: 77–84.

Minnow and Lotic. 2018. Fording River Operations Local Aquatic Effects Monitoring Program (LAEMP) Report, 2017. Prepared for Teck Coal Limited, Sparwood, British Columbia. May 2018. Project #177202.0022.

Minnow and Lotic. 2019. Fording River Operations Local Aquatic Effects Monitoring Program (LAEMP) Report, 2018. Prepared for Teck Coal Limited, Sparwood, British Columbia. May 2019. Project #187202.0022.

Minnow and Lotic. 2020. Fording River Operations Local Aquatic Effects Monitoring Program (LAEMP) Report, 2019. Prepared for Teck Coal Limited, Sparwood, British Columbia. May 2020. Project #197202.0022.

Moore, R. D., A. S. Hamilton, and J. Scibek. 2002. Winter streamflow variability, Yukon Territory, Canada. Hydrological Processes 16:763-778.

Morse, B., and F. Hicks. 2005. Advances in river ice hydrology 1999 – 2003. Hydrological Processes 263:247–263.

Needham, P.R. and A.C. Jones, 1959. Flow, temperature, solar radiation, and ice in relation to activities of fishes in Sagehen Creek, California. Ecology, 40: 465-474.

Orr, P., and Ings, J. 2021. Subject Matter Expert Report: Food Availability. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population. Report prepared for Teck Coal Limited. Prepared by Minnow Environmental Inc.

Peterson N.P. 1982. Immigration of juvenile coho salmon (*Oncorhynchus kisutch*) into riverine ponds. Canadian Journal of Fisheries and Aquatic Sciences 39: 1308–1310.

Prowse T.D. 1994. Environmental significance of ice to streamflow in cold regions. Freshwater Biology 32: 241–259.

Prowse T.D, and J.M. Culp. 2004. Ice breakup: a neglected factor in river ecology. Canadian Journal of Civil Engineering 39: 128–144.

Prowse, T.D. 2001. River-ice ecology I: Hydrologic, geomorphic and water quality aspects. Journal of Cold Regions Engineering 15:1–16.

Prowse, T., B.R. Bonsal, C.R. Duguay, and M.P. Lacroix. 2007. River-ice break-up/freeze-up: A review of climatic drivers, historical trends and future predictions. Annals of Glaciology 46:443–451.

Prowse, T.D., and T. Carter. 2002. Significance of ice-induced storage to spring runoff: A case study of the Mackenzie River. Hydrological Processes 16:779–788.

Resources Information Standards Committee (RISC). 2018. Manual of British Columbia Hydrometric Standards, Version 2.0, December 2018. Knowledge Management Branch, B.C. Ministry of Environment and Climate Change Strategy, Victoria, B.C.

Simpkins, D. G., W.A. Hubert, and T.A. Wesche. 2000. Effects of fall-to-winter changes in habitat and frazil ice on the movements and habitat use of juvenile rainbow trout in a Wyoming tailwater. Transactions of the American Fisheries Society 129:101–118.

Stickler, M., K.T. Alfredsen, D.A. Scruton, C. Pennell, A. Harby, and F. Økland. 2007. Mid-winter activity and movement of Atlantic salmon parr during ice formation events in a Norwegian regulated river. In: Developments in Fish Telemetry. 81-89. Springer, Dordrecht.

Stickler, M., E.C. Enders, C.J. Pennell, D. Cote, K.T. Alfredsen, and D.A. Scruton. 2008. Habitat use of Atlantic salmon Salmo salar parr in a dynamic winter environment: the influence of anchor-ice dams. Journal of Fish Biology 73:926-944.

Stickler, M., and K. Alfredsen. 2009. Anchor ice formation in streams: a field study. Hydrological Processes 23:2307–2315.

Stickler, M., K.T. Alfredsen, T. Linnansaari, and H.P. Fjeldstad. 2010. The influence of dynamic ice formation on hydraulic heterogeneity in steep streams. River research and Applications, 26:1187-1197.

Swales, S., R.B. Lauzier, and C.D. Levings. 1986, Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology 64: 1506-1514.

