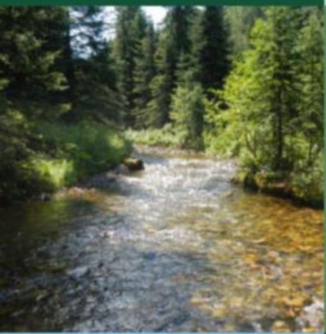

EVALUATION OF CAUSE

Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population

March 2023

Report prepared for Teck Coal Limited by Evaluation of Cause Team

When citing the Evaluation of Cause Report use:

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Executive Summary

This Evaluation of Cause focuses on the population of Westslope Cutthroat Trout *(Oncorhynchus clarkii lewisi)* in Harmer Creek, a small stream located in the Elk Valley in the southeast corner of British Columbia, Canada. An analysis of population monitoring data collected from 2017 to 2019 indicated that the abundance of juvenile Westslope Cutthroat Trout was very low. It was low enough to indicate that few fish survived their first year to be "recruited" to the population (Cope & Cope, 2020). Teck Coal Limited (Teck Coal) initiated this Evaluation of Cause to evaluate and report on what may have contributed to the low recruitment.

BACKGROUND

The lands in Qukin ʔamakʔis (the Elk Valley) have been occupied by the Ktunaxa Nation for more than 10,000 years, and the Ktunaxa people continue to value wuʔu (water) and ʔa·kxamis ʼqapi qapsin (All Living Things) highly. The Elk Valley contains the main stem of the Elk River, and one of the tributaries to the Elk River is Grave Creek. Grave Creek has tributaries of its own, including Harmer Creek. Upstream of a waterfall on Grave Creek, Harmer and Grave Creeks are home to an isolated population of genetically pure Westslope Cutthroat Trout. This fish species is iconic, highly valued in the area and of special concern under federal and provincial legislation and policy.

In the Grave Creek watershed, disturbance from logging, roads and other development is limited, except for an area in the southwest of the Harmer Creek sub-watershed which is part of Teck Coal's Elkview Operations. These operations influence water quality both in Harmer Creek, through its tributary Dry Creek, and in Grave Creek, below its confluence with Harmer Creek. In addition, as part of mine operations, the Harmer Dam was built in 1971. Until that time, the Harmer Creek and Grave Creek fish populations were a single population. When the dam was constructed, it effectively created separate populations in Harmer Creek and Grave Creek by restricting the upstream movement of fish.

WHAT HAPPENED TO THE JUVENILE FISH?

Westslope Cutthroat Trout populations in both Harmer and Grave Creeks are part of Teck Coal's aquatic monitoring program. Analysis of annual monitoring data for 2017 to 2021 indicated that recruitment for the 2017 to 2019 spawn years in the Harmer Creek population and for the 2018 spawn year in the Grave Creek population was likely less than the long-term average required for the populations to be stable. In other words, if the patterns in those years persisted, the spawning fish would not have produced enough young to replace themselves in their lifetime, and the number of fish in the population would have declined. Variability in recruitment rates among years is expected. However, recruitment in the Harmer Creek population was not only below replacement in those three spawn years, but it was also notably lower than in the Grave Creek population. In addition, recruitment for the 2018 spawn year in Harmer Creek was extremely low compared to other years in Harmer Creek. In the Evaluation of Cause, the below replacement recruitment in the 2017 to 2019 spawn years in the Harmer Creek population is referred to as Reduced Recruitment, and the extremely low recruitment for the Harmer Creek population for the 2018 spawn year is referred to as Recruitment Failure.

OUR APPROACH TO UNDERSTANDING WHAT CONTRIBUTED TO THE RECRUITMENT PATTERNS

Teck Coal established an Evaluation of Cause Team (the Team) composed of 14 Subject Matter Experts. Representatives from the Ktunaxa Nation Council, various regulatory agencies and the Independent Scientist of the Environmental Monitoring Committee (Permit 107517) (Participants) provided input throughout the process. Together we determined the overarching question addressed in the Evaluation of Cause, which was: **What potential stressors can explain changes in the Harmer Creek Westslope Cutthroat Trout population over time, specifically with respect to patterns of Reduced Recruitment (including Recruitment Failure)?**

The Team initially developed an understanding of the recruitment patterns and which life stages were most likely contributing to them. At the same time, through engagement with the Evaluation of Cause participants (i.e., Ktunaxa Nation Council, other government agencies and committees), a suite of potential stressors that may have contributed to the Reduced Recruitment and Recruitment Failure patterns in the Harmer Creek population were identified. For each potential stressor, Subject Matter Experts characterized patterns for the Harmer Creek and Grave Creek population areas, compared the differences between the two population areas for the period of Reduced Recruitment and identified differences within the Harmer Creek population area between 2018, when there was Recruitment Failure, and 2017 and 2019 when there was not. They then compared the patterns in the stressors with patterns in Westslope Cutthroat Trout endpoints (e.g., egg to age-1 survival, body condition). The Subject Matter Experts then evaluated causal pathways by which potential stressors could have impacted the trout and determined if the stressors were present at a sufficient magnitude and for a sufficient duration to have had an adverse effect on the fish that could have contributed to an impact on recruitment. Finally, the Team estimated the potential contribution of stressors to the recruitment patterns.

INTEGRATED FINDINGS

The Team developed an integrated hypothesis about the combination of stressors most likely to have contributed to the Reduced Recruitment and Recruitment Failure in the Harmer Creek population. This was based on analyzing the fish monitoring data and the findings of the individual stressor reports. The data suggested that the recruitment patterns were primarily caused by low survival of fish in their first winter, due to their small size at the onset of winter. Although fish can feed in winter, they get vastly more of their nutrition during the growing season and rely on energy stores accumulated during the growing season to meet the metabolic requirements to survive winter. In addition, larger fish use their energy more efficiently than smaller fish. If fish do not have enough energy to survive winter, either because their energy stores are insufficient and/or their energetic costs are too high, this can result in fewer fish being recruited to the population after their first full year. In addition, other potential stressors could have directly reduced fish survival. The key findings for each recruitment pattern are summarized below.

Reduced Recruitment for the 2017 to 2019 Spawning Cohorts

The primary stressors that the Evaluation of Cause Team identified as contributing to Reduced Recruitment from 2017 to 2019 in the Harmer Creek population were growing season degree days (i.e., thermal energy accumulated through the growing season), exposure to dietary selenium and habitat conditions in Dry Creek.

As noted above, Westslope Cutthroat Trout in the Harmer Creek population are small going into their first winter and, as result, they are susceptible to increased overwintering mortality. We found that their small size is likely related to the following stressors that could have impacted recruitment through the energetic pathway.

- **Growing Season Degree Days.** Fish growth is influenced by the accumulation of thermal energy during the growing season. Because the growing season is short and the water temperatures are low, the Harmer Creek population area has low growing season degree days, resulting in small fish. In Harmer Creek, fish in their first year are consistently shorter than those in Grave Creek, which has higher growing season degree days, on average. Fish growth is influenced by the accumulation of thermal energy during the growing season. Because the growing season is short and the water temperatures are low, the Harmer Creek population area has low growing season degree days, resulting in small fish. In Harmer Creek, fish in their first year are consistently shorter than those in Grave Creek, which has higher growing season degree days, on average.

- **Selenium**. Concentrations of selenium have increased in recent years in the water and sediment of the Harmer Creek population area. Selenium is a bioaccumulative substance that disproportionately accumulates in biota, including in the diet of Westslope Cutthroat Trout, relative to water. Based on available information for the period of Reduced Recruitment, dietary selenium was high enough in the Harmer Creek mainstem to have been able to cause reduced growth in fish in their first growing season.

Both growing season degree days and selenium were found to explain some of the difference in recruitment between the Harmer Creek and Grave Creek populations. Based on modelling that estimated recruitment using different levels of these stressors, growing season degree days explained more of the difference in recruitment than selenium exposure did. However, both were at levels that could have contributed to reduced growth in fish in their first growing season, thereby affecting their energetic status and ultimately recruitment. But these stressors alone did not fully explain why recruitment was low in Harmer Creek from 2017 to 2019, and it is likely that other unknown factors also contributed.

Habitat conditions in Dry Creek. The Team also evaluated the potential contribution of habitat conditions in Dry Creek itself to Reduced Recruitment. Habitat quality has been impacted in Dry Creek since before Reduced Recruitment was detected. Spawning has largely been precluded by calcite formation in the substrate, and concentrations of sulphate and selenium have been sufficient to affect early life stage development and survival since at least 2010.

The available data indicate that dietary selenium was at high enough concentrations in food items to have caused reproductive effects in fish that were feeding in the lower reaches of Dry Creek or in the Harmer Creek Sedimentation Pond. While there are no data to indicate how many adult fish may have been exposed to selenium in those areas, a conservative estimate (i.e., assuming adult densities were the same in Dry Creek as the rest of the Harmer Creek population area) was that this would explain about 4% of the recruitment rate for the Harmer Creek population.

Recruitment Failure in the 2018 Spawning Cohort

In the Harmer Creek population area, growing season degree days, selenium and Dry Creek habitat conditions in 2018 were similar to those in 2017 and 2019. Therefore, while these stressors acted on recruitment as described above, they do not explain the Recruitment Failure that occurred over and above the observed Reduced Recruitment. The Team hypothesizes that

Recruitment Failure for the 2018 spawning cohort was related to the small size of age-0 fish in 2018. Age-0 fish in the fall of 2018 had lower body condition and were shorter than in other years, indicating that they had low energy reserves entering the 2018/2019 winter. Because fish were small at the onset of winter, the 2018 spawning cohort would have been more vulnerable to other stressors. For instance, the early winter of 2018/2019 was unusually warm and was followed by an extreme cold snap in February/March, and an evaluation of ice formation indicated that ice may have extended further upstream in early 2019 than in more moderate years. This may have led to challenging conditions that could have been energetically costly to the small fish and/or may have led to direct mortality due to icing conditions; however, there were no direct observations to support further analysis. There was also no direct evidence to explain why fish were shorter in the Harmer Creek population in 2018 than other years or why body condition was low in 2018 in both the Harmer Creek and Grave Creek populations. The Team believes those were likely due to factors that reduced energy intake and/or energy assimilation in the summer of 2018.

MANAGEMENT RESPONSE AND WAY FORWARD

Work on the Evaluation of Cause spanned a two-year period. Simultaneously, several other projects were ongoing to understand and improve conditions within the watershed. In addition, some key data gaps identified in the Evaluation of Cause process were addressed in ongoing studies and resulted in changes to monitoring. Looking into the future of this watershed, our understanding is that Teck Coal is working with the Ktunaxa Nation Council and agencies to develop a fish recovery plan to ensure the long-term viability of this Westslope Cutthroat Trout population.

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Ktunaxa “lifeways” within Qukin ʔamakʔis © Darcy Luke & Marisa Phillips.

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Subject Matter Expert Reports

The Evaluation of Cause report is underpinned by Subject Matter Expert reports and memos. The authors of these documents are acknowledged in the table below. Full report citations are provided in Appendix A.

Report Title	Authors
Subject Matter Expert Report: *Calcite. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.*	M. Hocking, PhD, RPBio R. N. Cloutier, MSc, RPBio J. Braga, PhD T. Hatfield, PhD, RPBio
Subject Matter Expert Report: *Dissolved Oxygen. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.*	J. Abell, PhD, EP X. Yu, PhD, PEng J. Braga, PhD T. Hatfield, PhD, RPBio
Subject Matter Expert Report: *Energetic Status at the Onset of Winter Based on Fork Length and Wet Weight. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.*	J. Thorley, PhD, RPBio M. Branton, PhD, PAg
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Subject Matter Expert Report: *Water Temperature and Ice. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.*	M. Hocking, PhD, RPBio C. Whelan, MSc, RPBio T. Hatfield, PhD, RPBio
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Evaluation of Groundwater as a Potential Stressor to Westslope Cutthroat Trout in the Harmer and Grave Creek Watersheds	E. Canham, MSc, PGeo S. Humphries, MSc, PGeo

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Acronyms

Abbreviation	Term
ATU	accumulated thermal unit
BC	British Columbia
BCWQG	British Columbia Water Quality Guidelines
BC WSQG	British Columbia Working Sediment Quality Guidelines
BZY (-R1, etc.)	Balzy Creek
CI	confidence/compatibility/credible interval (see glossary)
COPC	constituent of potential concern
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DC (-R1, etc.)	Dry Creek
DO	dissolved oxygen
ENV	BC Ministry of Environment and Climate Change Strategy
EV-CEMF	Elk Valley Cumulative Effects Management Framework Working Group
EVFFHC	Elk Valley Fish and Fish Habitat Committee
EVO	Elkview Operations
GRV (-R1, etc.)	Grave Creek in stream reach names
GSDD	growing season degree days
HRM (-R1, etc.)	Harmer Creek in stream reach names
LWD	large woody debris
rkm	river kilometre
SEV	severity of ill effects
SME	Subject Matter Expert
SWE	snow water equivalents

TDS	total dissolved solids
TSS	total suspended solids
WCT	Westslope Cutthroat Trout
WSC	Water Survey of Canada

1. Introduction

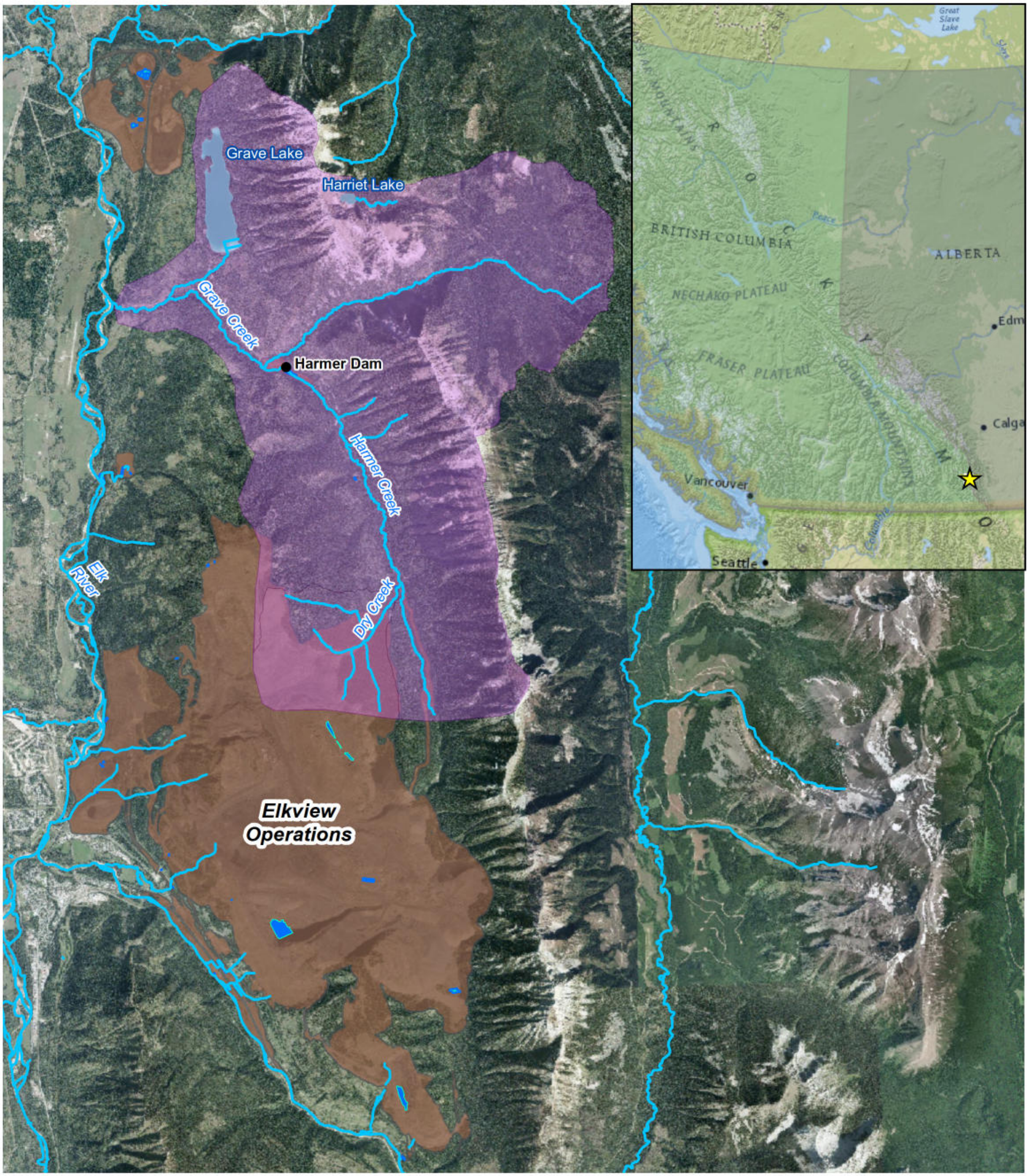
1.1. BACKGROUND

The Elk Valley (Qukin ʔamaʔkis) is located in the southeast corner of British Columbia (BC), Canada. “Ktunaxa people have occupied Qukin ʔamaʔkis for over 10,000 years. … The value and significance of ʔa·kxamisʼqapi qapsin (All Living Things) to the Ktunaxa Nation and in Qukin ʔamaʔkis must not be understated” (text provided by the Ktunaxa Nation Council [KNC]).

The Elk Valley contains the main stem of the Elk River, and one of the tributaries to the Elk River is Grave Creek. Grave Creek has tributaries of its own, including Harmer Creek. Harmer Creek and its tributaries, Dry Creek in particular, are the focus of this report. A natural waterfall in Grave Creek 2.1 km upstream of its confluence with the Elk River forms a barrier to upstream fish passage (see Chapter 2, Figure 2-3). Above this waterfall, an isolated, genetically distinct population of Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*) inhabits the Grave Creek watershed. Westslope Cutthroat Trout are of special concern to the Ktunaxa Nation and are also of special concern under federal and provincial legislation and policy.

The location of the Grave Creek watershed is shown on the following page in Figure 1-1. Its caption is:

Figure 1-1. Location of the Grave Creek watershed



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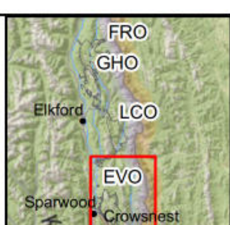

Grave Creek Watershed Overview

★	Grave Creek Watershed Location
Stream	
Grave Creek Watershed	
Permit Boundary	

N

0 180,000 360,000 Meters

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The WCT in the Grave Creek watershed are separated into the Harmer Creek and Grave Creek population areas[1] by the Harmer Creek Dam, which is at the downstream end of the Harmer Creek Sedimentation Pond (see Figure 2-3, Chapter 2). The Harmer Creek Sedimentation Pond and associated Harmer Creek Dam are part of the infrastructure that supports Elkview Operations (EVO). Elkview Operations is an open pit steelmaking coal mine operated by Teck Coal Limited (Teck Coal) and located in an adjacent watershed. This mine influences the Grave Creek watershed through Dry Creek, where Dry Creek flows into Harmer Creek which flows into Grave Creek. The Grave Creek watershed is subject to limited disturbance from logging, roads and other development. Teck Coal undertakes aquatic monitoring programs in the Grave Creek watershed, which, since 2017, have included monitoring the fish population annually.

Using fish population monitoring data collected from 2017 to 2019, Cope and Cope (2020) reported low abundance of juvenile (i.e., < 150 mm) WCT in Harmer Creek, which was attributed to apparent Recruitment Failure. In 2020, Teck Coal initiated an Evaluation of Cause — a process to evaluate and report on what may have contributed to the apparent Recruitment Failure. Data were analyzed from the annual fish monitoring programs in the Harmer and Grave Creek population areas from 2017 to 2021 (Thorley et al., 2022; this report, Chapter 4). From the analysis, several patterns related to recruitment[2] were identified:

- Reduced Recruitment[3] occurred during the 2017, 2018 and 2019 spawn years[4] in the Harmer Creek population, and it occurred in the 2018 spawn year in the Grave Creek population.
- The magnitude of Reduced Recruitment in the Harmer Creek population in the 2018 spawn year was significant enough to constitute Recruitment Failure[5].
- Recruitment was Above Replacement[6] for the 2020 spawn year in both the Harmer and Grave Creek populations.

[1] "Grave Creek population area" includes Grave Creek upstream of the waterfall at river kilometre (rkm) 2.1 and Harmer Creek below the Harmer Sedimentation Pond. "Harmer Creek population area" includes Harmer Creek and its tributaries (including Dry Creek) from the Harmer Sedimentation Pond and upstream.

[2] Recruitment refers to the addition of new individuals to a population through reproduction. For the Evaluation of Cause, this is documented during the fall (i.e., late September/early October) fish monitoring the year after the fish are spawned.

[3] For the purposes of the Evaluation of Cause, Reduced Recruitment is defined as a probability of > 50% that annual recruitment was < 100% of that required for population replacement (see Chapter 4).

[4] The spawn year is the year fish eggs were deposited and fry emerged.

[5] For the purposes of the Evaluation of Cause, Recruitment Failure is defined as a probability of > 50% that annual recruitment is < 10% of that required for population replacement (see Chapter 4).

[6] For the purposes of the Evaluation of Cause, Recruitment Above Replacement is defined as a probability of > 50% that annual recruitment is > 100% of that required for population replacement (see Chapter 4)

The recruitment patterns from 2017, 2018 and 2019 in Harmer Creek are collectively referred to as Reduced Recruitment in the Evaluation of Cause report. To the extent that there are specific nuances within 2017 to 2019 recruitment patterns that correlate with individual years, such as the 2018 Recruitment Failure, these are referenced as appropriate.

The Evaluation of Cause investigated, evaluated, and in this document, reports on the reasons for the Reduced Recruitment.

1.2. HOW THE EVALUATION OF CAUSE WAS APPROACHED

When the Evaluation of Cause was initiated, an *Evaluation of Cause Team* (the Team) was established. The Team was composed of 14 Subject Matter Experts (SMEs), all of whom are Qualified Professionals, and it was coordinated by a Team Lead and Technical Team Lead.

- The Team Leads liaised with Teck Coal, led the overall process and supported Teck Coal's engagement with the participants.
- The SMEs contributed to the causal evaluation in their areas of expertise and collaborated with other team members, as needed. They prepared presentations and, ultimately, reports. The SME team members and their qualifications and experience are listed in Appendix A.
- The Technical Team Lead and a subset of SMEs wrote this overarching document and conducted an integrated assessment of all the population and stressor data to support conclusions about the relative contribution of each potential stressor to the Reduced Recruitment observed in the Harmer Creek population area.

Throughout the Evaluation of Cause process, the Team engaged with the Ktunaxa Nation Council and various agencies (the Participants) whose representatives are recognized in this report's Acknowledgements.

The key Participant organizations involved included:

- Ktunaxa Nation Council (KNC)
- BC Ministry of Energy, Mines and Low Carbon Innovation
- BC Ministry Environment and Climate Change Strategy
- BC Ministry of Forests
- BC Ministry of Water, Land and Resource Stewardship
- Environmental Assessment Office

- Permit 107517 Environmental Monitoring Committee (EMC)
- Elk Valley Fish and Fish Habitat Committee (EVFFHC)

Teck Coal (see Acknowledgements) supported the Team by:

- Providing information and data to the SMEs
- Reviewing deliverables for facts and accuracy and, where applicable, providing technical input
- Providing funding for the Evaluation of Cause Team to perform their work
- Leading engagement with the KNC, regulators and technical committees (EVFFHC and EMC)

During the Evaluation of Cause process, the Team held regularly scheduled meetings with the Participants. These meetings included discussions about the overarching question that would be evaluated and about technical issues, such as identifying potential stressors, natural and anthropogenic, which had the potential to impact recruitment in the Harmer Creek WCT population. This was an iterative process driven largely by the Team's evolving understanding of the stressors and of key WCT population parameters, such as abundance, density, size, condition and patterns of recruitment over time. Once the approach was finalized and the data were compiled, SMEs presented methods and draft results for informal input from participants. The SMEs then revised their work to address feedback and, subsequently, participants reviewed and commented on the reports. As part of this process, several new reports and memos were written to address questions that arose during the Evaluation of Cause. Finally, results of the analysis of the population monitoring data and potential stressor assessments were integrated. The integration considered how potential stressors may have contributed individually or interacted to affect recruitment in the Harmer Creek population.

1.3. HOW THE EVALUATION OF CAUSE PROCESS WAS DEVELOPED AND IMPLEMENTED

The Evaluation of Cause Project Team investigated one overarching question: **What potential stressors can explain changes in the Harmer Creek Westslope Cutthroat Trout population over time, specifically with respect to patterns of Reduced Recruitment?** The Team developed a systematic and objective approach with five main activities, as shown in Figure 1-2.

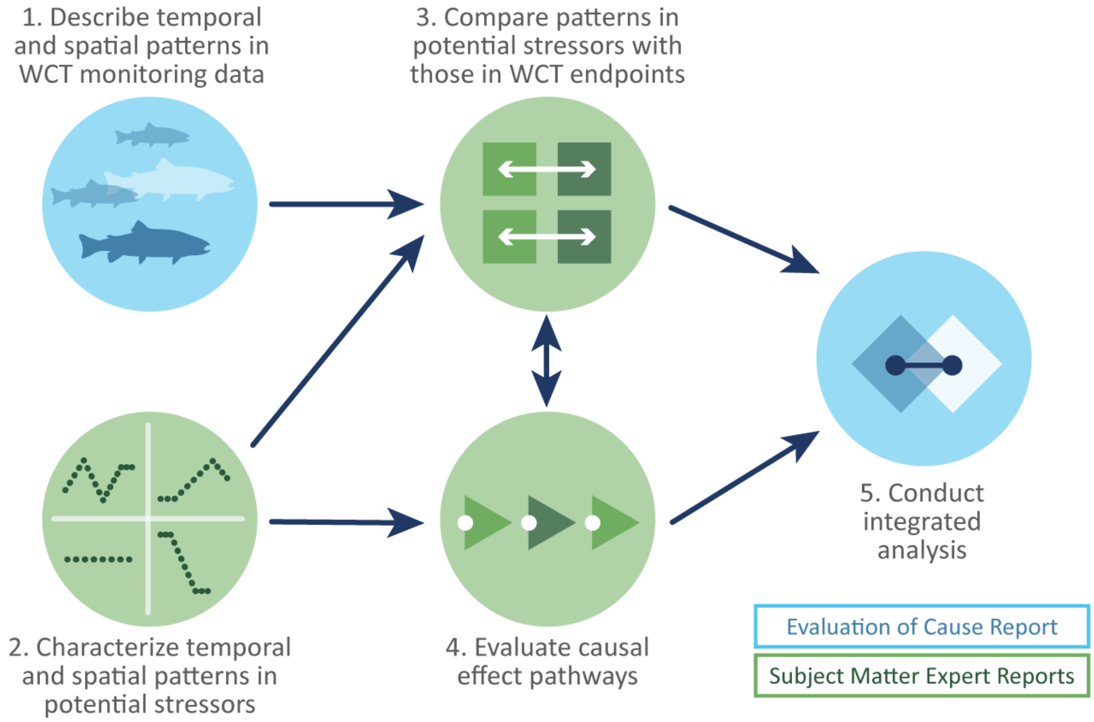


Figure 1-2. Conceptual approach to the Evaluation of Cause for the Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout population

The following subsections describe each of the five steps, which were to some degree concurrently delivered. Ahead of and throughout these steps, watershed-specific data were compiled and updated.

The Evaluation of Cause process generated 11 SME reports and four memoranda, which were prepared and then reviewed as described below. The reports and documents are listed in the Acknowledgements.

1.3.1. Step 1: Describe Temporal and Spatial Patterns in WCT Population Parameters

Historical WCT population data and data collected in ongoing monitoring programs (2017–2021) were summarized and used to describe broad temporal patterns in WCT abundance. The data from 2017 to 2021 (reported in Thorley et al., 2022) were used to assess temporal and spatial patterns and trends in WCT population parameters, including size, condition and recruitment. The Grave Creek population area was used as a reference area for this evaluation.

The results are provided in Chapter 4. This information was relayed to the SMEs and Participants as it was developed.

1.3.2. Step 2: Characterize Temporal and Spatial Patterns in Potential Stressors

All currently available data[7] for the potential stressors were compiled. The completeness of datasets, from a temporal and spatial perspective, varied by potential stressor and are described in the SME reports. The Team developed naming conventions for sampling locations and stream reaches to ensure congruency across the Evaluation of Cause and SME reports.

The general approach SMEs used to analyze potential stressors for the Evaluation of Cause was to (1) characterize trends in each stressor for the Harmer and Grave Creek population areas, (2) compare the trends between the two population areas and (3) identify any changes in the Harmer Creek population area during the period of Reduced Recruitment, including the Recruitment Failure of the 2018 spawn year.

The results of these analyses are detailed within the SME reports (see Acknowledgements and Appendix A) and are summarized in Chapter 5.

[7] The Evaluation of Cause process was initiated early in 2021 with currently available data. Although the process continued through mid-2022, data collected in 2021 were not included in the Evaluation of Cause because most stressor reports were already complete. Exceptions were made for the 2021 fish monitoring data, selenium data (because the selenium report was not complete and substantive new datasets were available) and water temperature data (because a new sampling location was added in upper Grave Creek that contributed to our understanding of the Grave Creek population area).

1.3.3. Step 3: Compare Temporal and Spatial Patterns Between Potential Stressors and Fish

The focus of individual SME reports was to compare patterns or changes in their respective stressors with those in WCT endpoints such as density, condition and recruitment. The purpose of the comparisons was to characterize the spatial and/or temporal co-occurrence of changes in stressors in the Harmer Creek population area with those in WCT endpoints. Where data were available, comparisons between these relationships in the Harmer Creek population area and those in the Grave Creek population area were made.

Terminology

Causal effect pathway: *The causal linkage(s) between exposure to stressors and effects. The linkages may be specific physical, ecological or physiological mechanisms, or they may be conceptual.*

Potential stressor: *Used in a general way to describe the main cause of a causal effect pathway, such as water quality, water temperature or calcite. Potential stressors can be natural or anthropogenic.*

The results of these analyses are detailed within the SME reports (see Acknowledgements and Appendix A) and are summarized in Chapter 5.

1.3.4. Step 4: Evaluate Causal Effect Pathways

The SMEs identified mechanisms by which their potential stressors could impact WCT. They used the data compiled in Step 3 to investigate causal effect pathways for their respective stressors and to determine if the stressors were present at a sufficient magnitude and for long enough to have had an adverse effect on WCT during the period of Reduced Recruitment, including the Recruitment Failure of the 2018 spawn year where appropriate.

The results of these analyses are detailed within the SME reports (see Acknowledgements and Appendix A) and are summarized in Chapter 5.

1.3.5. Step 5: Integrate Findings

Integrating the findings to evaluate the likely cause of the Reduced Recruitment required a process beyond the work the SMEs did for their individual stressors. It was done by a subset of the Team with input from all SMEs and Participants. While the SME reports were designed to investigate specific potential stressors, they were not designed to consider possible interactions with other stressors and baseline conditions that may have contributed to Reduced Recruitment. Consequently, using the knowledge base of the fish population analyses (Thorley et al., 2022; Chapter 4, this report) and SME reports, the Team discussed stressors and their interactions to identify and explore potential scenarios in which these could have contributed to the Reduced Recruitment. Interim findings were also presented to, and discussed with, the Participants. This process led to improvements in the way potential stressors were evaluated and how the SME results were characterized. In some cases, this resulted in additional analyses (e.g., water temperature and ice analyses) or reports (i.e., de Bruyn et al., 2022; Thorley & Branton, 2023), which provided in-depth evaluations of topics that were identified as requiring additional attention.

1.4. PREPARATION OF THE EVALUATION OF CAUSE REPORT

The Evaluation of Cause report (this document) was prepared by a core group of SMEs (see Acknowledgements), with input from the entire Evaluation of Cause Team. The report was prepared to:

- Provide readers with context for the way in which SME reports were developed and interpreted
- Describe the Grave Creek watershed, the history of development in the area, Harmer and Grave Creeks, and the natural history of WCT in these creeks
- Present fish monitoring data, which characterize the Harmer Creek and Grave Creek WCT populations over time, and which were used to identify patterns that could provide insight into the period of Reduced Recruitment, including the Recruitment Failure in the 2018 spawn year
- Summarize the findings of the SME reports and integrate them with what we know about the Reduced Recruitment
- Integrate what was learned about temporal and spatial patterns of stressors together with the findings of the SME reports, to determine the likelihood for each potential stressor to have contributed individually or through interactions with other stressors to the Reduced Recruitment in the Harmer Creek WCT population

- Report uncertainties and data gaps identified in the Evaluation of Cause and describe relevant data collection activities that are underway as part of other Teck Coal programs

The table below provides an overview of the six chapters in this report, which are aligned with each of the steps described in Section 1.3.

Chapter	Description	Why it's important
1. Introduction	Background information to the Evaluation of Cause	It sets the stage for the project.
2. Grave Creek Watershed	Overview of the Grave Creek watershed, including Harmer and Grave Creeks	Understanding historical conditions in the watershed provides context for understanding baseline conditions for WCT.
3. Westslope Cutthroat Trout	Overview of general WCT life history and introduction to the populations in the Grave Creek watershed	It provides the necessary context to understand the spatial and temporal distribution of WCT which is used in the assessment of the potential for their exposure to stressors.
4. Understanding the Reduced Recruitment	A detailed analysis of all available population data (Step 1)	Analysis supports understanding the recruitment patterns in the Harmer Creek population.
5. Summary of Findings from SME Reports	Summary of SME findings on potential stressors (Steps 2 to 4)	It provides a narrative and tabular summary of the findings of the SME reports that supports the integration in Chapter 6.
6. Integrated Findings	Description of what we did and what we found (Step 5)	This process integrates information about stressors and Harmer Creek WCT to understand the contribution of stressors of concern to the Reduced Recruitment.

1.5. EXTENSIVE REVIEWS WERE CONDUCTED

The SME reports, memos and the Evaluation of Cause report (this document) produced through the Evaluation of Cause process were subjected to a multi-phase review process. This included:

- Azimuth Reviewers, who provided consistency checks and technical reviews
- SME Reviewers, who performed technical reviews of each other's work and the Evaluation of Cause report
- Participant Reviewers from the KNC and the committees and agencies listed in Section 1.2, who performed technical reviews
- Teck Coal Reviewers, who reviewed for site-specific accuracy and confirmed that SMEs had been provided the available, relevant data.

1.6. MEETINGS AND WORKSHOPS WERE HELD

Engagement and collaboration took place throughout the Evaluation of Cause process. Across the SME team, this involved:

- About 90, weekly, full-team meetings with SMEs
- About 80 other SME meetings for technical discussions on key topics, as needed
- Two SME workshops
- Engagement with the agencies, KNC and committees. This, in turn, involved:
  - Roughly 25 bi-weekly meetings to discuss progress and make presentations
  - Five workshops, including SME overview presentations, where initial questions about SME reports were raised and discussions were held about how Evaluation of Cause findings were reached.

Note: The Evaluation of Cause took place largely during the COVID-19 pandemic, so the meetings, discussions and workshops took place remotely. While this posed communication challenges, these were mitigated by communicating more frequently, as evidenced by the numerous meetings.

2. The Grave Creek Watershed

2.1. INTRODUCTION

This chapter describes the history of the Grave Creek watershed, its tributaries and the state of watershed conditions for the Harmer Creek Evaluation of Cause.

The Ktunaxa people who have occupied Qukin ʔamakʔis (Elk Valley) for over 10,000 years provided the following statement:

Statement by Ktunaxa Nation Council Provided to Evaluation of Cause Team:

Ktunaxa people have occupied Qukin ʔamakʔis (Elk Valley) for over 10,000 years. There have been significant impacts to ʔa·kxamis'qapi qapsin (All Living Things) in this area due to coal mining and other activities like forestry. The Ktunaxa Nation Council (KNC) is actively engaged in addressing the considerable challenges we face with impacts to wuʔu (water) and ʔa·kxamis'qapi qapsin which includes all the beings that swim, like qustiṫ (trout).

The value and significance of ʔa·kxamis'qapi qapsin to the Ktunaxa Nation and in Qukin ʔamaʔkis must not be understated. The Ktunaxa Nation Council will continue to be a voice for those who cannot speak for themselves — for the sake of qustiṫ, wuʔu, our future generations, and for ʔa·kxamis'qapi qapsin. It is a critical part of our role and responsibility in Qukin ʔamaʔkis as is given to us by Creator. We remain the stewards of these lands and will continue to honour our relationships in the ways we've been taught for generation upon generation.

We think of this population of qustiṫ, known as the Westslope Cutthroat Trout, as being interconnected with ʔa·kxamis'qapi qapsin (All Living Things) — if this population is impacted, so is everything else.

Ktunaxa lifeways within Qukin ʔamakʔis are visually represented in Figure 2-1.

Figure 2-1. Ktunaxa lifeways within Qukin ʔamakʔis

This image symbolizes "Ktunaxa being Ktunaxa on the land," and the tangible and intangible connection between ʔamak ȼ wuʔu (the land and water) and ʔa'kxam̓ is q̓ api qapsin. It is a product of Ktunaxa community participatory research drawn by two Ktunaxa artists, Darcy Luke and Marisa Phillips.

The WCT population in the Grave Creek watershed is separated from the Elk River system by natural bedrock falls that are 1.0 and 2.1 km upstream from the Elk River. The falls form a natural barrier to fish passage that has historically isolated a population of WCT within the Grave Creek watershed. Throughout the watershed, fish habitat and connectivity have been altered, restored and lost by natural disturbance and more recent anthropogenic change. For example, when the Harmer Dam was constructed in 1971, it separated the WCT into two populations, the Grave Creek population and the Harmer Creek population. To evaluate the ability of these WCT populations to respond to change and disturbance and provide context for the Evaluation of Cause, it is necessary to understand both the natural and anthropogenic constraints on fish habitat in the Grave Creek watershed.

The purpose of this chapter is to establish the state of watershed conditions at the time of WCT Reduced Recruitment. The chapter describes the evolution of the Grave Creek watershed and its sub-watersheds (i.e., Harmer Creek) and the fish habitat that has been available from the last glaciation to 2017 to 2019 (the period of WCT Reduced Recruitment). Chapter 3 then discusses general ecology and life history of the WCT subspecies and specific attributes of the WCT populations in the Grave Creek watershed. Temporal and spatial patterns and trends in WCT population parameters in the Grave Creek watershed are described in Chapter 4, with a focus on the period of Reduced Recruitment.

This chapter is organized as follows:

- **Grave Creek watershed.** Overview of the Grave Creek watershed over time
- **Setting: Geology, hydrology and climate.** Description of the climatic, hydrologic and geologic context of the Grave Creek watershed, with a focus on how fish habitats were formed prior to industrial anthropogenic disturbances (i.e., prior to the early 1900s) and how natural factors continue to affect the watershed
- **Watershed-scale anthropogenic change.** Description of anthropogenic disturbances that occurred after 1900, including the large-scale mining and forestry activities that influenced the habitat available to WCT in the Grave Creek watershed up to present day
- **Changes to Westslope Cutthroat Trout habitat.** Description and quantification of changes in WCT habitat pre-mining and at present
- **Existing habitat condition.** Present day habitat conditions within each reach of Grave, Harmer and Dry Creeks

2.2. GRAVE CREEK WATERSHED

This section describes the boundaries of the Grave Creek watershed and the Grave Creek study area. These are different because the waterfalls on Grave Creek are a barrier to upstream movement of fish. Stream reaches follow the boundaries first delineated by Berdusco (2008). Both the Grave Creek watershed and Grave Creek study area are further delineated into sub-watersheds and WCT population areas. These are defined below and shown in Figure 2-2 and Figure 2-3.