Tesaker E. 1994. Ice formation in steep rivers. In Proceedings of the 12th International Ice Symposium, vol. 2. 630–638.

Tschaplinski P.J. and G.F. Hartman. 1983. Winter distribution juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwintering survival. Canadian Journal of Fisheries and Aquatic Sciences 40: 452–4761.

West R.L., M.W. Smith, W.E. Barber, J.B. Reynolds, and H. Hop. 1992. Autumn migration and overwintering of Arctic grayling in coastal streams of the Arctic National Wildlife Refuge, Alaska. Transactions of the American Fisheries Society 121: 709–715.

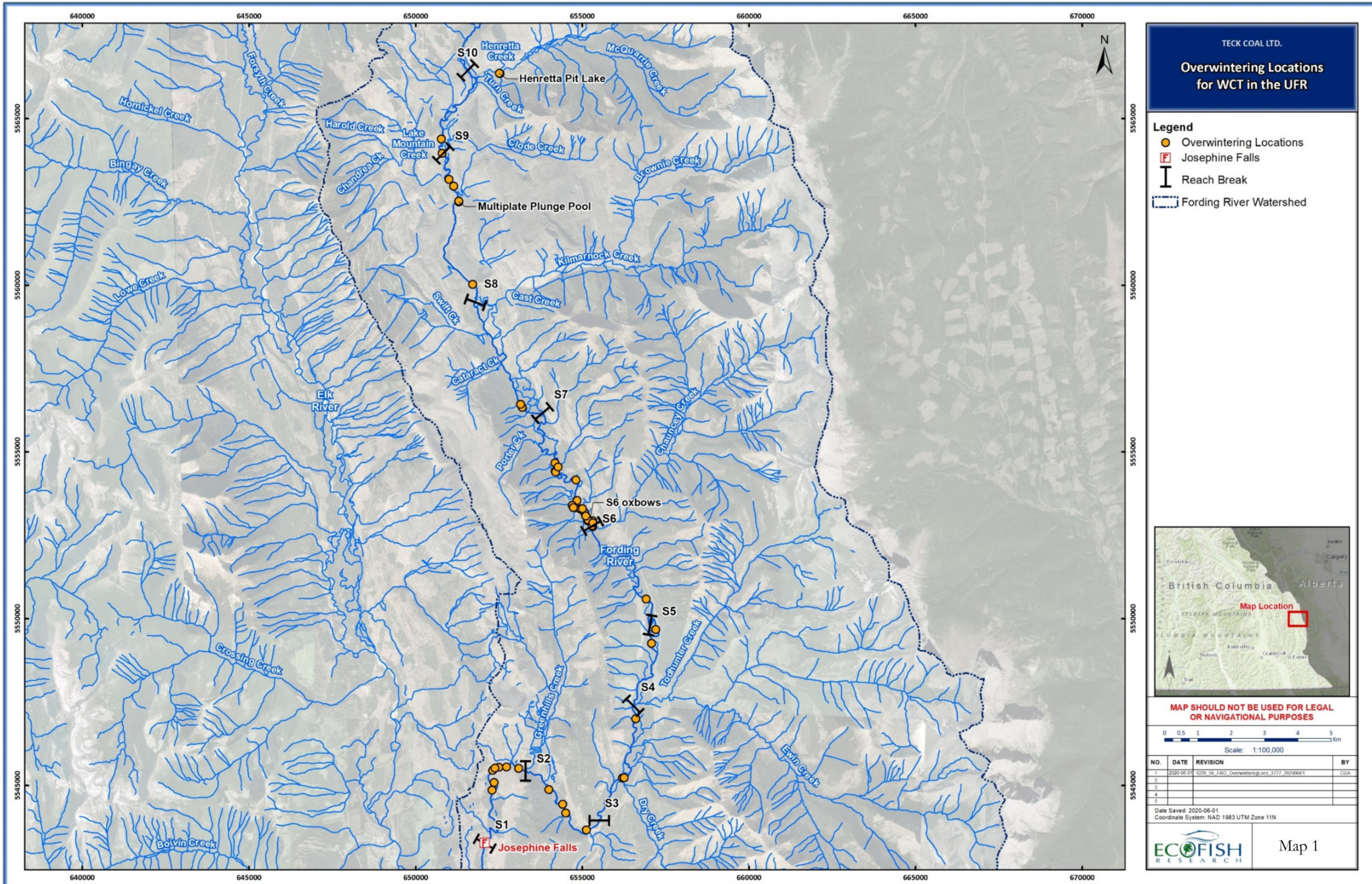
Whalen K.G., D.L. Parrish, and M.E. Mather. 1999. Effect of ice formation on selection of habitats and winter distribution of post-young-of-the-year Atlantic salmon parr. Canadian Journal of Fisheries and Aquatic Sciences 56: 87–96.