Grave Creek watershed. The Grave Creek watershed flows into the Elk River upstream of Sparwood, BC (Figure 2-2). It is topographically diverse and ranges in elevation from 1,173 m to 2,494 m above sea level. The entire drainage area of 89.3 km^2 includes the **Harmer Creek sub-watershed** (30.3 km^2), which drains the **Dry Creek sub-watershed** (7.3 km^2). Dry Creek originates in the EVO mine property and flows northeast to its confluence with Harmer Creek, which flows north-northwest and joins Grave Creek approximately 600 m downstream of the Harmer Dam. Grave Creek originates on the eastern side of Sheep Mountain and Gaff Peak, where it flows westward and over the Grave Creek falls before entering the Elk River. Grave Lake Creek, the outflow of Grave Lake, is a tributary that flows into Grave Creek below the waterfall at river kilometre (rkm) 2.1, which is 2.1 km upstream of the confluence with the Elk River. There are two waterfalls in GRV-R1/R2, the first being Grave Creek falls (at rkm 1) and the second being the waterfall located at rkm 2.1 (Figure 2-3).

Grave Creek Watershed Reach Abbreviations

In this report, we use abbreviations for creek names and stream reaches.

Creeks are abbreviated as follows: Harmer Creek is HRM, Grave Creek is GRV and Dry Creek is DC.

Reaches associated with these creeks are abbreviated as "-R" followed by the associated number.

For example, Harmer Creek reach three is HRM-R3, Grave Creek reach two is GRV-R2 and Dry Creek reach one is DRC-R1.

Note that: "Harmer Mainstem" refers to HRM-R3 to HRM-R5.

Grave Creek study area. The Grave Creek study area is naturally accessible to the isolated WCT population upstream of the waterfall at rkm 2.1 (Figure 2-3 and Figure

2-4). It includes all mainstem and tributary reaches of the Grave Creek watershed upstream of this waterfall barrier to migration near the upstream end of GRV-R1 (Figure 2-3).

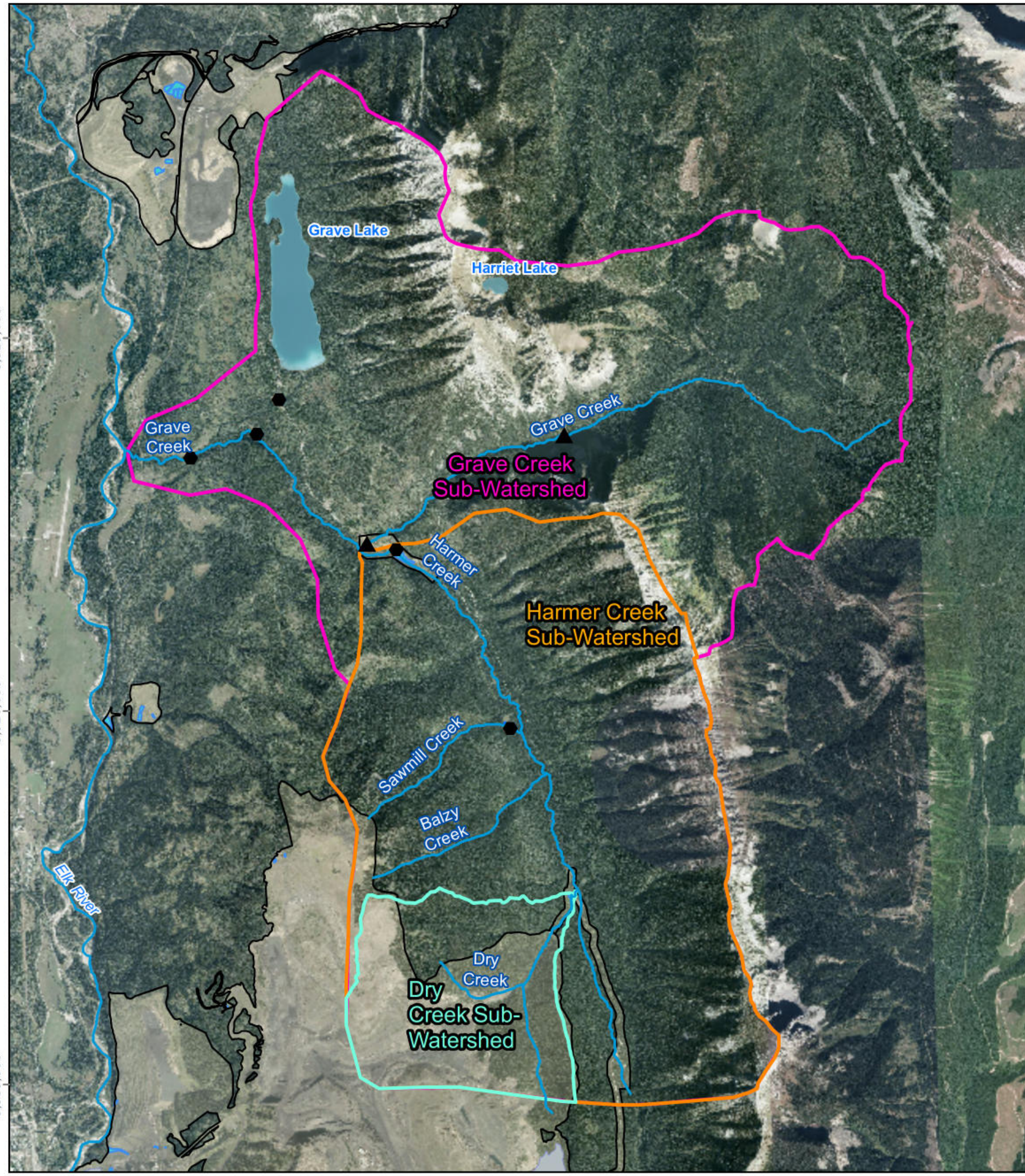
The Harmer Dam bisects the Grave Creek study area into two sub-areas, Grave Creek population area (28.5 km^2) and Harmer Creek population area (37.5 km^2, Figure 2-3). The Grave Creek population area includes all mainstem Grave Creek reaches upstream of the falls (i.e., GRV-R2 to GRV-R4), HRM-R1, which is the single reach downstream of Harmer Dam, and tributaries including Harriet Lake and its outlet channel. The Harmer Creek population area includes Harmer Creek reaches HRM-R2 to HRM-R6, Dry Creek and its south tributary, Sawmill Creek, Balzy Creek and unnamed tributaries primarily to the east of Harmer Creek.

Figures 2-2 and 2-3 appear on the following two pages. Their captions are:

Figure 2-2. Map of the Grave Creek watershed, which also shows the Harmer Creek sub-watershed and Dry Creek sub-watershed

Figure 2-3. Study area for Evaluation of Cause includes the Grave Creek and Harmer Creek population areas

Grave Creek Falls (at rkm 1) and the second waterfall (at rkm 2.1) are shown as "impassable barriers" in Grave Creek Reach 1 (GRV-R1). The Grave Creek population area begins upstream of the second waterfall.



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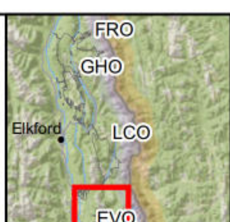

Watershed Boundaries

- ⬢ Impassable Barrier
- ▲ Historical Barrier
- Streams
- Permit Boundary
- Dry Creek Sub-Watershed
- Harmer Creek Sub-Watershed
- Grave Creek Sub-Watershed
- Watercourse

N

0 445 890 1,780 Metres

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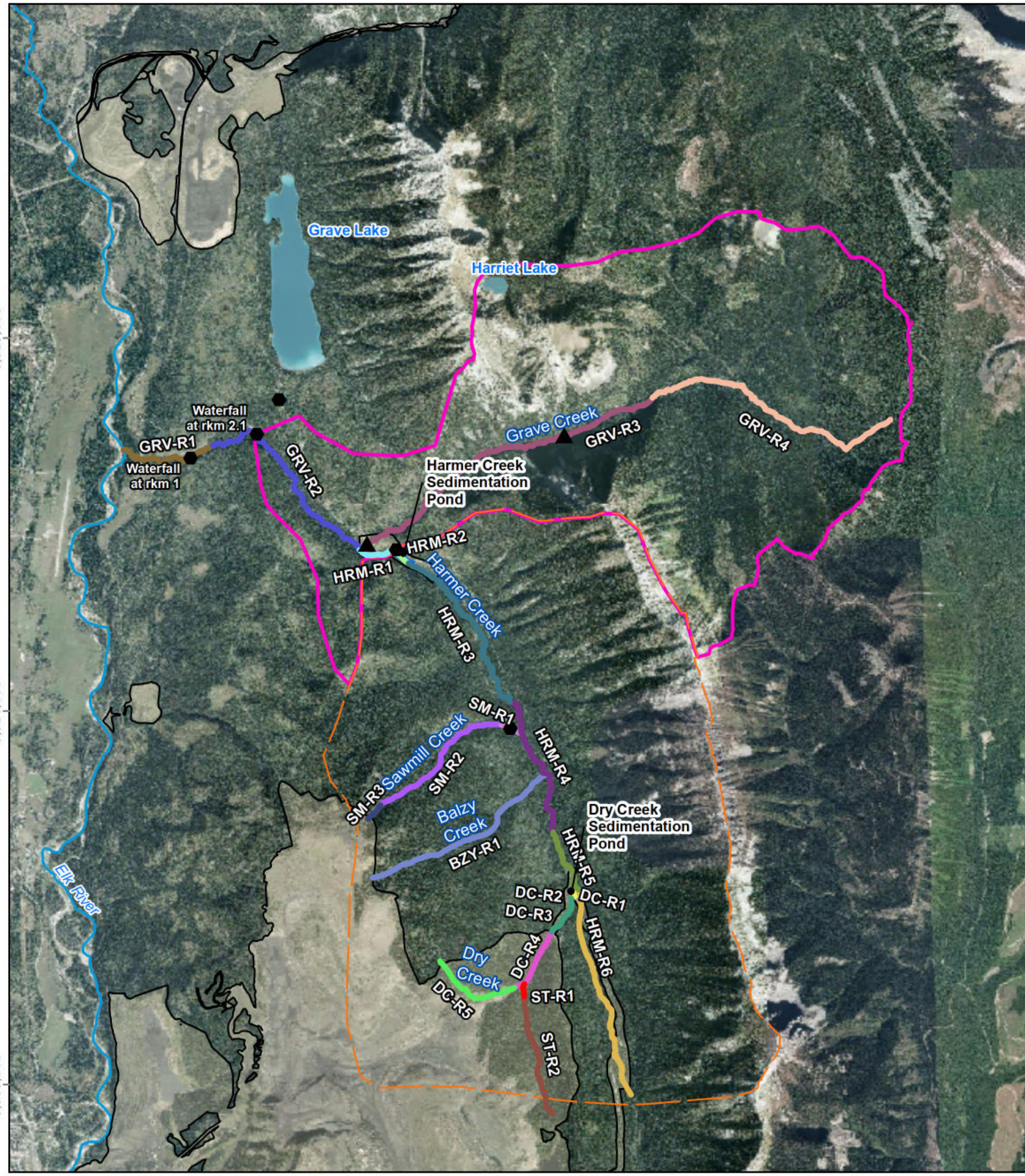

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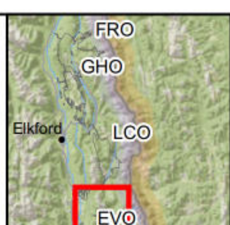

Fish Populaton Areas

- Impassable Barrier
- Historical Barrier
- Streams
- Settling Pond
- Grave Creek Updated
- Harmer Creek Population Area
- Permit Boundary

N

0 445 890 1,780 Metres

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Figure 2-4. Cross-channel view of the waterfall located at rkm 2.1, the downstream end of the Grave Creek population area

2.3. SETTING: GEOLOGY, HYDROLOGY AND CLIMATE

The setting of a watershed — climate, geology, soils, vegetation and topography — drives the form and function of a stream, which can change as a result of historical or contemporary disturbance, both natural and anthropogenic. Landscape change due to loss of forest cover or geologic disturbance can affect how aquatic habitats change over time and space. To evaluate this change, there is a need to understand how the watershed drives stream form and function.

2.3.1. Geological History

The Grave Creek watershed is in the Rocky Mountain Foreland Belt within the Elk Valley coalfield (Bustin & Smith, 1993). During the Upper Jurassic to Lower Cretaceous period (~120–150 million years ago), sedimentary rocks were formed from sand, silt, mud and plant matter that were deposited on the sea floor and the continental shelf of the proto-Pacific Ocean. As a series of island arc complexes drifted eastward and collided with the North American Plate, the sedimentary rocks were folded and faulted, and they created the Rocky Mountains (i.e., during the Laramide orogeny). This mountain building process exposed the Mist Mountain Formation, which also thickened and concentrated the coal deposits into seams in several locations along the Elk Valley (Bustin & Smith, 1993).

2.3.2. Hydrogeologic Setting

The topography of the Elk Valley is characterized by steep U-shaped valleys, moraine-dammed lakes and hanging valleys, glacial debris and glacial meltwater channels. Glacial history helps determine the vegetation composition, the structure, production and delivery of sediment to streams, and the source and flow path of water.

In the Grave Creek watershed, the subsurface geologic framework interacts with the overlying surface drainage network. The surficial and bedrock geology exert strong control on the source and flow path of groundwater and on surface-water–groundwater interactions. The ability of a geologic unit to store and transmit water (its permeability) controls groundwater flow and influences both the residence time (how long groundwater remains in the subsurface) and the predominant direction of flow (vertical vs lateral; Smerdon et al., 2009). Local, subsurface flow systems occur close to the stream and have short residence times relative to regional flow systems, which have residence times ranging from years to decades to centuries.

The bedrock units in the Grave Creek watershed are sedimentary and have a moderate to low permeability (Golder, 2015a), which increases the residence time of groundwater and limits vertical groundwater flow. The groundwater system is recharged on the ridge tops and upper- to mid-valley flanks (Golder, 2015a). It is likely the flow systems in the study area are predominantly near-surface or shallow subsurface pathways to the stream (i.e., they are local) (Smith et al., 2014; Spencer et al., 2019). Surface flow and mostly shallow groundwater from the upstream tributaries likely recharge the alluvial valley aquifer that interacts with the Elk River (Golder, 2015a), which comprises a heterogenous mixture of silt, clay and gravel deposits (George et al., 1987). The bedrock groundwater likely represents a relatively small percentage of total groundwater flow (i.e., it is a regional flow path), given the small recharge area relative to the length of the flow path and the low permeability of deeper bedrock units (Golder, 2015a).

The amount of water delivered to the stream network is also influenced by the vegetation composition and the watershed structure. Forests in the Grave Creek watershed store water and move it through the hydrologic cycle. The forest canopy intercepts a fraction of rain or snow, which is either stored in the canopy or lost to the atmosphere via evaporation or sublimation and transpiration from plant leaves (Winkler et al., 2010). Precipitation that is not intercepted falls to the ground. Changes in the forest cover generate a hydrologic and geomorphic response that creates a range of conditions, which result in diverse fish habitats within the stream network.

2.3.3. Hydrogeomorphic Regime

The study area receives orographic precipitation, falling as snow in the winter and rain in the summer. Through the winter months, streamflow is primarily composed of groundwater (i.e., baseflow) with a periodic melt or mid-winter rainfall event. The timing of snowmelt largely governs streamflow in the Grave Creek watershed. The winter snowpack that develops from November to March begins to melt as air temperatures rise in the spring, which results in high runoff from April through July. After snowmelt, the low flows of late summer are supplied by water delivered by rainstorms and groundwater.

Instream flow is an important component of habitat for aquatic organisms. At the scale of reaches or channel units, instream flows are a function of hyporheic exchanges, i.e., the two-way transfer of water between stream and saturated sediments in the bed and riparian zone. These exchanges can vary substantially over space and time. The exchange of surface water and groundwater can result in the stream having gaining reaches (reaches that receive groundwater discharge) or losing reaches (reaches that recharge groundwater). At different times of the year the same reach can be gaining or losing (Smerdon et al., 2009). Two losing reaches were inferred to occur along Harmer Creek near the confluence with Balzy Creek and immediately upstream of Harmer Creek Sedimentation Pond, based on evidence of alluvial deposits and because fault structures in the bedrock underlying the stream network could also influence groundwater-stream interactions (Lorax Environmental Services, 2019). A gaining reach of ~300 m was reported to exist along Harmer Creek at or near the confluence with Dry Creek (Lorax Environmental Services, 2019). A more recent study found reaches near Harmer Creek Sedimentation Pond were stable, including a 2,200 m reach that started 300 m downstream of Harmer Dam and a 400 m reach that ended 200 m upstream of Harmer Creek Sedimentation Pond (SNC-Lavalin, 2020).

The hydrogeomorphic regime of the Grave Creek watershed will change over time, as streamflow associated with flood or drought events varies. High flows can re-form channel morphology (i.e., widen the channel, deepen it or cause lateral channel migration) and affect how the aquatic ecosystem functions. The historical, average daily stream discharge measured at Grave Creek, illustrated in Figure 2-5, shows the inter-annual variability in streamflow and the seasonal hydrologic pattern. To provide more recent hydrologic context of flow conditions in the region, data from Line Creek, an upstream tributary of the Elk River, is presented, because the Grave Creek gauge was decommissioned in 1999. Line Creek had very different levels of discharge compared to Grave Creek but had similar patterns. Stream discharge measured weekly from 2014–2020 at Harmer Creek at the discharge of the Harmer Creek Sedimentation Pond (Figure 2-6) shows a hydrologic regime similar to Grave Creek (Figure 2-5) with peaks in late spring. Discharge was low in late summer of 2018 through early 2019 (also see Wright et al., 2022). For the years leading up to the WCT Reduced Recruitment (i.e., prior to 2017), the hydrologic regime in the region was within the range of average conditions.

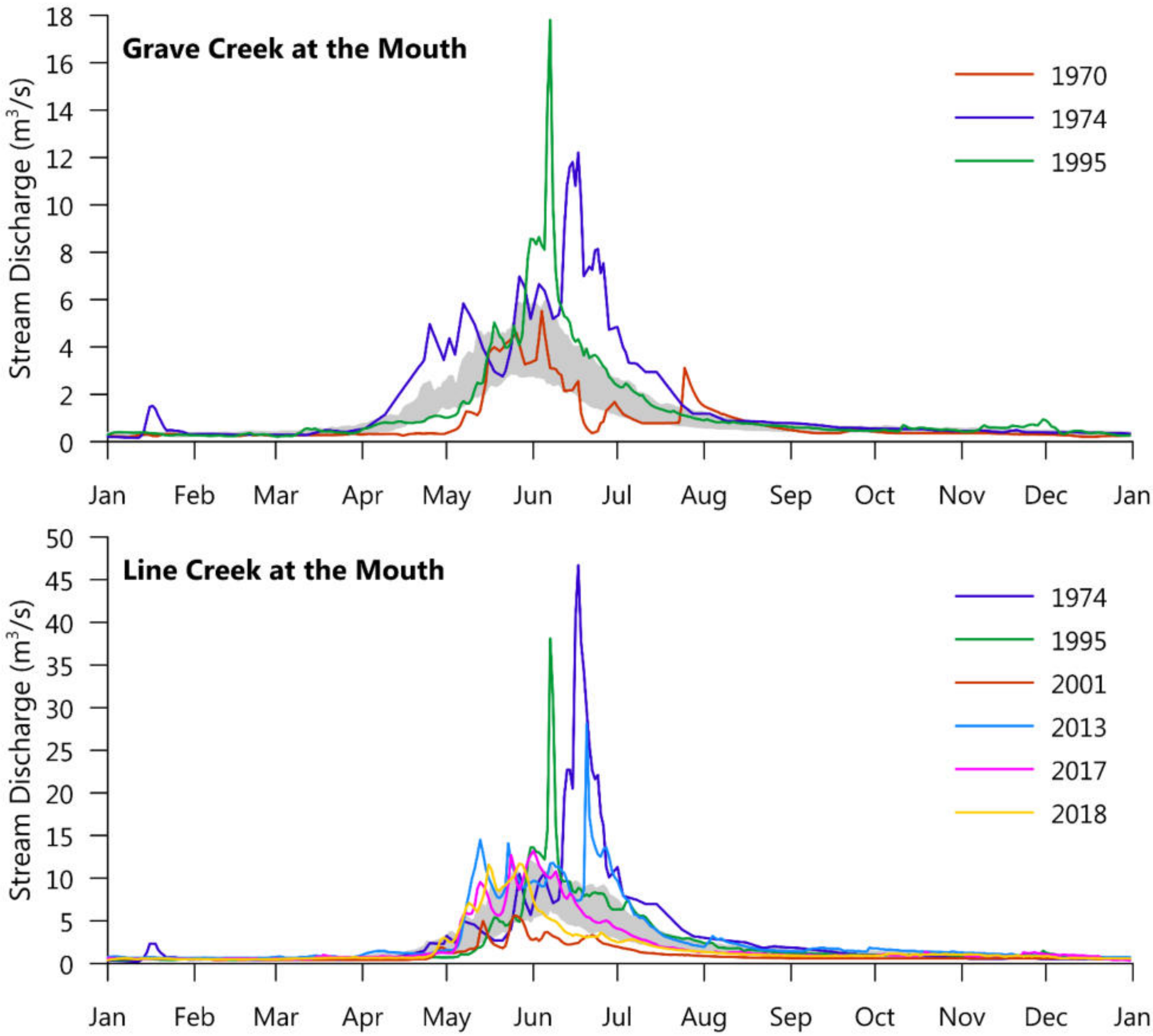


Figure 2-5. Daily average streamflow for Grave Creek at the mouth (Water Survey of Canada, 08NK019, 1970–1999, inclusive) and Line Creek at the mouth (Water Survey of Canada, 08NK022, 1971–2019, inclusive)

High flow years include 1974 (blue), 1995 (green) and 2013 (light blue). Low flow years include 1970 and 2001 (red). The grey band represents the 75th and 25th percentiles of average daily streamflow for the entire record. The years 2017 (pink) and 2018 (yellow) are shown to provide context of flow conditions in the region leading up to the period of WCT Reduced Recruitment.

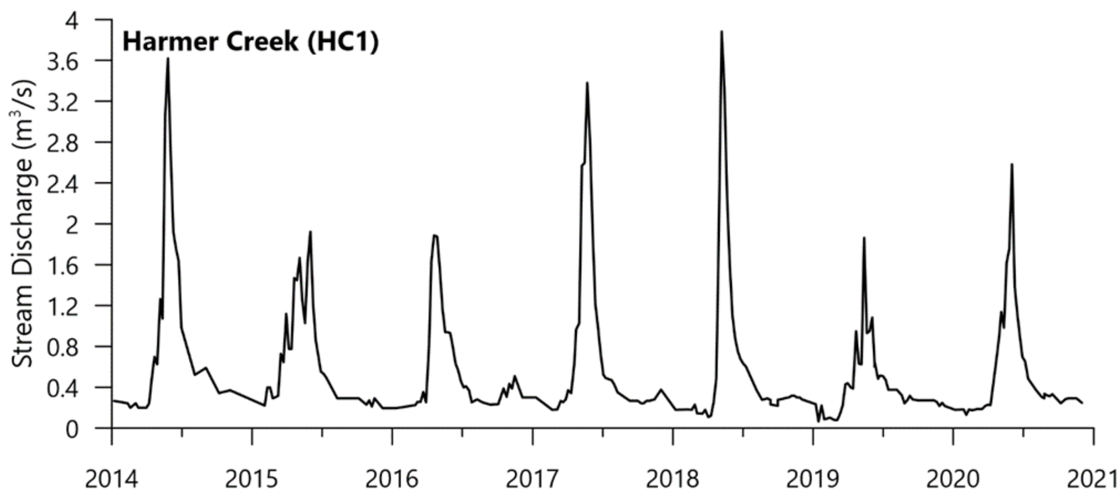


Figure 2-6. Weekly streamflow measured in Harmer Creek at the discharge of Harmer Sedimentation Pond (EV_HC1)

2.3.4. Natural Disturbance Regime

Natural disturbance has contributed to changes in the hydrology and geomorphology of the stream network in the Grave Creek watershed. The most extreme flooding events in the area over the last 50 years, which were in 1974, 1995 and 2013, were caused by large precipitation events at near-peak snowmelt (Pomeroy et al., 2016). Extreme floods likely altered the width and depth of the stream channels by eroding them.

In addition to flooding, events such as wildfires and bark beetle outbreaks (e.g., mountain pine beetle, *Dendroctonus ponderosae*) can indirectly affect the amount of water and sediment that is delivered to the stream and can alter channel morphology. In snowmelt-dominated watersheds like the Grave Creek watershed, wildfire (which causes forest cover loss and hydrophobic soils) can increase snowmelt rates and peak runoff (Seibert et al., 2010; Mahat et al., 2015). The last major wildfires in the region were in the 1930s (EV-CEMF Working Group, 2018). Recent mountain pine beetle outbreaks are not likely to have resulted in major hydrogeomorphic changes to the stream network. Recent research in the Rocky Mountains within Canada and the United States suggests that changes in streamflow related to pine beetle outbreaks have been small relative to inter-annual variability. Empirical studies found that streamflow changes were more likely related to climate variability, which drives precipitation and snowmelt timing, than to pine beetle outbreaks (Biederman et al., 2015; Slinski et al., 2016). Model simulations suggested large snowmelt inputs from the alpine area and adjacent unaffected areas (i.e., healthy forest or non–forested area) would likely result in a muted response to mountain pine beetle disturbance (Pomeroy et al., 2012; Penn et al., 2016).

Last, mass wasting events such as landslides can also frequently alter channel morphology in mountain environments. A landslide approximately 1.3 km upstream from Harmer Creek Sedimentation Pond entered HRM-R3 at some unknown date in the past. This resulted in a noticeable change in channel morphology that may be substantial enough to be an additional reach break.

2.3.5. Thermal Regime

When water flows through a stream reach, the temperature changes as a function of energy and water exchanges that occur across the water surface, the streambed and streambanks (Moore et al., 2005). Radiative inputs to the stream surface include incoming solar radiation and long-wave radiation emitted by the atmosphere, forest canopy and topography. Sensible and latent heat exchanges between the stream and atmosphere are driven by air temperature and humidity, which play a minor role in the stream's energy budget (Webb et al., 2008). Other factors that control stream temperature include the following, as described in Moore et al. (2005), Leach and Moore (2010) and MacDonald et al. (2014):

- Streambed heat exchanges and the thermal regime of the streambed
- Groundwater inflow
- Hyporheic exchange
- Tributary inflow
- The presence of pools
- The upstream temperature and discharge

Grave Creek and Harmer Creek are cool summer streams, where observed stream temperatures did not exceed 13°C, as indicated by temperature loggers installed from 2017 to 2019 (Cope & Cope, 2020). Overall, summer water temperatures at measured locations in the Grave Creek population area were warmer than in the Harmer Creek population area. A more detailed discussion about water temperature is provided in Chapter 3 of this report and in the water temperature and ice SME report (Hocking, Whelan & Hatfield, 2022).

2.4. WATERSHED-SCALE ANTHROPOGENIC CHANGE

This section focuses on the large anthropogenic changes to the Grave Creek watershed attributed to industrialization over the past 150 years. It excludes any previous, low impact disturbances from the Ktunaxa people who have occupied the Elk Valley for more than 10,000 years.

In the 1890s, William Fernie and coal miners who were brought in from Cape Breton started the first coal mine up Coal Creek and then rapidly expanded with mines near Sparwood (Kinnear, 2012). Since then, the Grave Creek watershed has been altered by anthropogenic disturbances that include coal mining, forestry and linear developments such as roads. In the Grave Creek watershed, approximately 7.9% (2.4 km^2) of the land area has been disturbed, primarily by clear-cut harvest and roads. In the Harmer Creek sub-watershed, approximately 12.4% (4.1 km^2) of the land area has been disturbed by mining activities, clear-cut harvest and roads. And in the Dry Creek sub-watershed, approximately 23% (1.7 km^2) of the land area has been disturbed by mining activities.

2.4.1. Mining

Coal has been mined in southeastern BC for more than 120 years. The first mines were underground but, in the 1960s, mining shifted to open pit extraction (Kinnear, 2012). Open pit mining removes the topsoil and overburden/interburden (i.e., waste rock) to expose the coal seams. The materials that overlie the coal are deposited in spoil disposal areas, and the coal itself is extracted, processed and transported to markets. Mining activities also require roads and railways, sedimentation ponds and operational buildings, and these increase the area that is disturbed.

In the Harmer Creek watershed, open pit steelmaking coal mining began in 1969 with EVO. Since 2016, the mining footprint has increased by 0.1% (0.005 km^2) and, as of 2020, open pit mining and waste rock deposition have affected 11% (i.e., 3.54 km^2) of the Harmer Creek watershed, primarily in Dry Creek which drains the northern end of EVO. In Sawmill Creek, a tributary to Harmer Creek, mining activities have disturbed 0.002% (0.0007 km^2) of the Harmer Creek watershed. There was also a lumber mill located on Sawmill Creek; however, the dates of its operations are unknown. In the Dry Creek sub-watershed, waste rock spoiling came from mining Cedar Pit. Dewatering from Cedar Pit was directed to Dry Creek, but volumes and timing of flow are unknown (Lorax Environmental Services, 2019). Generation of waste rock spoiling from the mining at Cedar Pit ended approximately between 2009 and 2012 (Lorax Environmental Services, 2019; M. Moore, pers. comm).

Hydrologic response to mining is generally poorly understood because mining activities alter surface and subsurface flow pathways and watershed storage (Miller & Zegre, 2014; Zegre et al., 2014). However, changes to watershed elevation profiles can alter large-scale hydrologic and geomorphic processes (Villeneuve et al., 2017). In the Harmer Creek population area, open pit mining has changed the elevation profile, while the Grave Creek population area profile has remained unchanged (Figure 2-7). Mining activities in the Harmer Creek population area have resulted in elevation loss at higher elevations (1,800–1,900 m above sea level) and elevation gain at lower elevations (1,600–1,700 m above sea level (Figure 2-7). Dry Creek is heavily calcified and has channel morphology typical of a calcified creek, such as pools and terraces (Lorax Environmental Services, 2019; Figure 2-8). Sedimentation ponds were also created along Dry Creek and along Harmer Creek (see Figure 2-3). A dam constructed on Harmer Creek in 1971 created the Harmer Creek Sedimentation Pond in Reach 2.

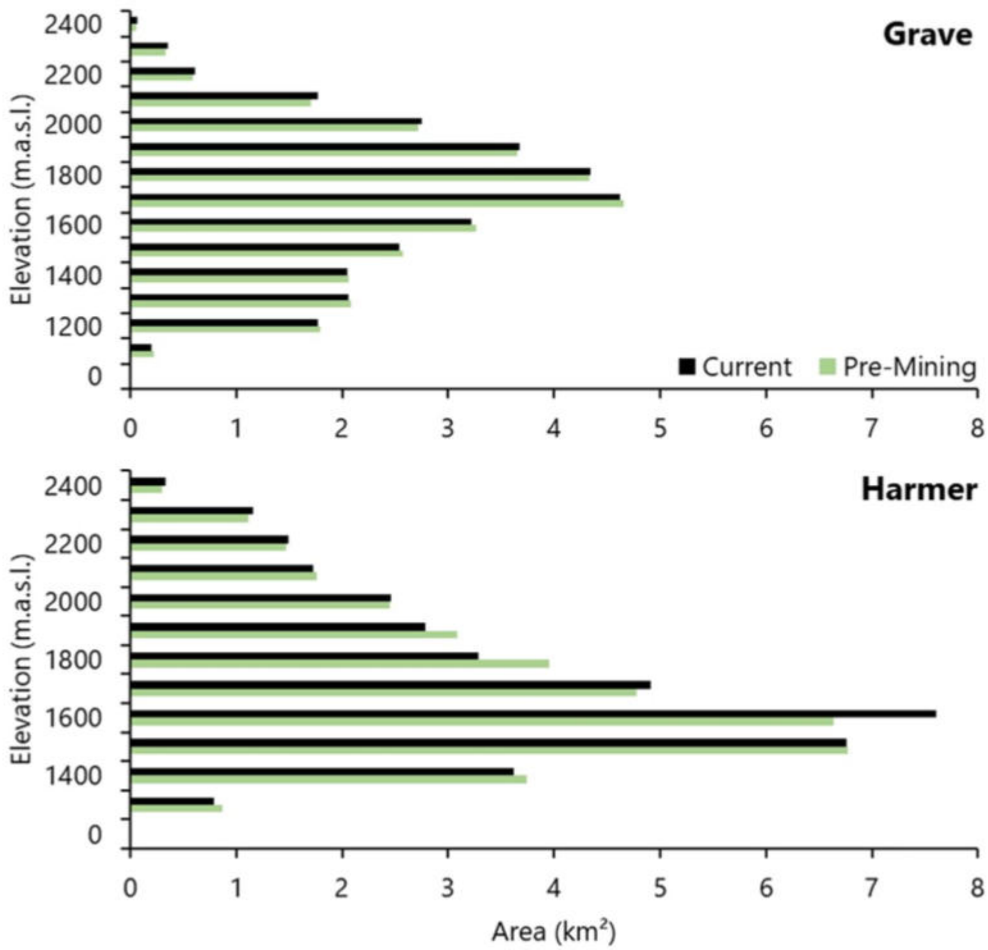


Figure 2-7. Elevation profile derived for the pre-mining (1950) and current conditions in Harmer Creek and Grave Creek population areas

Figure 2-8. Calcified streambed (left) and calcified pools and terraces (right) in Dry Creek

2.4.2. Forest Disturbance

Forests in the Grave Creek watershed have been disturbed by activities that include fire suppression, harvesting, road building and habitat/riparian disturbance. Fire suppression activities in the region have occurred since 1905 when the Bush Fire Act was enacted, and they have reduced wildfire as the dominant disturbance. Currently, timber harvest activities are the primary disturbance to the region's forested ecosystems. A review of paired watershed studies in the Rocky Mountain/Inland Intermountain region determined that measurable increases in annual water yield can be expected when at least 15% of the watershed area has been harvested (Stednick, 1996). Forest harvesting, including cutblocks and a road network, has affected approximately 7.9% (2.38 km^2) of the land area in the Grave Creek population area and 1.4% (0.52 km^2) of the land area in the Harmer Creek population area. Road densities are low in both the Grave Creek population area (0.0025 km/km^2; 0.074 total km) and Harmer Creek population area (0.0020 km/km^2; 0.073 total km).

A 2021 riparian biodiversity assessment using terrestrial ecosystem mapping suggests that change in riparian habitat in the Grave Creek watershed has been minimal. No evidence was found of any substantial change in the quantity of riparian habitat from pre-mining to current conditions in either population area.

2.5. CHANGES TO WESTSLOPE CUTTHROAT TROUT HABITAT

2.5.1. Pre-Mining Habitat Conditions

Westslope Cutthroat Trout is the only fish species that occurs throughout the Grave Creek and Harmer Creek population areas. Suitable habitat for these fish in the Grave Creek watershed would have developed post-glaciation (10,000–13,000 years ago). Over time, considerable changes to the habitat would have occurred through fluvial processes that altered the stream network. Approximately 128.4 linear km of stream habitat would have existed in the Grave Creek watershed upstream of the waterfall at rkm 2.1 (estimated from the BC provincial stream network dataset). However, WCT would have had limited access in some parts of the stream network due to the steep gradient (i.e., > 20%), barriers and the ephemeral or intermittent flow known to occur in the smaller tributaries. Higher gradient tributaries or tributaries with physical or thermal barriers would not have been fish bearing. During pre-mining conditions, the WCT's use of habitat in the mainstem of Grave Creek (upstream of Grave Creek Falls) and Harmer Creek, as well as any accessible tributaries with gradient less than 20% would have depended on factors that include suitable temperature, food availability, hydraulics, cover and refuge from ice.

When mining and forestry began in the watershed, the amount and quality of WCT habitat changed. Adverse changes and improvements to the habitat are described below.

2.5.2. Adverse Impacts to Habitat

The changes described in this section have adversely impacted WCT habitat in various ways. These include causing habitat to be converted or lost, causing habitat connectivity to be disrupted, impacting water quality and, potentially, impacting fish distribution.

Harmer Dam and Harmer Creek Sedimentation Pond. The Harmer Dam is located at the downstream end of the Harmer Creek Sedimentation Pond and 600 m upstream of the Grave Creek confluence. It consists of a 12 m high embankment and spillway. The dam was built in 1971 to limit downstream movement of fine sediment from the EVO mine's rock storage facilities. Construction of the dam also created the Harmer Creek Sedimentation Pond (Figure 2-9). Over time, both fine and coarse sediments have deposited upstream of the dam within the Harmer Creek Sedimentation Pond and have resulted in the pond being dredged once. In 2021, the pond was surveyed and reported to have a surface area of 16,484 m^2, a maximum depth of 5.7 m and a mean depth of 2.0 m.

While the sedimentation pond has resulted in habitat being converted, the Harmer Dam has also affected habitat connectivity by acting as a barrier to upstream fish movement, thereby isolating the Harmer Creek WCT from the Grave Creek population. This created the Grave Creek population area (35 km of fish-bearing stream length) and the Harmer Creek population area (14 km of fish-bearing stream length).

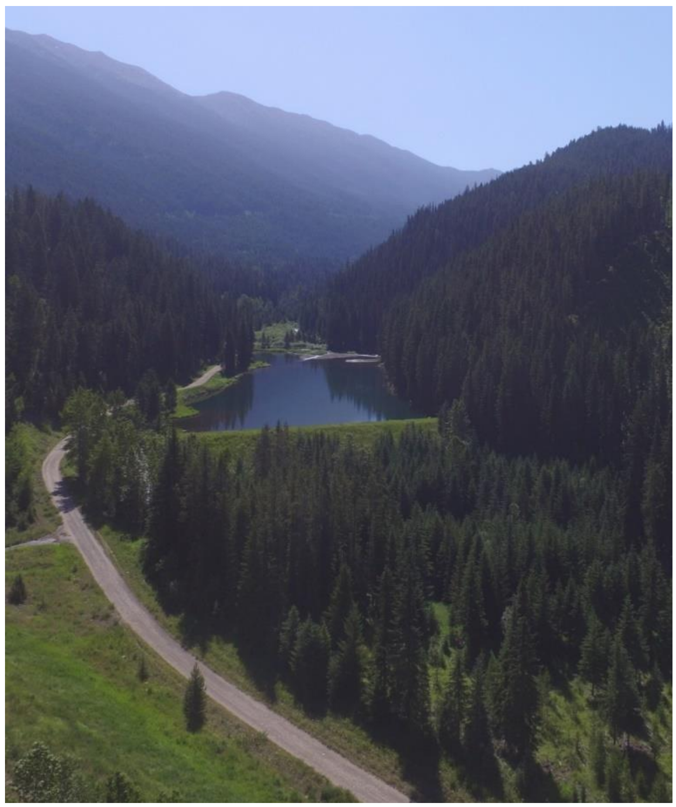


Figure 2-9. Upstream view of Harmer Dam and Harmer Creek Sedimentation Pond (July 2017)

Grave Creek culvert barriers. Culverts were constructed under two road crossings on GRV-R3, likely during road building in the late 1960s, and disrupted habitat connectivity. Until October 2017, the Grave Creek population was subdivided by one of these (Culvert #1), a hanging culvert that created a barrier to upstream fish movement at rkm 4.6, approximately 150 m above the confluence with Harmer Creek (Lotic Environmental, 2015). Culvert #1 was replaced with a bridge in 2017. The second culvert

(Culvert #2) at rkm 7.8 is understood to have been passable until it was damaged in a flood, after which it was replaced by an impassable hanging culvert in 2013. As a result, Upper Grave Creek was further subdivided until Culvert #2 was removed in October 2018.