Wright, N., Greenacre, D., and Hatfield, T. 2021. Subject Matter Expert Report: Climate, Temperature, and Streamflow Trends. Evaluation of Cause – Decline in Upper Fording River Westslope Cutthroat Trout Population. Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.

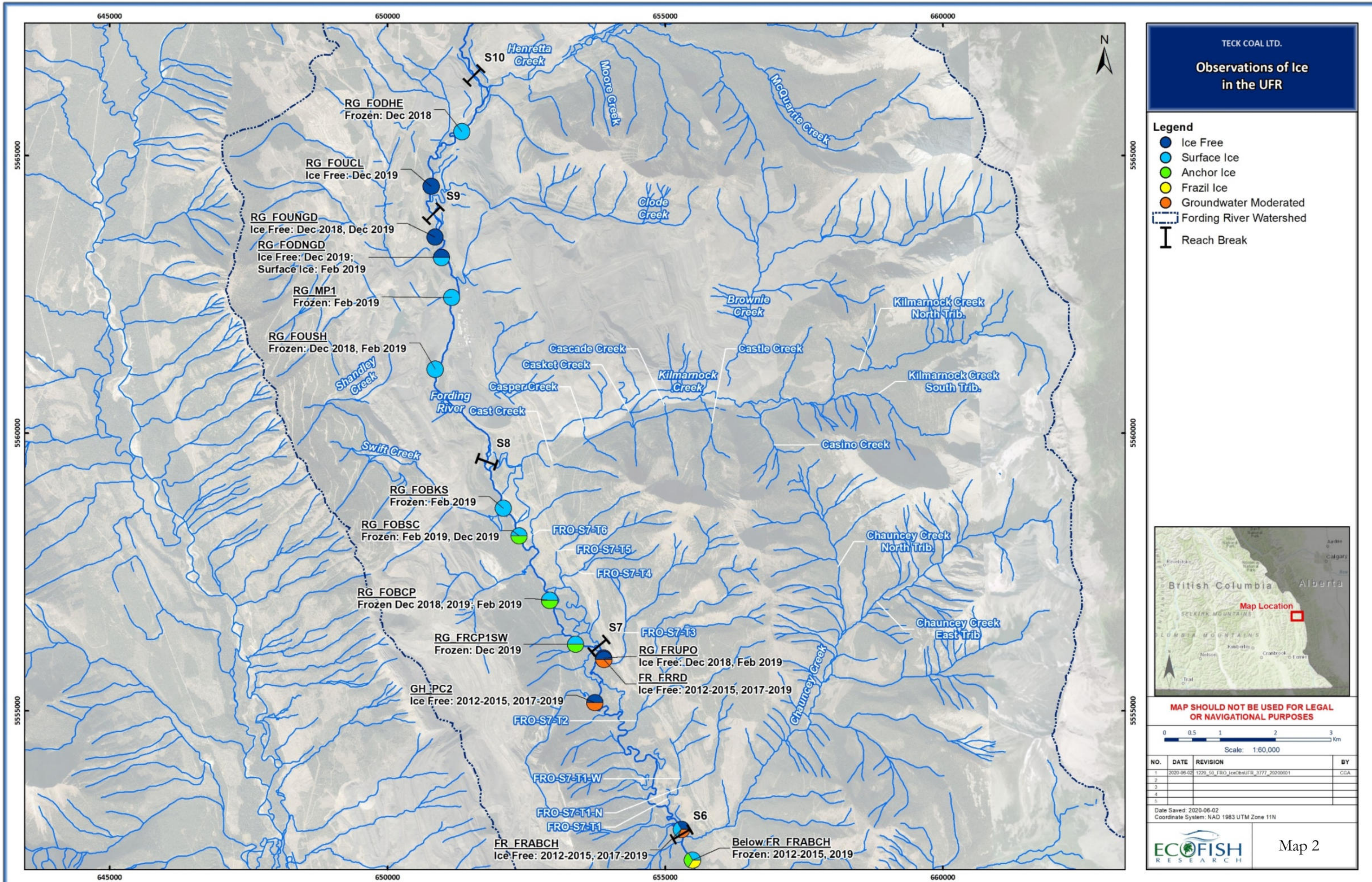
Personal Communications

Cope, S. 2020. Westslope Fisheries. Personal Communication. Email communication with Todd Hatfield, March 25 2020