Water and sediment quality in mine-affected reaches. Constituents of potential concern from EVO mining operations have impacted water and sediment quality in Dry Creek. Mining related constituents also influence Harmer Creek through inflow from its tributary Dry Creek, and they influence Grave Creek below its confluence with Harmer Creek. Below the confluence of Harmer Creek, concentrations of constituents generally decrease moving downstream. This is discussed further in several SME stressor reports (de Bruyn et al., 2022; Warner & Lancaster, 2022; Wiebe et al., 2022b).

Calcite in Dry Creek. Water that infiltrates waste rock produced from mining at EVO contributes toward calcite deposition, resulting in physical changes to the habitat and, ultimately, habitat loss. Dry Creek is routinely reported as one of the most heavily calcified streams in the Elk Valley and has pools and terraces typical of a calcified creek (Zathey et al., 2021). The calcite in Dry Creek covers the streambed and makes the gravels immovable, which can affect both the diversity of the benthic invertebrate community and the habitat quality for spawning WCT. All reaches in Dry Creek exceed the short-term performance objective of a calcite concretion score less than or equal 0.5 (Zathey et al., 2021). Both DC-R3 and DC-R4 showed an increasing trend in calcite scores from 2013–2018. Calcite levels in the rest of the Grave Creek watershed, including the Harmer Creek mainstem and Grave Creek, remain below a calcite index of 1 and calcite concretion of 0.2. A calcite index greater than 1 and a calcite concretion of greater than 0.5 are considered moderate to high intensity (Hocking, Cloutier, et al., 2022).

Dry Creek spoil (related to Cedar Pit). Historically, dewatering from mining Cedar Pit was directed to Dry Creek (Lorax Environmental Services, 2019), and waste rock spoiling was deposited in the Dry Creek sub-watershed. Mining at Cedar Pit ended approximately between 2009 and 2011, and the last spoils were deposited in 2012. Compared to pre-mining conditions, open pit mining and waste rock deposition had, by 2020, impacted water quality and resulted in an estimated loss of 58% (4.35 km) of stream in the Dry Creek sub-watershed (including the loss of two unnamed tributaries). It is unknown how much of this was fish bearing.

In addition to dewatering and depositing spoiling, spoil failures have occurred in Dry Creek. Based on historical photos, there was a large spoil failure in the late 1960s that extended almost to the Dry Creek Sedimentation Pond (M. Moore, personal communication, July 20, 2021).

Dry Creek Sedimentation Pond. A sedimentation pond was constructed within what would have historically been DC-R1. This likely occurred in 1969. The Dry Creek Sedimentation Pond resulted in approximately 70 m of lotic habitat being converted into pond habitat and approximately 100 m of channel being redirected. The pond, which now forms DC-R2, is fish bearing and has an area of 3,218 m^2 (Lotic Environmental, 2015) and a maximum depth of approximately 2.9 m. Bi-directional fish passage is possible into and out of the pond (Figure 2-10).

Dry Creek salvage and temporary fish fence. Fish in Dry Creek were salvaged from September 26 to October 1, 2017, as part of operations in support of proposed spoiling. All salvaged fish were relocated to the mainstem of Harmer Creek just below the confluence with Dry Creek (Golder, 2017). As part of the salvage, an exclusion fence was temporarily installed at the outlet of the Dry Creek Sedimentation Pond (DC-R2) from September 26 to December 8, 2017, thereby affecting habitat connectivity and, potentially, fish distribution during this two-month period. The temporary fence was removed in consultation with the EVFFHC when spoiling was deferred.

Figure 2-10. Upstream view of Dry Creek Sedimentation Pond

Credit : Lotic Environmental (2015)

2.5.3. Improvements to Habitat

To date, improvements to fish habitat have been limited to improving fish access in the Grave Creek population area. From October to November 2017, Culvert #1 was replaced with a clear-span bridge, and, in November 2018, Culvert #2 was replaced with a clear-span bridge. This restored the ability for fish to move upstream and pass between GRV-R2 and GRV-R4.

2.6. EXISTING HABITAT CONDITION

Grave Creek is a tributary of the Elk River and a fourth-order stream. The reaches GRV-R1 and GRV-R2 are below the Harmer-Grave confluence and are affected by the mine, whereas GRV-R3 and GRV-R4 are above the confluence and are not affected by the mine (Figure 2-3). Much of Grave Creek is confined by narrow valley walls that limit sinuosity and access to the floodplain.

Harmer Creek is a tributary of Grave Creek and a third-order stream. Dry Creek, which is a tributary of Harmer Creek, enters HRM-R5 and has a waste rock spoil at the upstream end. This contributes mine-affected water and sediments to the rest of Dry Creek, to Harmer Creek via HRM-R5 and to downstream areas into GRV-R1. Reach HRM-R6 is upstream of the confluence with Dry Creek and is, therefore, not affected by the mine.

Habitat features within Grave Creek and Harmer Creek are summarized in Table 2-1. The descriptions here are from Lotic Environmental (2015) and are based on methods and habitat quality classifications listed in Johnston and Slaney (1996).

2.6.1. Grave Creek

In Grave Creek, reaches GRV-R1, GRV-R2 and GRV-R3 are similar, with moderate gradients dominated by riffles and cobble substrates and a mean bankfull width greater than 8 m. The channel width in Grave Creek decreases above the confluence with Harmer Creek. While GRV-R1 and GRV-R2 are considered transitional in morphology between riffle-pool and cascade-pool, GRV-R3 is classified as cascade-pool and is highly confined in the canyon. Large woody debris provides complex pool habitat. It provides overhead cover occasionally in GRV-R1 and GRV-R2 and more frequently in GRV-R3. Overall, cover is considered low (3–4%). The riparian vegetation is dominated by mixed forest. In GRV-R4, the channel is narrower, with a bankfull width of 5 m. This reach is dominated by cascades and boulder substrates. Overall, the habitat quality within Grave Creek is good, meaning it is in a natural state, has instream complexity and a mature, intact riparian zone.

A notable feature at high elevation in the Grave Creek population area is Harriet Lake. Harriet Lake occurs at 2,109 m elevation and has a surface area of 0.1 km^2 (BC Ministry of Environment, 2021). It is connected to GRV-R4 by a steep channel with a series of 10 m waterfalls that would likely prevent fish from migrating into the lake from the creek but could allow fish to emigrate from the lake into the creek. Harriet Lake was stocked with WCT in 1985, 1986, 1989, 1992 and 2002 from Connor Lake stocks by Kootenay Trout Hatchery. Although Harriet Lake may serve as a source of fish input into the Grave Creek population area, the Harmer Creek population area has no such source of fish input.

2.6.2. Harmer Creek

In Harmer Creek, reaches HRM-R1 and HRM-R3 to HRM-R5 all have riffles as the dominant mesohabitat and cobble as the dominant substrate (Table 2-1). Gradient varies between lotic reaches from 1.7% (HRM-R5) to 3.9 % (HRM-R6). Reaches HRM-R1, HRM-R3 and HRM-R5 have poor instream cover (9%, 6% and 6%), whereas HRM-R4 has moderate cover (13%) (Lotic Environmental, 2015). The Harmer Creek Sedimentation Pond (HRM-R2) provides rearing and holding potential for fish; however, fish use has been documented as essentially non-existent in this reach through multiple years of capture effort and telemetry tracking (e.g., Cope & Cope, 2020; Lotic Environmental, 2015). HRM-R6 differs from the other reaches in being strongly dominated by groundwater, which gives it a consistent and cold thermal profile. Except for the Harmer Creek Sedimentation Pond, the habitat quality of Harmer Creek is good for WCT, meaning the habitat is in a near-natural state, has instream complexity and has a mature, intact riparian zone.

2.6.3. Dry Creek

Dry Creek is a moderate-gradient stream, ranging from 2.6–4.9% in the three lotic reaches. Instream cover was moderate, ranging from 4–11%. Dry Creek is a highly impacted stream with heavy calcification throughout. Much of the natural substrate is immobilized from concretion by calcite deposition. As well, the lotic habitat was converted to a sedimentation pond (DC-R2). Extensive historical beaver activity can still be seen in DC-R4, where the beaver dams, now heavily calcified, span across the valley bottom to create extensive ponded areas capable of increasing water residence time.

The physical habitat in Dry Creek reaches DC-R1 to DC-R4 is heavily altered from mining due to deposition of spoil. This has resulted in infilling of the upper creek, extensive calcite deposition and habitat loss compared to pre-mining conditions. Calcite deposits have occurred over much of the channel, to the extent that calcite terraces have formed that push streamflow into the surrounding floodplain. In some cases, these terraces may act as obstacles to upstream fish movement. Throughout DC-R1 to DC-R4, the deposited calcite has resulted in concretion of the substrate, which makes it unsuitable for WCT spawning.

Table 2-1. Grave Creek, Harmer Creek and Dry Creek habitat features

Source: Lotic Environmental (2015) and Cope and Cope (2020)

Reach	Mean gradient (%)	Mean bankfull width (m)	Dominant habitat by length*	Dominant substrate
Grave Creek				
GRV-R1*	3.3	8.4	Riffle (59.8%)	Cobble
GVR-R2	2.4	8.4	Riffle (61.7%)	Cobble
GVR-R3	4.8	8.3	Riffle (61.2%)	Cobble
GVR-R4	9	5.1	Cascade (64.5%)	Boulder
Harmer Creek				
HRM-R1	3.6	6.7	Riffle (45.4%)	Cobble
HRM-R2	0.0	78.0	Pond	Fines
HRM-R3	2.2	7.0	Riffle (64.9%)	Cobble
HRM-R4	2.5	6.0	Riffle (49.8%)	Cobble
HRM-R5	1.7	6.0	Riffle (63.6%)	Cobble
HRM-R6	3.9	7.5	Cascade (52.3%)	Gravel
Dry Creek				
DC-R1	6.0	8.3	Step-pools	Calcite**
DC-R2	0.0	48	Pond	Fines
DC-R3	2.6	4.5	Cascade-pool	Calcite**
DC-R4	2.3	11.0	Cascade (40.9%)	Calcite**

*The total reach length was sampled, not only the portion above the falls.

**Dominant natural substrate unable to be determined due to extensive calcite formation.

2.7. SUMMARY

Streams within the Grave Creek watershed were formed through processes of glaciation and erosion, and the WCT population within the Grave Creek watershed was disconnected from other Elk Valley populations when the waterfalls formed post-glaciation. The streams of the Grave Creek watershed continue to change due to natural processes such as wildfires and floods, and, more recently, due to human activities. Landscape-scale anthropogenic disturbance that has occurred in the last 50 years, specifically open pit mining and forestry, has altered the Grave Creek watershed and affected watershed function, habitat availability, habitat quality and habitat connectivity. Changes to the watershed's elevation profile from mining activities have potentially changed hydrologic function. Waste rock deposited over streams in Dry Creek has resulted in direct habitat loss, and habitat quality has been reduced both within Dry Creek and downstream of it, due to the release of constituents from mining activities and the associated concretion of substrate due to calcification.

The construction of the Harmer Creek Dam separated the Grave Creek watershed WCT population into the Harmer Creek population and the Grave Creek population and fragmented the fish-bearing portions of Grave and Harmer Creeks into two roughly equal portions. Nonetheless, anthropogenic impacts have been spatially limited in the Harmer Creek and Grave Creek mainstems, and physical habitat condition is in a good, near-natural state throughout, except for the Harmer Creek Sedimentation Pond.

3. Westslope Cutthroat Trout

An isolated, genetically pure population of WCT inhabits the Grave Creek watershed. These fish are of special concern to the Ktunaxa Nation and are also of special concern under federal and provincial legislation and policy. This chapter describes WCT broadly at a species level, and it summarizes pertinent details of the population in the Grave Creek watershed from a biological and ecological perspective.

3.1. TAXONOMY AND DISTRIBUTION

The WCT is a subspecies of Cutthroat Trout *(Oncorhynchus clarkii)* that is endemic to North America. The *Oncorhynchus* genus is made up of Pacific Salmon and trout and is one of three North American genera within the subfamily Salmoninae, all of which are cold water species that breed in freshwater. Two subspecies of Cutthroat Trout are endemic to BC, the Coastal Cutthroat Trout *(O. c. clarkii)* and the WCT, which is found inland. In Canada, WCT are also found in Alberta, and in the United States they are found in Montana, Idaho, Washington, Oregon and Wyoming. Westslope Cutthroat Trout distribution in BC is limited to the southeastern portion of the province, which is the northern extent of the range for this species (Figure 3-1). In southeastern BC, WCT mainly occur in small, isolated headwater streams but can also be found in larger systems such as the Elk River. In the Elk River watershed, WCT are found approximately 800–2,000 m above sea level, with observations of Harmer Creek and Grave Creek WCT populations falling within the species' core elevation range (Figure 3-2).

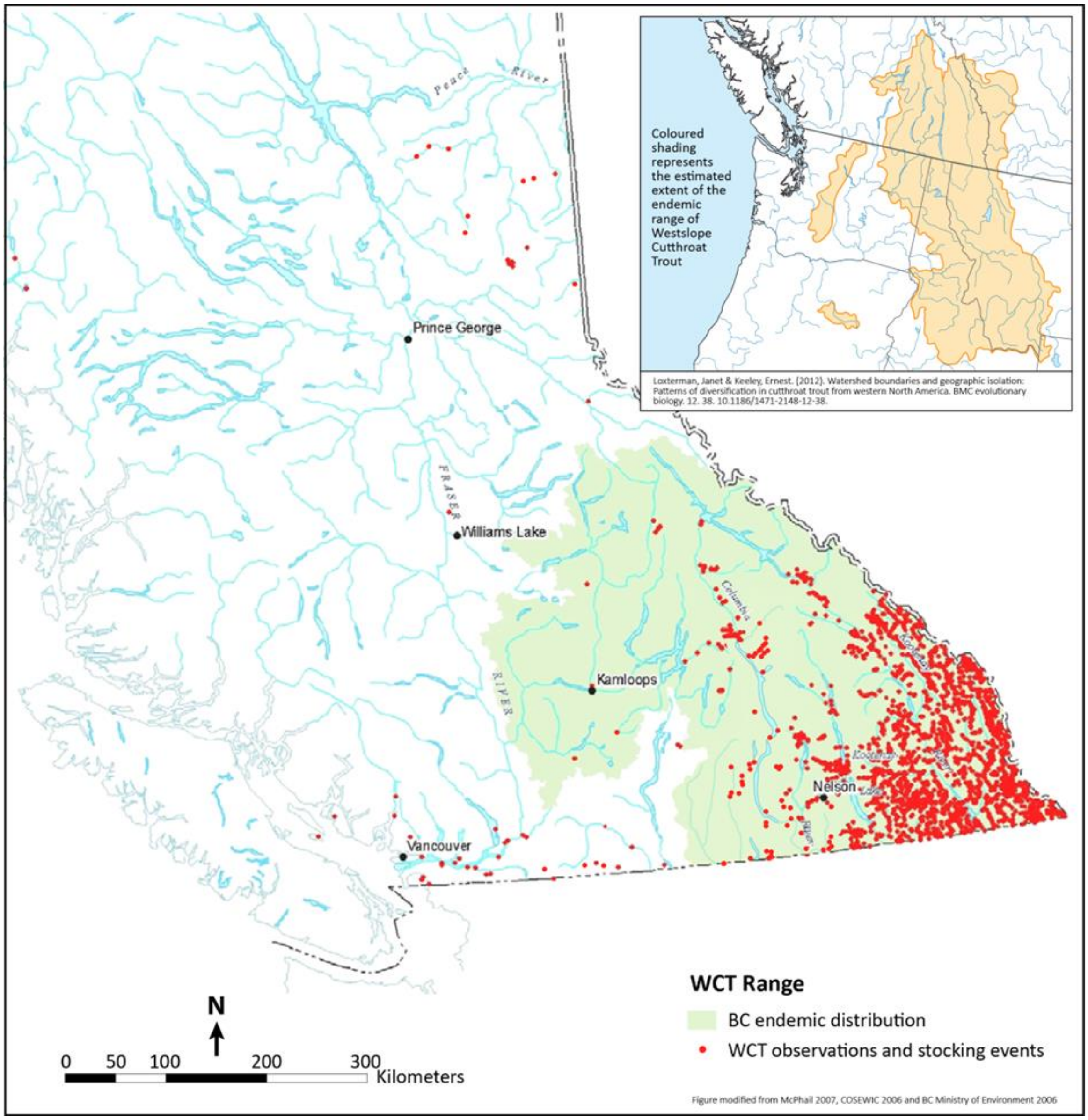


Figure 3-1. Westslope Cutthroat Trout distribution in BC

Endemic populations are red dots over green shading, and translocated populations are red dots outside green shading. Figure inset shows endemic distribution throughout North America.

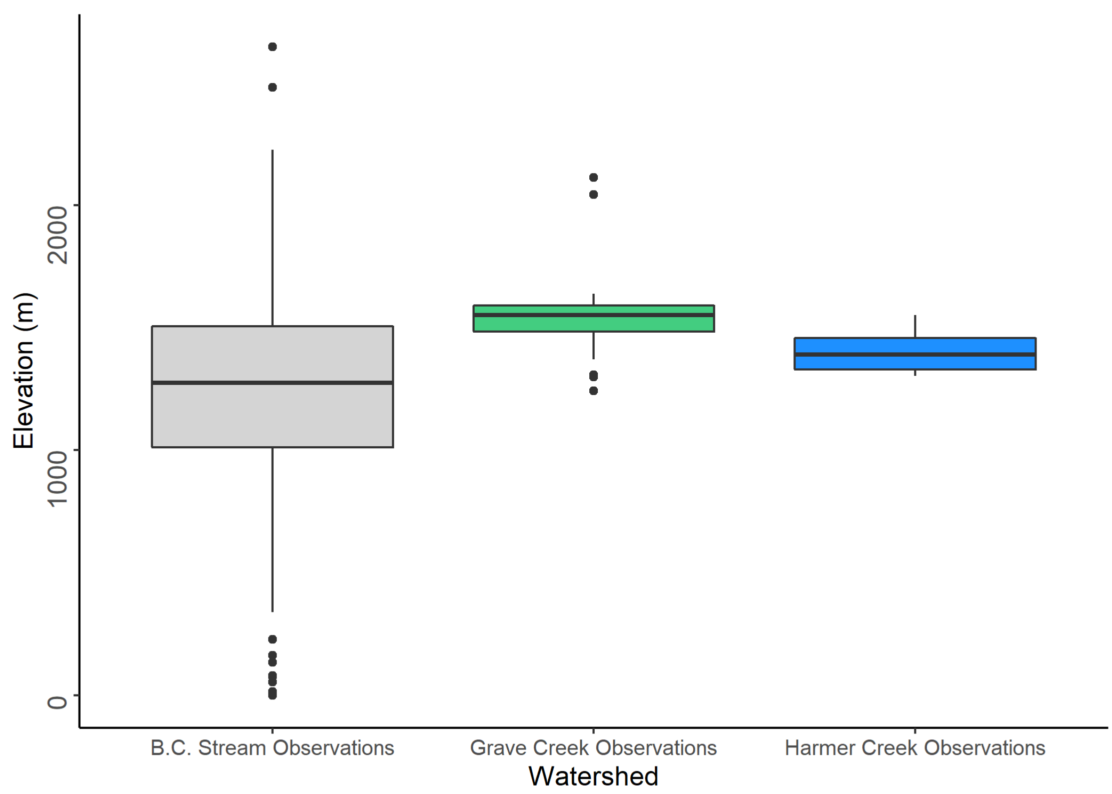


Figure 3-2. Elevation boxplot for frequency of fish observations in the Elk Valley

Grave Creek is shown in green and Harmer Creek in blue. Data are from BC ENV (2022). Boxplot whiskers represent 1.5x the inter-quartile range beyond the box, and points outside of this represent outliers.

Watersheds in BC's East Kootenay region are home to WCT populations that are either genetically pure or are hybridized with Rainbow Trout *(O. mykiss)* that have been introduced (see text box). Genetically pure populations hold high value for the persistence of the species (Shepherd et al., 2005). There have been concerns of hybridization in the Grave Creek watershed due to the stocking of fertile Rainbow Trout and other species such as Kokanee *(Oncorhynchus nerka)* into Grave Lake that occurred between 1936 and 2000. Hybridization is a concern because it can result in the genetic introgression of genetically pure individuals, which reduces both the overall range of the species and connectivity between pure populations (Robinson, 2007; Rubidge et al., 2001). Although only sterile fish have been stocked into Grave Lake since 2000, there was, nonetheless, concern that hybridization had occurred between historically stocked, fertile Rainbow Trout and WCT. However, genetic analysis conducted by the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) in

2016 found no hybridized WCT in the Harmer Creek or Grave Creek populations, suggesting that they remain genetically pure (FLNRORD, 2016).

Hybridization (Cross-Breeding) and Genetic Introgression

Rainbow Trout (O. mykiss) *and Cutthroat Trout* (O. clarkii) *are often found in the same waterbodies. Although the two species diverged taxonomically about 2 million years ago, they did not develop behaviours to prevent or reduce hybridization. Rainbow Trout are a commonly stocked species, and where they have been introduced into waters containing WCT, genetic introgression — the transfer of genetic information from one species to another — has occurred. As a result, Rainbow Trout genes have hybridized with WCT populations to the extent that genetically pure populations now only persist over small portions of their historical range (Shepard et al., 2005; Rubidge et al., 2001).*

Before the Harmer Dam was built in 1971, the Harmer Creek and Grave Creek populations were a single population isolated from other WCT moving upstream by the Grave Creek waterfall, which is 1 km upstream of the confluence with the Elk River, and by the waterfall at rkm 2.1 km. When the dam was constructed, it created separate WCT populations in Harmer Creek and Grave Creek, each with access to approximately half the amount of habitat that was previously available to them (Figure 2-3). The Grave Creek population was further fragmented by culverts that were barriers to upstream fish movement. The first culvert was at rkm 4.6, just above the confluence with Harmer Creek, and it was in place from the late 1960s to 2017. The second culvert was at rkm 7.8, and it was in place from 2013 to 2018 (Figure 2-3).

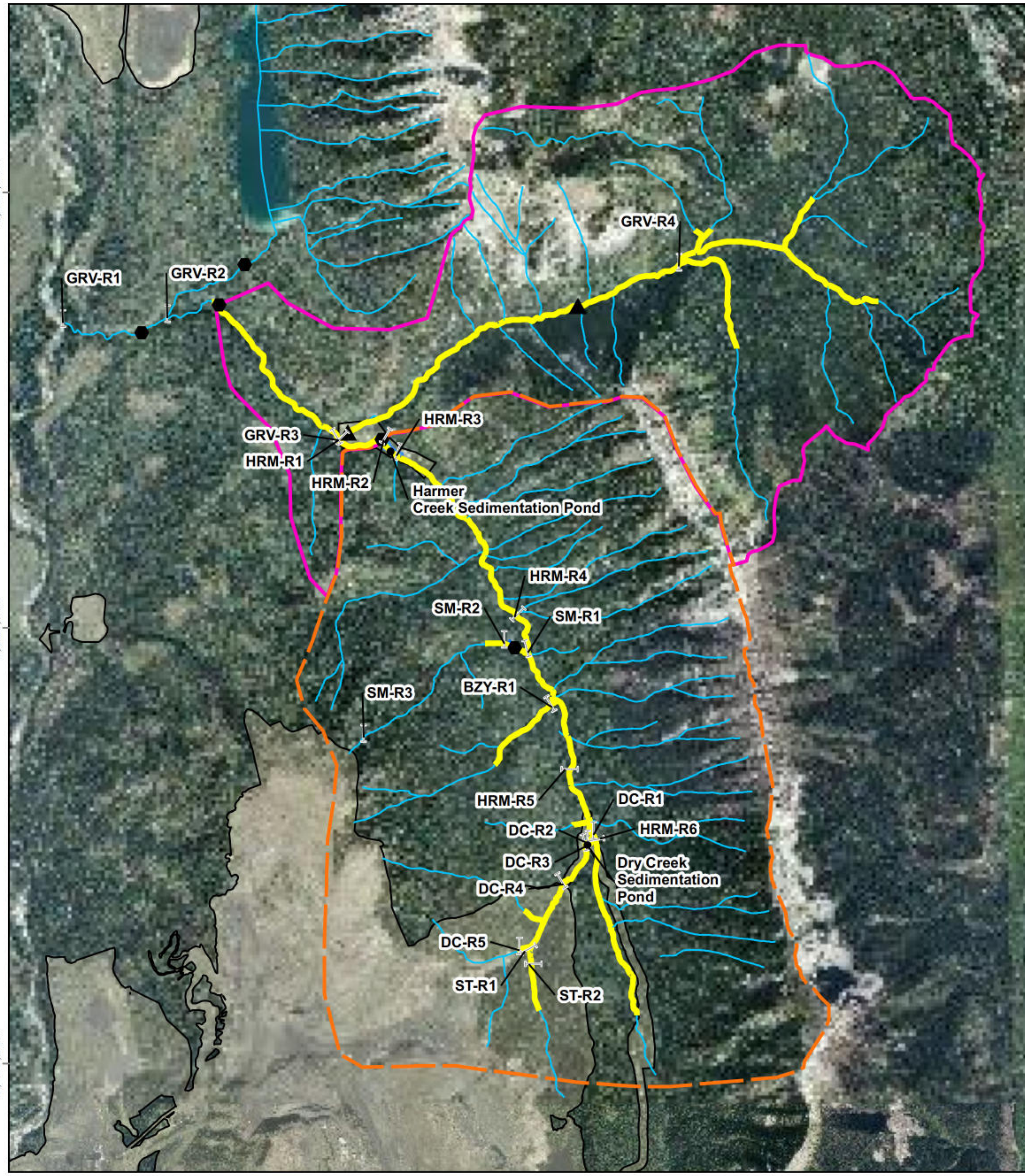
In small, isolated populations, potential exists for inbreeding depression to occur. This is the loss of population fitness due to a lack of genetic diversity that results from inbreeding. Inbreeding depression can occur when low population numbers are combined with a lack of dispersal (i.e., where members of the population live in close proximity), which can result in closely related individuals breeding (Wang et al., 2002). The potential for inbreeding depression to explain the Reduced Recruitment and

Recruitment Failure in the Harmer Creek was assessed in the SME report that evaluated small populations (Thorley et al., 2022). Inbreeding depression was not considered to contribute to the recruitment differences between the populations or among the years.

At present, the Grave Creek population area has a total of 12.0 km mainstem and approximately 23 km of tributary fish-bearing stream (Table 3-1, Figure 3-3). The Harmer Creek population area is smaller with 8.3 km mainstem and 5.5 km tributary fish-bearing stream. Fish-bearing status was assigned after conducting field sampling programs that followed provincial protocol (Cope & Cope, 2020; Lotic Environmental, 2015; Berdusco, 2008). For these programs, fish sampling, gradient and migratory barriers were used to confirm whether fish were present or absent or to confirm default reaches as fish bearing or non–fish bearing (a gradient of > 20% can default to non–fish bearing) (Figure 2-3, Table 3-1). The stream reaches studied are those that Berdusco (2008) first delineated. Fish-bearing status does not include or imply any quantification of use, meaning that a reach can be classified as fish-bearing based solely on the fact that fish have access to it. The reach would retain its fish-bearing status regardless of the number of failed attempts to show that fish actually use it. The distinction between a reach being fish bearing and being used by fish is an important one in the Grave Creek watershed, as it is in many other headwater systems. In this chapter, we use data from different sampling programs to represent what we know about fish presence and movement in the Harmer Creek and Grave Creek population areas (Section 3.4).

Figure 3-3 is presented on the next page. Its caption is:

Figure 3-3. Fish-bearing and non-fish-bearing streams within Harmer Creek and Grave Creek population areas



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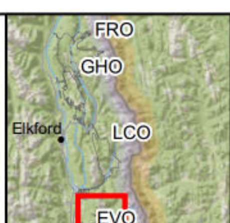

Harmer Creek and Grave Creek Population Areas Fish-Bearing and Non–Fish Bearing Streams

- Start of Reach
- Impassable Barrier
- Historical Barrier
- Fish Bearing
- FWA Non Fish Bearing
- Grave Creek Population Area
- Harmer Creek Population Area
- Permit Boundary

N

0 380 760 1,520 Metres

MINE OPERATION: Elkview	DATE: 2/2/2023	GIS NUMBER: XXXXXX
SCALE: 1:60,000	COORDINATE SYSTEM: NAD 1983 UTM Zone 11N	

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Table 3-1. Total stream length and fish-bearing stream length for Grave Creek and Harmer Creek populations

	Total (m)	Fish Bearing (m)	% Fish Bearing
Grave Creek Population Area	**59,958**	**35,019**	**58%**
Mainstem			
GRV-R1	362	362	100%
GRV-R2	2,952	2,952	100%
GRV-R3	4,745	4,745	100%
GRV-R4*	3,907	2,714	69%
HRM-R1	549	549	100%
Mainstem Total	*12,515*	*11,322*	*90%*
Tributaries			
Unnamed	34,852	11,061	32%
Tributaries Total	*34,852*	*11,061*	*32%*
Harmer Creek Population Area	**76,761**	**13,779**	**18%**
Mainstem			
Harmer Creek			
HRM-R1	25	25	100%
HRM-R2	247	247	100%
HRM-R3	2,663	2,663	100%
HRM-R4	2,183	2,183	100%
HRM-R5	932	932	100%
HRM-R6	2,999	2,236	75%
Mainstem Total	*9,049*	*8,286*	*92%*
Tributaries			
Balzy Creek			
BZY-R1	2,867	1,084	38%
Dry Creek			
DC-R1	148	148	100%
DC-R2	58	58	100%
DC-R3	563	563	100%
DC-R4	975	975	100%

	Total (m)	Fish Bearing (m)	% Fish Bearing
DC-R5	1,260**	45	4%
Sawmill Creek			
SM-R1	298	298	100%
SM-R2	2,117	532	25%
SM-R3	264	0	0%
South Tributary			
ST-R1	180	180	100%
ST-R2	1,682	1,139	68%
Unnamed	57,301	471	1%
Tributaries Total	*67,712*	*5,493*	*8%*

* Values for GRV-R4 reflect field observations from 2022. All other reaches reflect 2021 data.
**DC-R5 is formally classified as a stream but is buried under spoil.

3.2. GENERAL LIFE HISTORY OF WESTSLOPE CUTTHROAT TROUT

This section provides general information about the life history of WCT and related observations about WCT in the Grave Creek watershed. It provides context for the Evaluation of Cause and the SME stressors reports.

3.2.1. Size and Maturity

Westslope Cutthroat Trout are long-lived, slow-growing fish that are adapted to cold, unproductive environments (McPhail, 2007). For the Elk River population, Wilkinson (2009) reported a maximum age of 12 years, based on otoliths, which is comparable to WCT in southwestern Alberta that have a maximum age of up to 10 years (Robinson, 2007). Fish reach reproductive maturity at 3–4 years old, after which their growth rates appear to be greatly reduced. Cope et al. (2016) reported that a recaptured WCT from the upper Fording River grew just 60 mm in fork length over 6 years since it was first captured and measured at 350 mm fork length. This slow-growing, long-lived strategy is thought to be a selected trait that this subspecies developed as it evolved in inland refugia during the last glaciation (Robinson, 2007).

Westslope Cutthroat Trout in the Harmer Creek and Grave Creek populations have a small body form. They rarely exceeded 250 mm, and mature fish as small as 150 mm have been found (Cope & Cope, 2020; Lotic Environmental, 2015) (see Chapter 4). By comparison, the fork length of mature WCT in the larger Elk River system frequently exceeds 300 mm, and the fish can grow to sizes that exceed 400 mm fork length (Westslope Fisheries, 2003). Body size is relevant for several reasons. For example, fish biology suggests that smaller females produce smaller eggs (Duarte & Alcaraz, 1989), which can affect egg survival and size of age-1 fish. Also, body size influences habitat requirements for specific life history activities. Small-bodied WCT, for example, do not require the same stream depth to spawn or overwinter as larger, fluvial-migratory WCT.

In the Evaluation of Cause, fish are considered to be age-0 when they emerge from the gravels. They become age-1 approximately 4 months later, on January 1, become age-2 the following January, and so on.

3.2.2. Life History Forms and Movement

Across North America, three broad life history forms (strategies) have been identified, based on migration patterns (COSEWIC, 2016):

- **Fluvial-resident.** These are headwater stream populations that live above barriers and complete their life cycle within a restricted distribution. Their body size remains relatively small (i.e., < 200 mm) due to the cold, nutrient-poor nature of the small streams.
- **Fluvial-migratory.** These are migratory populations that move between small spawning/rearing tributaries and larger, more productive, adult-rearing rivers. As adults, they are generally larger than fluvial-resident populations (> 400 mm).
- **Adfluvial-migratory.** These are populations that migrate between spawning/rearing tributaries and adult-rearing lakes. Adults can exceed 500 mm in length if productivity in lakes is high.

A spectrum of these strategies can be exhibited within the same waterbodies. Populations that employ different strategies are considered more resilient because they are better able to adapt to variable conditions.

All WCT in the Harmer and Grave Creek study areas are fluvial-resident, based on their small size, localized movements and isolation from the Elk River due to the waterfalls at rkms 1 and 2.1 (Akaoka & Hatfield, 2022; Cope & Cope, 2020). Based on telemetry data collected in 2017 and 2018 (Cope & Cope, 2020), the average WCT home range in Harmer Creek was less than 1 km. The maximum was 4.19 km, but this amount of movement was rare (Akaoka & Hatfield, 2022). Home range could not be estimated for the Grave Creek WCT population because culverts present during the telemetry study were barriers to upstream fish movement (see Section 2.5.2). The small home ranges suggest that WCT in Harmer Creek use the same stream reaches for overwintering and summer rearing, i.e., that their home range over the course of a year is small (Akaoka & Hatfield, 2022). No information is available regarding spawning migration.

3.2.3. Thermal Requirements of Westslope Cutthroat Trout

Temperature is a strong determinant of fish growth and survival. Westslope Cutthroat Trout can be sensitive to high summer temperatures. In a study that evaluated WCT thermal requirements, the optimal growth temperature was 13.6 °C and the ultimate upper incipient lethal temperature (the temperature at which 50% of a population survives for 60 days) was 19.6 °C (Bear et al., 2007). High temperatures are, however, not of concern here because the Grave Creek watershed is a cold water system and the daily average extreme temperatures did not exceed the upper incipient lethal temperature in any reach of the Grave Creek study area (Hocking, Whelan & Hatfield, 2022). In contrast, the impacts of summer temperatures on the timing of fry emergence, growth and, ultimately, on survival, are of concern in cold water systems, because at lower temperatures fry emergence is delayed and metabolism is slower, which can result in decreased growth (Coleman & Fausch, 2006). Stream summer temperatures must therefore be warm enough to promote early emergence growth to ensure overwintering survival. Larger fish in their first winter have a higher chance of survival than smaller fish (Smith & Griffith, 1994). In an analysis of streams that have low numbers of Cutthroat Trout (Greenback and Rio Grande cutthroat subspecies), low summer temperatures (< 7.8 °C mean daily temperature in July) prevented recruitment in most years, whereas warm temperatures (10 °C mean temperature) resulted in successful reproduction (Harig & Fausch, 2002).

Low temperatures during overwintering can cause mortality (Chisholm et al., 1987; Brown & Mackay, 1995); however, streams with dynamic (fluctuating) water temperatures and ice cover can also be lethal to fish (Smith & Griffith, 1994). In streams with fluctuating temperatures, frazil or anchor ice can form.

This can cause fish stranding, and it can cause physical abrasions (Brown et al., 2011). The formation of frazil ice has been linked to large-scale movements by fish and changes in the way they use the habitat (Simpkins et al., 2000). These

Types of Ice

Anchor Ice: *ice attached to the beds of streams, lakes and shallow seas*

Frazil Ice: *soft or amorphous ice formed by the accumulation of ice crystals in water that is too turbulent to freeze solid* increased movements have an energetic cost that fish may not be able to sustain during the winter when their metabolism is slowed and food is scarce. Overwintering in areas with stable temperatures and ice cover, such as deeper pools and groundwater-fed areas, is believed to promote winter survival (Chisholm et al., 1987; Brown & Mackay, 1995; Jakober et al., 1998). In small systems such as Grave Creek and Harmer Creek, overwintering is suspected to occur in interstitial spaces of larger substrate, which is low velocity habitat where energetic requirements are expected to be lower.

The potential for water temperature and ice to impact WCT recruitment in the Grave Creek watershed was evaluated by Hocking, Whelan & Hatfield (2022) and is discussed in Sections 5.2.5 and 5.2.12).

3.3. PERIODICITY AND HABITAT USE IN HARMER CREEK AND GRAVE CREEK WESTSLOPE CUTTHROAT TROUT

This section describes the timing of WCT life history activities in the Grave Creek watershed and provides specific details about habitat use by life stage in each of the Harmer and Grave Creek population areas.

3.3.1. Westslope Cutthroat Trout Periodicity

Spawning, incubation, summer rearing and overwintering make up the main life history activities of WCT (Figure 3-4). The timing, or periodicity, of each of these life stages for the Grave Creek watershed is summarized in the following sections, together with the information that was used to derive these periods. A periodicity table (Table 3-2) was developed to show the life history activities in the Grave Creek watershed. The time periods were determined based on observations of spawning, water temperatures and accumulated thermal units (ATUs) (see text box).

Accumulated Thermal Units

Accumulated thermal units (ATUs) are a cumulative measure of temperature commonly used in hatchery settings to determine when eggs will hatch and then to track the development of fry over time. Coleman and Fausch (2007a) determined that WCT emerge from redds between 570–600 ATU. This is similar to 600 ATU reported by the Kootenay Trout Hatchery for WCT emergence.

Table 3-2. Westslope Cutthroat Trout periodicity in the Grave Creek study area

WCT Periodicity Table for the Harmer Creek and Grave Creek Population Areas																																																
Life History Activity	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[1]																																																
Incubation (egg & alevin)[2]																																								*								
Summer Rearing (>5° C)[3]																																																
Over-wintering[4]																																																

[1] The spawning period is based on spawning data from Lotic (2015) and Cope and Cope (2020). Cope and Cope reported that in 2018 peak spawning occurred 13 June to 11 July; in 2019, it occurred 12 June to 4 July. Mean temperature was 6.5 °C.

[2] Early incubation, indicated by the solid green cells is set to start with the earliest potential egg deposition (June 12). It is set to end based on warmest reach, GRV-R1, achieving 600 ATU. Late incubation, indicated by the hatched green cells, is set based on latest spawn date (July 11), beginning from the latest date a redd was observed by Cope and Cope and the ATUs of the coldest reach (GRV-R3 in 2019) (July 11). Emergence occurs at 575–600 ATU.

[3] Summer rearing represents the period when the fish are growing. As defined by Coleman and Fausch (2007a) it is the first week when the sustained weekly average water temperature is > 5 °C.

[4] Overwintering is the opposite season to summer rearing.

* Although the data record ended on October 15, the daily temperature was carried forward to October 31. 600 ATU was not reached, and on October 31 an ATU of 566 was achieved.