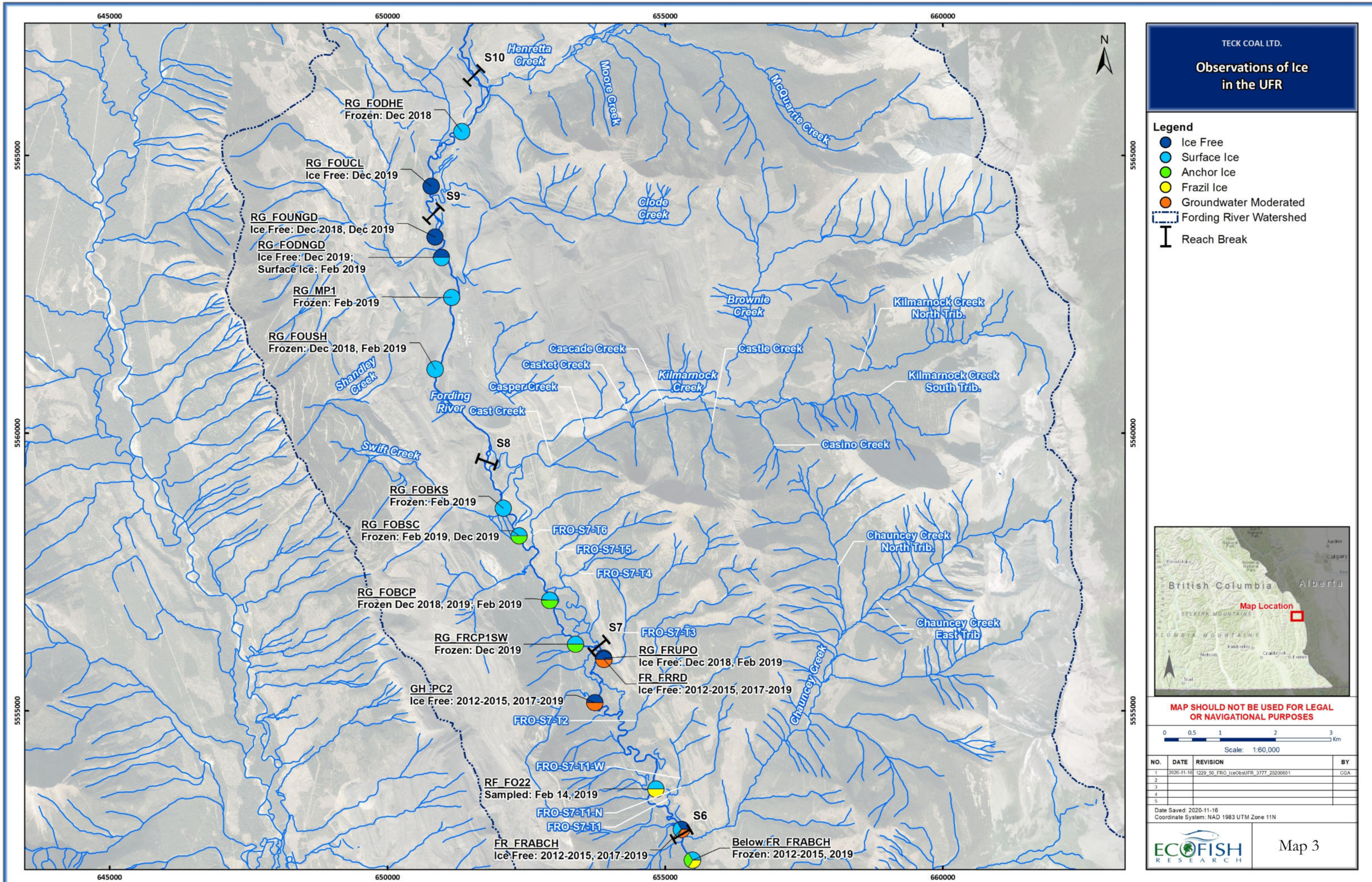
PROJECT MAPS



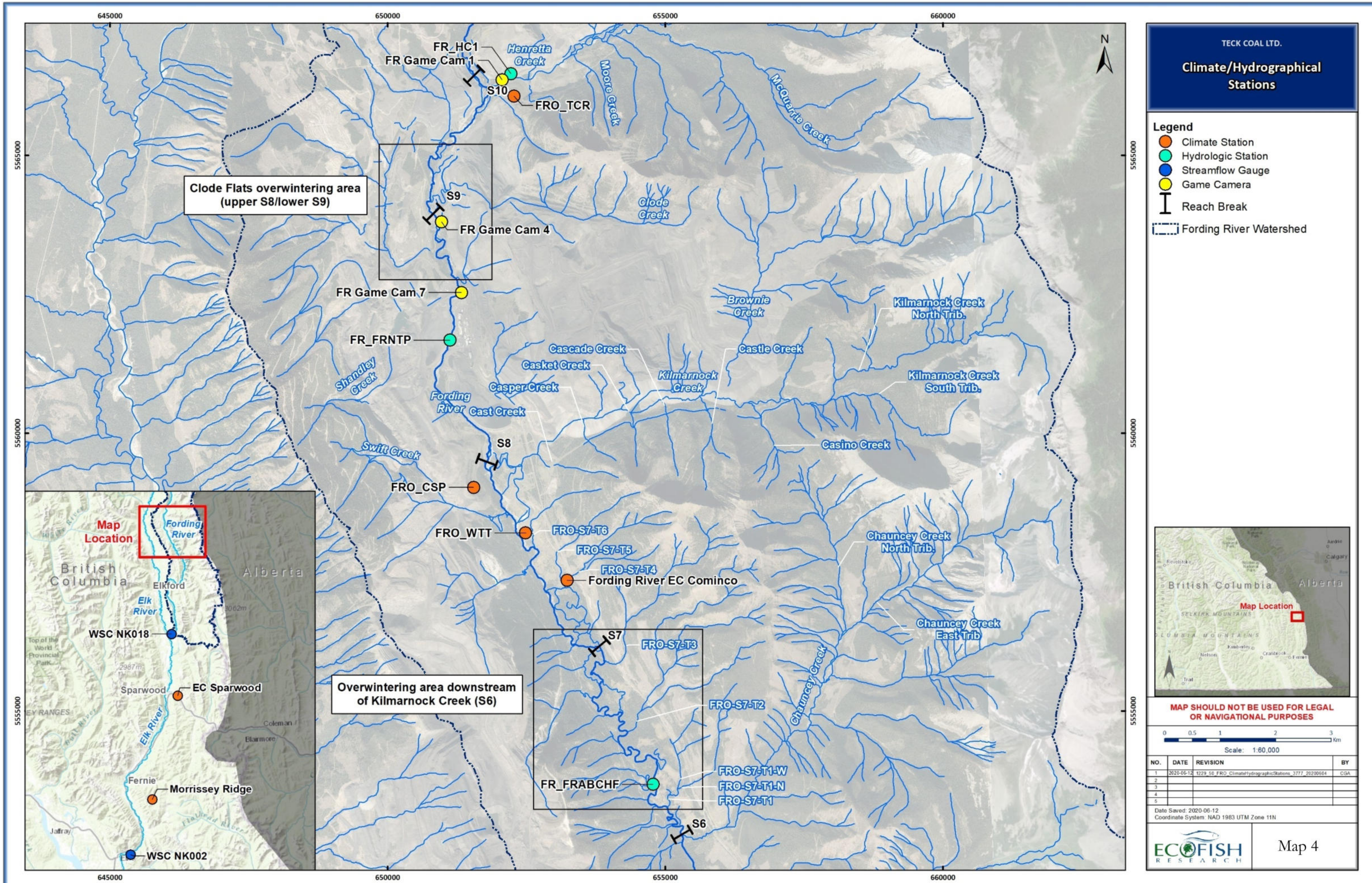
Path: M:\Projects-Active\1229_EVWQP\MXD\Hydrology\1229_50_FRO_OverwinteringLocs_3777_20200601.mxd