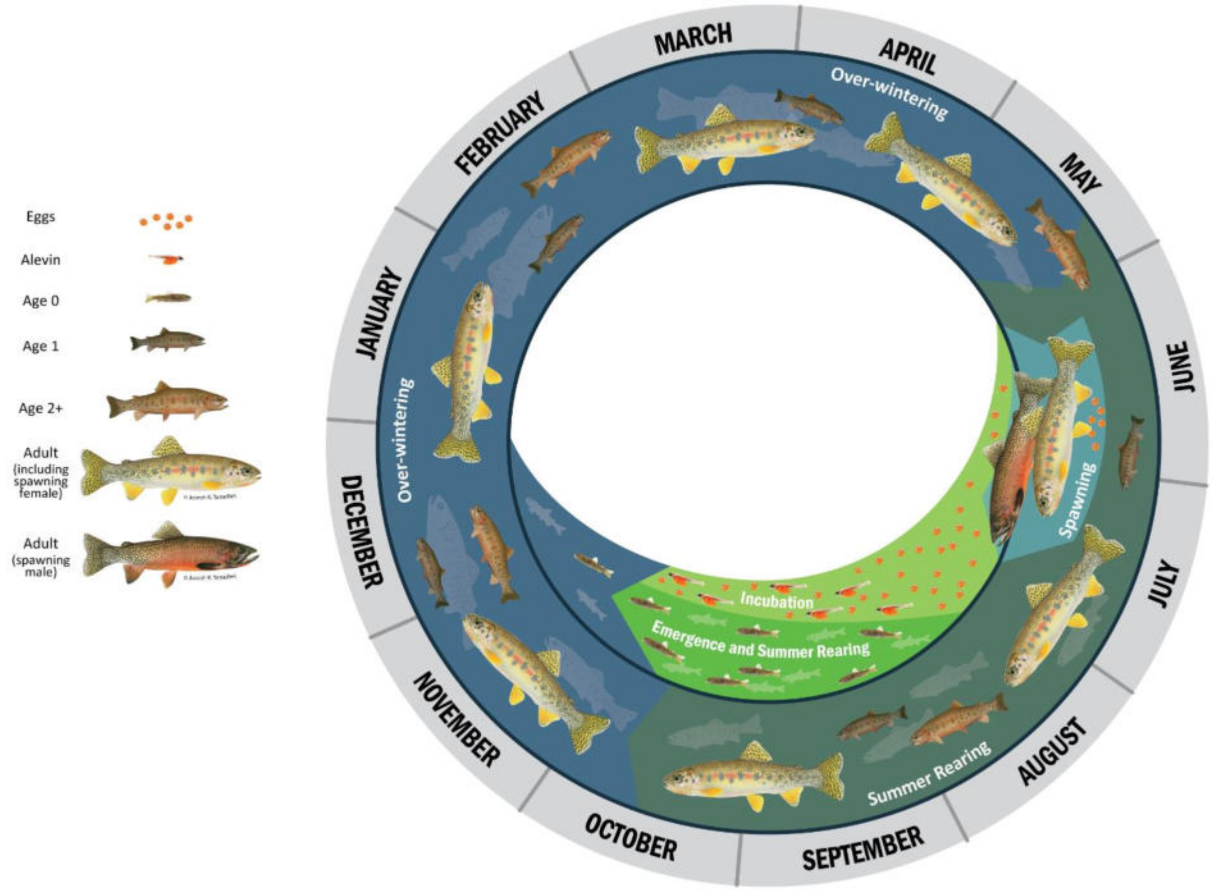


Figure 3-4. An illustration of the life cycle of Westslope Cutthroat Trout in the Harmer and Grave Creeks study area

Adult WCT image(s) used with permission; see Acknowledgements.

3.3.1.1. Spawning

The period when most fish are expected to spawn is referred to as peak spawning. Based on spawning surveys, peak spawning was considered to be June 12 to July 11 (Cope & Cope, 2020; Lotic Environmental, 2015; Thorley et al., 2021). This is presented in Table 3-2.

3.3.1.2. Incubation

Incubation, in Table 3-2 is shown as two overlapping windows, an early window (solid green) and a late window (hatched green). Dates were set as follows. Early incubation (June 12 to August 12) was set to begin at the start of peak spawning and end with the earliest account of a stream reach achieving 600 ATU (GRV-R1 in 2018). Late incubation (July 11 to October 31) was set to begin at the latest spawning date observed by Cope and Cope (2020) and end either with the last reach to achieve 600 ATU or once the incubation was considered incomplete, as the fry would not have emerged during the growing season. The end of late incubation was set using GRV-R3 temperature data from 2019. Temperature loggers were removed from all sites on October 15, 2019. At this point, GRV-R3 had only achieved 539 ATU. The next 2 weeks were estimated using the last recorded temperature of 1.7 °C on October 15, 2019. By October 31, 2019, ATUs were still only at 566.2. The incubation period was ended here because incubation would likely not have been successful beyond this point.

To summarize:

- Early incubation begins June 12 and ends August 12
- Late incubation begins July 11 and ends October 31

Incubation by reach varied enough to warrant an incubation-specific table (Table 3-3). Dates were set using the criteria described above. For context, the end of growing season is also shown on the incubation table to depict how much growing time an emerged fish would have had before entering its first winter. End dates shown for the growing season are the more restrictive data available for 2017 and 2018 (i.e., those that occurred earlier in the year). In all reaches monitored, if fish followed the early incubation timeline, they would have emerged prior to the end of the growing season. However, if they followed the late incubation period, fry would not have emerged within the growing season in GRV-R3, HRM-R3 and HRM-R5. And failing to emerge with adequate time to grow before winter affects winter survival (Coleman & Fausch, 2007a).

Table 3-3. Westslope Cutthroat Trout incubation periods in the Harmer Creek and Grave Creek population areas, predicted using spawning and stream temperature dates (from Cope & Cope, 2020) and a 600 ATU limit for fry

WCT Incubation Table for the Harmer Creek and Grave Creek Population Areas																																																				
Reaches	Jan				Feb				Mar				Apr				May				Jun				Jul				Aug				Sep				Oct				Nov				Dec				Early Emergence		Late Emergence	
	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	Start	End	Start	End
GRV-R1																																																	June 12	Aug 12	July 11	Sept 11
GRV-R2																																																	June 12	Aug 18	July 11	Sept 16
GRV-R3																																								*									June 12	Aug 31	July 11	Oct 31*
HRM-R1																																																	June 12	Aug 16	July 11	Sept 13
HRM-R3																																																	June 12	Aug 27	July 11	Oct 06
HRM-R5																																																	June 12	Sept 08	July 11	Oct 17
DC-R3																																																	June 12	Aug 06	July 11	Sept 01

incubation period assuming spawn date of June 12

incubation period assuming spawn date of July 11

end of growing season using earlier date between 2017 and 2018

Early emergence end - earliest year

Late emergence end - latest year

* Data record ended at Oct 15, daily temperature was carried forward to Oct 31, 600 ATU was not reached. At Oct 31, and ATU of 566 was achieved

3.3.1.3. Summer Rearing

Summer rearing is defined in this report as a period of higher growth associated with warmer water temperatures during summer and into the shoulder seasons. Rearing is not life stage specific and refers to adults, juveniles and fry. The summer rearing period begins when the mean weekly water temperature is sustained at above 5 °C. It stops when mean weekly temperature drops below 4° C (Coleman & Fausch, 2007b). The start of rearing ranged from May 20 (HRM-R1 in 2019) to June 12 (HRM-R5 in 2017), with the average being May 28. The last day of rearing ranged from October 6 (GRV-R2 in 2019) to October 30 (HRM-R3 in 2014), with a mean of October 10. The average dates were used to create a rearing period of May 28 to October 10 (135 days) for the Grave Creek watershed, but the specific timing would vary spatially and temporally.

3.3.1.4. Overwintering

Overwintering is the season opposite to rearing. This period extended from October 10 to May 28.

3.3.2. Habitat Use in the Harmer and Grave Creeks Study Area by Life History Stage

The section describes the habitat WCT use in the Harmer and Grave Creeks study area by life stage. Details about specific habitat use are based on telemetry studies (Cope & Cope, 2020) and electrofishing observations.

3.3.2.1. Spawning and Incubation

Rising water temperatures (5 °C or above) and increasing flow trigger spawning migrations (McPhail, 2007). Spawning occurs as peak runoff begins to decline and temperatures approach 9 °C, typically in May to June (Schmetterling, 2001; Muhlfeld, 2009). Redds are typically observed in the laminar flow of glides and pool tail-outs, which can often be found as tertiary habitat within riffles (McPhail, 2007). The optimal incubation temperature is 10 °C. After spawning, embryos generally incubate in the spawning gravels for 6 to 7 weeks, depending on water temperature. Once hatched, alevins (age-0) remain in the substrate until the yolk sac has been absorbed, and they then emerge from the streambed as fry (age-0) with a fork length of approximately 20 mm (Scott & Crossman, 1998).

Pools represented 42% of the spawning habitat used in the Grave Creek watershed, but they are only 4% of the available habitat in Grave Creek and 10% of available habitat in Harmer Creek (Cope & Cope, 2020). Pools are important spawning habitat in these watersheds and their value increases when they have cover in the form of large woody debris (LWD), undercut banks and vegetation. Peak spawning occurred from June 12 to July 11 in 2018 and 2019. The mean water temperature when redds were found was 6.5 °C, but it ranged from 4.5 °C to 10.9 °C.

3.3.2.2. Summer Rearing

The summer rearing period begins for juveniles[8] and non-spawners when water temperatures warm in spring, and it begins for spawners after spawning finishes (typically mid-July). Summer rearing continues through September. In Harmer Creek, pools are the dominant feature that subadult and adult WCT select for rearing (i.e., for summer holding and feeding), based on telemetry studies (Cope & Cope, 2020). Pools represent 63% of the summer rearing habitat. They are typically plunge pools associated with LWD jams and sediment wedges immediately upstream that create hydraulic scour. After pools, riffles are the next most selected feature. They represent 24% of summer rearing habitat. In Grave Creek, riffles were the dominant summer habitat the fish used (42%), followed closely by pools (37%). Pools with adequate cover are essential habitat for WCT, but the frequency of this type of meso-habitat across these creeks is low. The dominant cover for summer rearing habitat in Harmer Creek was LWD, and in Grave Creek it was boulders.

Rearing habitat for juveniles and fry[9] was not included in the telemetry work of Cope and Cope (2020), because small body size restricts the ability to tag these younger fish. Nonetheless, the rearing habitat the younger life stages use can be inferred from electrofishing results. Given the small size of these streams, all life stages of WCT can be found in any mesohabitat type. Some segregation occurs, based primarily on water velocity and depth, with juveniles preferring shallower habitat and fry being more abundant in slow, stream margin habitat. These observations are consistent for WCT in general.

[8] Juveniles are defined as fish that are age-1 (i.e., spawned the previous year) and age-2+ (i.e., > age-1 but not yet reproductively mature; can include multiple age-cohorts).

[9] Fry are age-0 fish that were just spawned. They become age-1 fish in January of the year after they were spawned. Fry are capable of feeding themselves but have not yet developed scales or fully formed fins.

3.3.2.3. Overwintering

Overwintering is defined as the part of the year when fish are not in the summer rearing phase. In the Grave Creek study area, the overwintering season is from October 10 to May 28. This is based on temperature data from Cope and Cope (2020) and was implied by Coleman and Fausch (2007b) (Figure 3-4, Table 3-2). Two dominant mesohabitats for WCT overwintering areas have been reported in the literature. Juveniles prefer riffles with cobble-boulder substrate and abundant overhead cover (Ford et al., 1995; Cunjak, 1996; Jakober et al., 1998; Ptolemy et al., 2006; McPhail, 2007), while adults prefer deep, slow-moving pools without anchor ice and with potential groundwater inputs (Boag & McCart, 1993; Brown & Mackay, 1995; Brown & Stanislawski ,1996; Prince & Morris, 2003; Morris & Prince, 2004; Cleator et al., 2009; Cope & Prince, 2012; Cope et al., 2016). Fry tend to be in low velocity water (i.e., water that is near standing), in off-channel areas and along the margins of the main channel.

The overwintering reaches that fish used mirrored the summer rearing habitat. This was expected because most of these fish had home ranges measured in metres, and they showed little movement within the system throughout the year (Akaoka & Hatfield, 2022). In the Harmer Creek population area, 75% of the radio-tagged adult WCT overwintered in riffle mesohabitat (Cope & Cope, 2020), where the mean maximum depth was 0.35 m. In the Grave Creek population area, 65% of tagged adults were found in riffle mesohabitat at a mean maximum depth of 0.42 m. For both populations, this represented a move from summer, pool-rearing habitat to nearby riffle habitat for overwintering. No younger fish were tagged during the telemetry study, so no equivalent data are available to understand overwintering during the same time period.

3.4. FISH PRESENCE — A SUMMARY OF THE HARMER AND GRAVE POPULATION AREAS

Quantifying fish-bearing habitat relies on a combination of observing fish directly and considering morphologic variables such as channel gradient and migratory barriers to conservatively assign fish-bearing status or the potential for fish to be present (BC MOF, 1998; this report, Chapter 3.1). Habitat that fish actually use can differ from estimates of fish distribution based on the habitat’s morphologic characteristics, because actual use is affected by factors such as stream size, habitat quality, flow and temperature. Cope and Cope (2020) comprehensively assessed fish use in the Harmer Creek and Grave Creek population areas, which is summarized in the preceding sections according to life history activity.

Fish presence from 2013 through 2021 is considered representative of current conditions. A summary of fish presence in the Harmer Creek and Grave Creek population areas was compiled by reach (Table 3-4) from the following datasets:

- Telemetry capture and detection locations (Cope & Cope, 2020)
- Electrofishing (Lotic Environmental, 2015; Golder, 2017; Cope & Cope, 2020; Thorley et al., 2022)
- Redd surveys (Cope & Cope, 2020; Thorley et al., 2022)
- Fresh Water Atlas Fish Observations (Government of British Columbia, 2021)
- Genetic study capture locations (Lamson, 2016).

Fish were considered to be present if at least one fish (or suspected redd) was observed in a reach in a given life history stage. However, presence alone does not reflect how much the fish used each reach. That is discussed further in Chapter 4 (Section 4.3.2.5). Limited data on fish presence were available for the tributaries of the Grave Creek population area (Cope & Cope, 2020; provincial stocking records of Harriet Lake). In the Harmer Creek population area, there was information only for Dry Creek, South Tributary and Sawmill Creek tributaries.

3.4.1. Harmer Creek Population

Fish at all life history stages were documented in mainstem Harmer Creek reaches HRM-R3, HRM-R4 and HRM-R5. No fish were documented at any life stage in HRM-R2 (the Harmer Creek Sedimentation Pond) between 2013 and 2021. Only one adult was documented in HRM-R6 in the summer of 2013, which is the most upstream reach and has the coldest water temperatures in the Harmer Creek population area. Although this reach was identified as having 2.2 km of fish-bearing length based on gradient (Section 3.1), it is considered to provide negligible habitat to the Harmer Creek WCT population due to cold water temperatures.

Other than Dry Creek, the tributaries were not sampled with the same intensity as the mainstem of Harmer Creek, i.e., spawning surveys are lacking for those other than Dry Creek. However, in summer, fish were documented in all the reaches identified as fish bearing. Fish were present in all Dry Creek reaches in at least one season. Age-2+ and adult WCT were documented in DC-R3 for all life history stages, and they were documented in all reaches of Dry Creek during summer rearing. Age-1 WCT were not reported in any sampling of Dry Creek. Fish were documented in the south tributary to Dry Creek (ST), Sawmill Creek (SM) and Balzy Creek during summer rearing, but no data were available for those tributaries during spawning (Cope & Cope, 2020). Telemetry data do not suggest larger fish use these tributaries for overwintering. Of note, a culvert barrier is located on Sawmill Creek near the break between SM-R1 and SM-R2 and prevents fish from moving upstream.

In the Harmer Creek population area, 8.3 km of mainstem habitat and 5.5 km of tributary habitat is used by WCT for at least one life history activity.

3.4.2. Grave Creek Population

During the summer rearing and overwintering periods, WCT were documented in all reaches of the Grave Creek population area. There was spawning in HRM-R1, GRV-R2 and GRV-R3. Cope and Cope (2020) assessed fish presence in tributaries in the Grave Creek population area and used stream gradient criteria to infer fish-bearing status where sampling was not completed. Stocking records for Harriet Lake were used to infer that the entire tributary connecting the lake to Grave Creek is fish bearing.

Table 3-4. Westslope Cutthroat Trout in Grave and Harmer Creeks by life history stage

Table excludes presence based on data collected before 2013, reaches with no documented fish presence (e.g., HRM-R2, SM-R3) and unnamed tributaries in the watershed

Reach	Overwintering	Summer rearing	Spawning
Grave Creek Population			
GRV-R1	Yes	Yes	No
GRV-R2	Yes	Yes	Yes
GRV-R3	Yes	Yes	Yes
GRV-R4	Yes	Yes	Yes*
HRM-R1	Yes	Yes	Yes
Harmer Creek Population			
Balzy Creek			
BZY-R1	NA	Yes	No
Dry Creek			
DC-R1	No	Yes	No
DC-R2	No	Yes	No
DC-R3	Yes	Yes	Yes
DC-R4	No	Yes	No
Harmer Creek			
HRM-R3	Yes	Yes	Yes
HRM-R4	Yes	Yes	Yes
HRM-R5	Yes	Yes	Yes
HRM-R6	No	Yes	No
Sawmill Creek			
SM-R1	NA	Yes	NA
SM-R2	NA	Yes	NA
South Tributary			
ST-R2	NA	Yes	NA

NA (Not applicable) — what it means for each life stage:

- **Overwintering.** No fish were tagged and no previously tagged fish were observed
- **Spawning.** No surveys were conducted in this reach
- **Incubation.** No temperature logger data were available in this reach

* Reflects an observation made during the 2021 field season

4. Understanding the Reduced Recruitment

4.1. CHAPTER OVERVIEW

In this chapter, we begin by discussing key aspects of WCT biology, particularly those that relate to recruitment. We summarize the available WCT monitoring data and use the summary to evaluate the status of the Harmer Creek and Grave Creek populations. The evaluation is based on temporal and spatial patterns in fish and population metrics, which include size, condition, local fish density and recruitment. Temporal patterns refer to changes prior to, during and after the period of Reduced Recruitment, and spatial patterns refer to differences between and within Harmer Creek and Grave Creek population areas. These patterns are used to understand which life stages were likely responsible for the Reduced Recruitment observed in the Harmer Creek population, i.e., whether the impacts were related to the adult stage (e.g., reduced fecundity, lack of spawning) or to early life stages (e.g., reduced growth and survival). Data collected in 1996, 2008 and 2013 are classified as "historical," while data from 2017 to 2021 are classified as recent. The "period of Reduced Recruitment" refers to the 2017 to 2019 spawn years.

4.2. BIOLOGY

This review describes aspects of WCT biology that are necessary to understand the recruitment analysis provided in this Evaluation of Cause and the SME reports. For further discussion of WCT biology, see Chapter 3. In the Evaluation of Cause, recruitment is defined as the number of age-1 fish present in the fall that were spawned in the previous year. Fish are considered to be age-0 when they emerge from the gravels. They become age-1 approximately four months later, on January 1, become age-2 the following January and so on. Fish cohorts that are older than age-1 but not yet reproductively mature are classified as age-2+. Fish spend several years as age-2+, so this class represents multiple cohorts. Once fish are reproductively mature, they are classified as adults. The abundance of age-0 fish was not used as a metric of recruitment because (1) the patchy distribution and low capture efficiency of age-0 fish means abundance estimates are uncertain, and (2) high mortalities in WCT populations typically occur during the first winter (Coleman & Fausch, 2007a, 2007b).

The number of age-1 recruits produced by spawning the previous year depends on the abundance and fecundity of the adults and on the multiple developmental stages, including:

- Gamete production
- Fertilization
- Burial in the gravels
- Egg incubation
- Hatching through alevin incubation in redd
- Fry emergence from the redd into the water column
- Fall survival
- Overwintering survival
- Growth and survival through to the fall the following year

It takes several years for a fish to reach reproductive maturity and become a spawner, and fish may spawn in multiple years. For a population to remain stable and be at replacement, i.e., to neither increase nor decrease, on average, every spawning fish (spawner) would need to produce one spawner over its lifetime. For a spawner to replace itself, enough eggs must be deposited and successfully hatch such that at least one individual survives and grows to become a spawner (Figure 4-1). If the average spawner produces more than one spawner, the population will increase; conversely, if it produces less than one spawner, the population will decline (Myers et al., 1999). In a population that is stable over the long term, recruitment may be below or above replacement in any particular year due to natural variation in vital rates (e.g., growth, reproduction, survival) driven by environmental variation.