Path: M:\Projects-Active\1229_EVWQP\MXD\Hydrology\1229_50_FRO_IceObsUFR_3777_20200601.mxd



Path: M:\Projects-Active\1229_EVWQP\MXD\Hydrology\1229_50_FRO_IceObsUFR_3777_20200601.mxd



Path: M:\Projects-Active\1229_EVWQP\MXD\Hydrology\1229_50_FRO_ClimateHydrographicStations_3777_20200604.mxd

APPENDICES

Appendix A. FRO LAEMP Photo Records (2016 – 2020)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF MAPS

1. LAEMP PHOTOS FROM GH_FR3

1. GH_FR3 - 2017/18

Figure 1. GH_FR3, December 12, 2017.

Figure 2. GH_FR3, January 17, 2018.

Figure 3. GH_FR3, February 5, 2018.

2. GH_FR3 - 2018/19

Figure 4. GH_FR3, December 4, 2018.

Figure 5. GH_FR3, January 29, 2019.

Figure 6. GH_FR3, February 27, 2019.

Figure 7. GH_FR3, March 11, 2019.

3. GH_FR3 – 2019/20

Figure 8. GH_FR3, December 11, 2019.

Figure 9. GH_FR3, January 6, 2020.

Figure 10. GH_FR3, February 6, 2020.

Figure 11. GH_FR3, March 4, 2020.

2. LAEMP PHOTOS FROM FR_CP1SW

1. FR_CP1SW – 2017/18

Figure 12. FR_CP1SW, November 15, 2017.

Figure 13. FR_CP1SW, December 13, 2017.

Figure 14. FR_CP1SW January 16, 2017.

Figure 15. FR_CP1SW, March 13, 2017.

2. FR_CP1SW – 2018/19

Figure 16. FR_CP1SW, November 6, 2018.

Figure 17. FR_CP1SW, December 5, 2018.

Figure 18. FR_CP1SW, January 30, 2019.

Figure 19. FR_CP1SW, March 12, 2019.

3. FR_CP1SW – 2019/20

Figure 20. FR_CP1SW, December 9, 2019.

Figure 21. FR_CP1SW, January 7, 2020.

Figure 22. FR_CP1SW, April 2, 2020.

3. LAEMP PHOTOS FROM FR_FRABCH

1. FR_FRABCH – 2017/18

Figure 23. FR_FRABCH, November 14, 2017.

Figure 24. FR_FRABCH, December 12, 2017.

Figure 25. FR_FRABCH, January 15, 2018.

Figure 26. FR_FRABCH, February 6, 2018.

Figure 27. FR-FRABCH, March 12, 2018.

2. FR_FRABCH – 2018/19

Figure 28. FR_FRABCH, December 7, 2018.

Figure 29. FR_FRABCH, January 31, 2019.

Figure 30. FR_FRABCH, February 26, 2019.

Figure 31. FR_FRABCH, March 13, 2019.

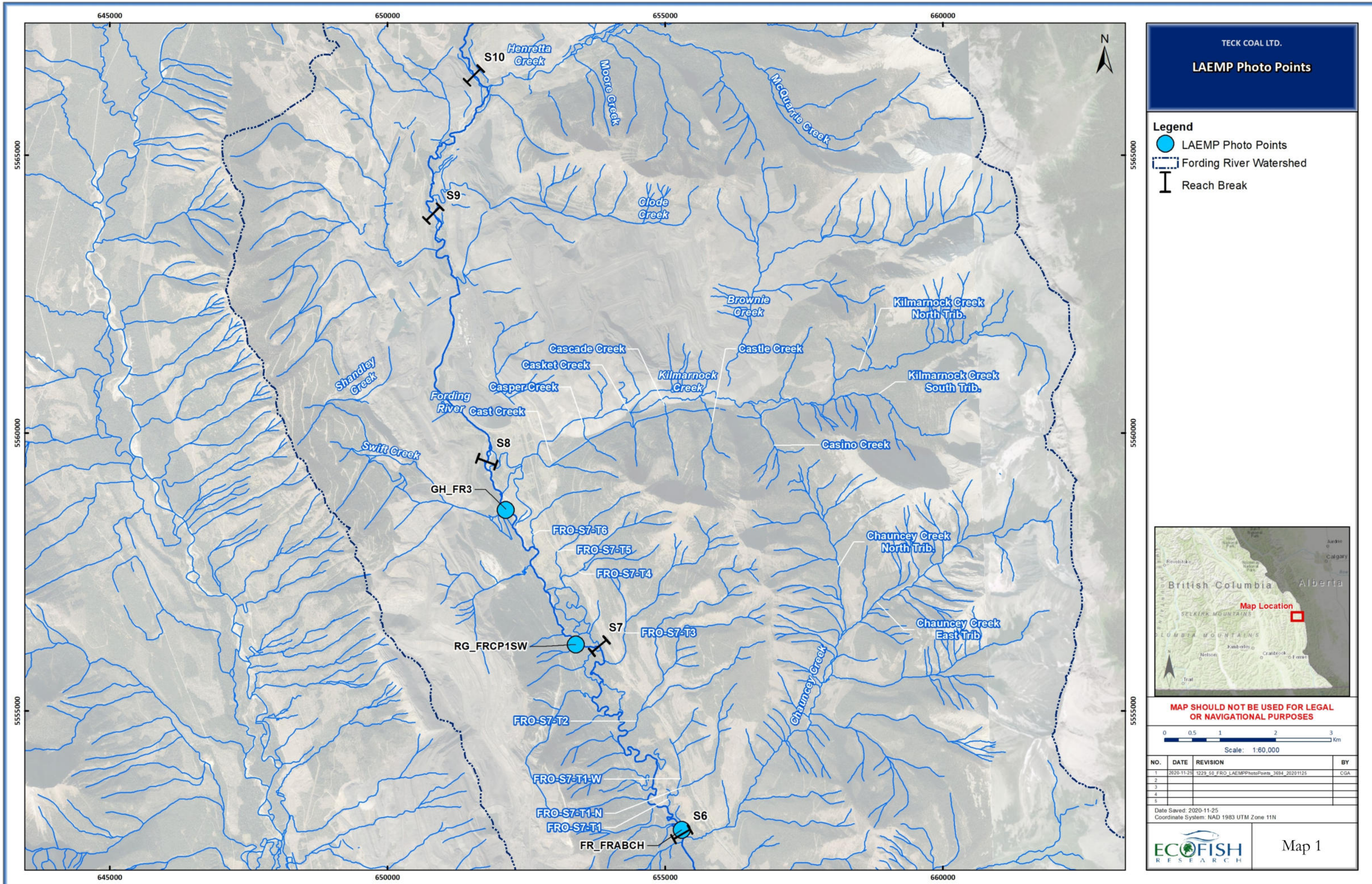
3. FR_FRABCH – 2019/20

Figure 32. FR_FRABCH, December 11, 2019.

Figure 33. FR_FRABCH, January 7, 2020.

Figure 34. FR_FRABCH, February 4, 2020.

Figure 35. FR_FRABCH, March 3, 2020.



Path: M:\Projects-Active\1229_EVWQP\MXD\Hydrology\1229_50_FRO_LAEMPPhotoPoints_3694_20201125.mxd