Key Terms

Condition *is a measure of fish health based on the ratio of fish weight to length.*

Fecundity *is the number of eggs produced by a spawning female fish in a single year.*

Growth *occurs when calorie intake exceeds the energy demands, including those associated with gamete production.*

Recruitment *refers to the addition of new individuals to a population through reproduction, and it is measured as the number of age-1 fish in the fall that were produced by spawning in the previous year.*

Reproduction *can be affected by changes in fecundity and/or spawning frequency (fish may not spawn every year), which, in turn, can affect the number of fertilized eggs in any given year.*

Survival *of any life stage is determined by interactions among factors such as predation, food limitation, energetic demands, physiological stress and disease.*

Survival through the early life stages is critical for recruitment and, ultimately, for population replacement. After fish emerge from redds, they are susceptible to predation, and they compete for feeding locations where the risk of predation is low. The proportion of age-0 fish that survive is a function of how many age-0 fish there are, the predation pressure, the availability of food and the number and suitability of the feeding locations. This density-dependent mortality contributes to "thinning" (i.e., reduction) of the cohort (Ahrens et al., 2012). Growth is particularly important for age-0 and age-1 fish, both because small fish are more susceptible to predation, including from conspecifics[10] (Rosenfeld, 2014), and because, in areas with long, cold winters such as the Grave Creek watershed, smaller fish may not have sufficient energy reserves to survive the winter. Indeed, overwintering survival of Cutthroat Trout from age-0 to age-1 depends strongly on body size at the onset of winter (Coleman & Fausch, 2007a, 2007b; Hocking, Whelan & Hatfield, 2022; Thorley & Branton, 2023).

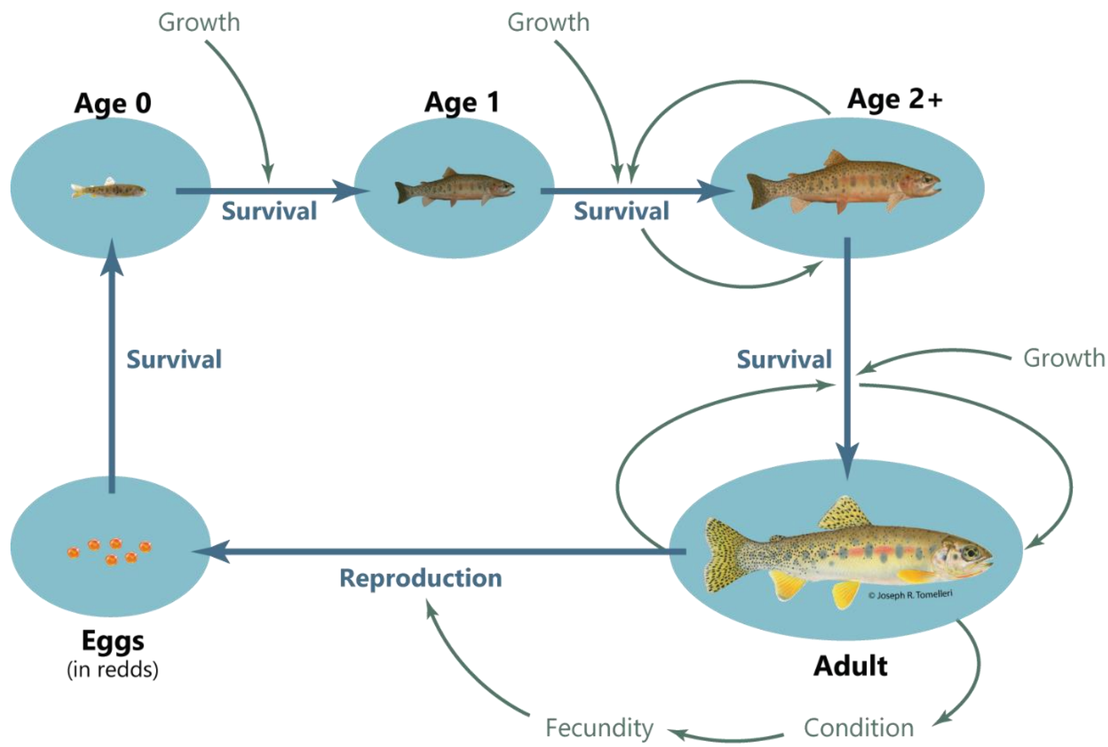


Figure 4-1. An illustration of key processes and life stages of Westslope Cutthroat Trout

To achieve population replacement, a typical WCT population in the Elk Valley requires a survival rate from egg to fall age-1 of ~5%[11] (Ma & Thompson, 2021). However, based on

[10] Although WCT are primarily insectivorous (McPhail 2007), cannibalism of fish between 25 and 40 mm has been recorded (Griffith 1974) and may represent an important predation pressure for the age-0 fish.

[11] This survival rate was based on parameter estimates from literature sources focused on the Upper Fording River and Elk Valley. Where estimates were not available in the Elk Valley, parameter values from other WCT populations throughout BC, Idaho and Alberta were used.

data from Harmer Creek and Grave Creek, an average egg to fall age-1 survival rate of 4% (1–11%; 95% compatibility interval [CI]) is estimated to be required in the long term for population replacement (Thorley et al., 2022). Fecundity, which is a function of length and condition, is a key determinant of reproductive success once the fish are mature (Figure 4-1).

4.3. SUMMARY OF DATA FROM THE HARMER AND GRAVE POPULATION AREAS

In this section we summarize the datasets and analytical methods used to understand the spatial and temporal trends in key WCT parameters. The results come from data collected during historical monitoring programs (1996 to 2013) and recent annual monitoring (2017 to 2021) in Harmer Creek and Grave Creek (Cope & Cope, 2020; Thorley et al., 2022). The full fish population analyses and methods are reported in Thorley et al. (2022).

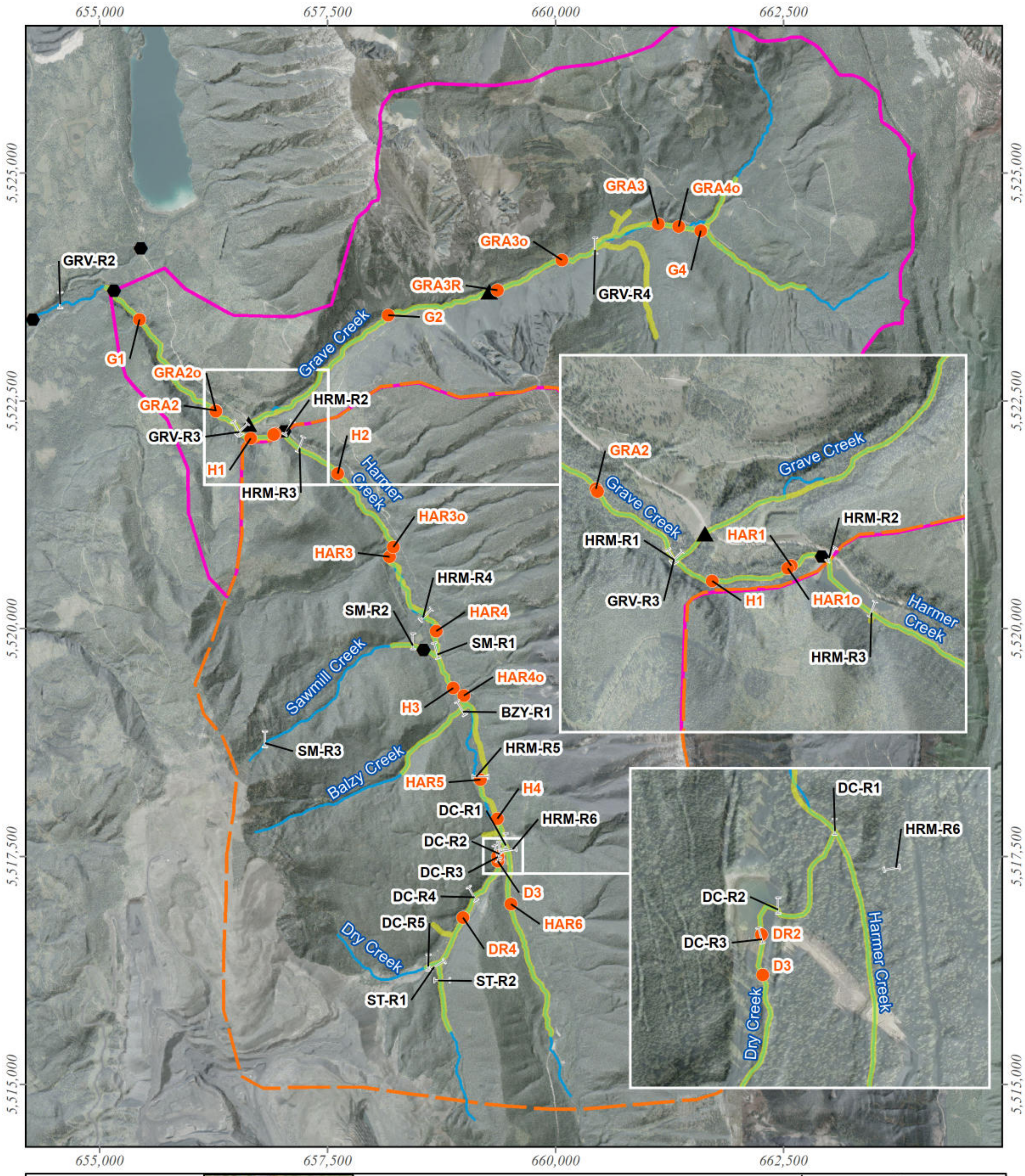
4.3.1. Data Sources

Adult and juvenile WCT in the Grave Creek watershed were inventoried and/or monitored using backpack electrofishing in 1996, 2008, 2013 and every year between 2017 and 2021. In 2017, a fish salvage also occurred in Dry Creek. The data provided information on fish abundance, length, weight and distribution (Thorley et al., 2022). The sample locations are shown in Figure 4-2 and the sources of these datasets are listed below:

- A fish inventory completed in 1996 (Morris et al., 1997)
- A fish and fish habitat assessment completed in 2008 to support the Cedar/Dry Creek Dump Extension (Berdusco, 2008)
- Fish and fish habitat baseline work completed in 2013 to support the Baldy Ridge Extension Project (Lotic Environmental, 2015)
- Data associated with a fish salvage completed on Dry Creek from late September to early October 2017 (Golder, 2017)
- The Harmer Creek and Grave Creek Westslope Cutthroat Trout Habitat and Population Assessment Report for March 1, 2017, to October 31, 2019 (Cope & Cope, 2020)
- Data from monitoring completed in 2020 (Thorley et al., 2021) and 2021 (Thorley et al., 2022).

Figure 4-2 appears on the following page. Its caption is:

Figure 4-2. Electrofishing locations in Harmer Creek and Grave Creek



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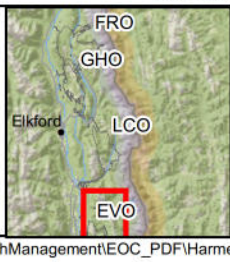

Electrofishing Locations 1996 - 2021

Start of Reach	WCT Distribution
Electrofishing Sites	Streams
Impassble Barrier	Grave Creek Population Area
Historical Barrier	Harmer Creek Population Area

N

0 350 700 1,400 Meters

DATE: 9/22/2022	MINE OPERATION: Elkview
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From 2018 to 2020[12], ~6% of the Harmer Creek population area was sampled each year using single- or multi-pass removal-depletion electrofishing. From 2017 to 2020, 6–7% of the Grave Creek population area was sampled using the same methods and in 2021, ~17% of the Harmer population area and ~19% of the Grave Creek population area were sampled.

In addition to electrofishing, the monitoring included:

- Redd surveys (Cope & Cope, 2020; Thorley et al., 2021, 2022)
- Individual studies on movements of radio-tagged adults based on detections at fixed antenna locations and in mobile surveys (2017 to 2019) (Cope & Cope, 2020; Akaoka & Hatfield, 2022)
- Genetic diversity from fin clips (Lamson, 2016; Thorley et al., 2022)
- The size of age-0 fish based on hand-netting them in the stream margin during bank walks (2021) (Thorley et al. 2022)

Removal-Depletion Estimates

Removal-depletion is a method used to estimate capture efficiency, i.e., how many fish are captured compared to the number of fish present. During removal-depletion, the fish captured on each pass are held in buckets until the survey is complete. By inference, removal-depletion estimates the total number of fish remaining, based on the number of fish caught on each pass and assuming that the capture efficiency is constant across passes. For example, capturing 50 fish on the first pass and 25 fish on the second pass is most consistent with an underlying population of 100 fish. Of those 100 fish, 50% are caught on the first pass and 50% of the remaining 50 individuals are caught on the second pass. However, the capture efficiency tends to decline after the first pass, so this method tends to underestimate the underlying densities.

The datasets for electrofishing and redd surveys were used to support various aspects of the Evaluation of Cause and underlying SME reports. This chapter relies primarily on the electrofishing data; therefore, additional detail on the electrofishing dataset is provided here, including how data collected using different methods were analyzed in a way that made them comparable.

From 2017 through 2021, for each location sampled during monitoring studies, multi-pass removal-depletion backpack electrofishing surveys were conducted at three of five distinct mesohabitat units (sites), corresponding to pool, riffle, run, glide or cascade. (For a

[12] In 2017, approximately 27% of Harmer Creek was electrofished because of the salvage in Dry Creek.

description of mesohabitats, see Cope et al. [2016].) Three relatively short sites of approximately 25 m in length were sampled at each location. The sites were closed by stretching stop nets at their upstream and downstream limits to prevent fish entering or leaving the sites between passes. From 2017 to 2019, Cope and Cope (2020) sampled three sites at each of eight locations in the Grave Creek population area (i.e., 24 individual sites) and three sites at eight locations[13] in the Harmer Creek population area. In 2020 and 2021, the same locations (16 locations with 48 sites) were revisited (Thorley et al., 2021, 2022). Monitoring surveys between 2017 and 2021 included a single sampling site in Dry Creek, in DC-R3. However, in 2017 a salvage was also carried out in Dry Creek (see Appendix B), during which all reaches of Dry Creek except for DC-R1 were fished using backpack electrofishing[14] (Golder, 2017). As these sites were sufficiently long, fish movement out of the site was considered minor and stop nets were not required.

A second electrofishing methodology was used in 2021 to address a potential bias in site selection for the removal-depletion methods and to increase the proportion of habitat sampled. The method consisted of a single open pass at seven long sites (~300 m). Stop nets were not used. A long site was randomly selected from each of GRV-R2 to GRV-4 and HRM-R1 to HRM-R4. The long sites covered an additional 12% of habitat for the Grave Creek population and an additional 11% for the Harmer Creek population. For a full description of methods, see Thorley et al. (2022).

In the 1996 fish inventory, single pass electrofishing was conducted at open sites of at least 100 m in length. If a fish was not caught, sampling was continued until a fish was caught, gradients exceeded 20%, significant barriers were encountered or at least 500 m of stream length had been sampled (Morris et al., 1997). In 2008, the sites, which were approximately 100 m long and open, were sampled using a single pass (Berdusco, 2008). In 2013, the sites, which were also approximately 100 m long but closed, were sampled using multiple removal passes (Lotic Environmental, 2015). When estimating fish densities, the differences in the number of passes and seconds per unit area were accounted for by the model (Thorley et al., 2022).

While there was consistent sampling in the mainstem of Harmer Creek and Grave Creek from 2017 to 2021, with some locations being sampled in all years and having data back to 1996, there are several considerations regarding the spatial and/or temporal frequency of sampling in other parts of the study area. These are described below.

[13] One location originally in HRM-R6 was reassigned to Dry Creek in 2018.

[14] The first pass in the Dry Creek Sedimentation Pond was from a boat. All other electro-fishing was with a backpack unit. No fish were successfully captured by angling, minnow traps or fyke nets (Golder, 2017).

Except for Dry Creek, very little monitoring has been conducted in the tributaries of the Harmer Creek and Grave Creek population areas. As a result, the tributaries were not included in the calculation of abundance estimates. While tributaries are expected to have fish production that would contribute to the overall populations, this contribution was expected to be relatively minor, based on the accessible length of most of the tributaries (i.e., except for Dry Creek) (see Table 3-1).

A salvage in 2017 removed eight fish from the Dry Creek Sedimentation Pond and 47 from above the pond (DC-R3 and DC-R4). Of these, 28 were adults (≥ 170 mm) and the remainder were age-2+ (104–169 mm). Also, 33 age-1s and age-2+ (80–143 mm) were removed from South Tributary, (Golder, 2017; also see Appendix B). The fish were relocated into Harmer Creek below the confluence with Dry Creek (Golder, 2017). Due to relatively sparse subsequent electrofishing data in Dry Creek and South Tributary, it is uncertain whether this salvage resulted in a long-term reduction of fish densities in these two creeks and a long-term relative increase in Harmer Creek. For the purpose of the Evaluation of Cause, the densities from the 2017 salvage are conservatively considered to be representative of Dry Creek during the period of interest.

4.3.2. Data Analysis and Results

This section provides a summary of the monitoring data and analyses reported by Thorley et al. (2022) for the Harmer Creek and Grave Creek population areas. The summarized data were used to understand the population structure and dynamics of the WCT populations, and ultimately the Reduced Recruitment in the Harmer Creek population area. For the Harmer Creek and Grave Creek populations, Thorley et al. (2022) used the available data described in Section 4.3.1 to characterize individual fish metrics (spawning, fecundity, fish length and condition) and population metrics (density, abundance and recruitment). The 2017 to 2020 monitoring data had been analyzed previously by Cope and Cope (2020), but Thorley et al. (2022) incorporated additional data and used different statistical methods. The data Thorley et al. (2022) used were from historical studies (Morris et al., 1997; Berdusco et al., 2008; Lotic Environmental, 2015), the 2017 fish salvage of Dry Creek and South Tributary (Golder, 2017) and the 2020 and 2021 monitoring programs.

Thorley et al. (2022) used hierarchical Bayesian methods, which estimate the ranges of probable values of particular parameters, based on all available data. The ranges of values, which have a probability of 95% of including the actual value, are referred to as the 95% compatibility intervals (CIs). To account for changes in the density of life stages from one year to the next, a hierarchical Bayesian removal stage-based life cycle model (Schaub & Kéry, 2022) was fitted to all the single and multi-pass electrofishing data. Abundance and egg to age-1 survival estimates are reported here based on this life cycle model[15]. The historical data, which were collected in single year sampling events, were used for fish weight and length but were not used to estimate survival and recruitment rates. The life cycle model uses data collected in consecutive years to estimate survival and recruitment rates because multiple years of data increase the certainty in the estimates. For more detailed methods and results associated with the data analyses and summary, see Thorley et al. (2022).

4.3.2.1. Spawning

Spawning migrations are triggered by rising water temperatures (5 °C or above) and increasing flow (McPhail, 2007). Spawning occurs as runoff begins to decline and temperatures approach 9 °C, typically in May to June (Schmetterling, 2001; Muhlfeld, 2009).

Redd surveys conducted from 2018 to 2020 in Harmer Creek and Grave Creek indicate a relatively consistent spatial distribution, with the notable exception of 2020 when no redds were recorded for the Grave population below km 5.8 in the mainstem in GRV-R3 and GRV-R2 or below the Harmer Dam in HRM-R1 (Figure 4-3). All redds in the Harmer Creek population area were recorded between the Harmer Creek Sedimentation Pond and the confluence with Dry Creek, except in 2018 and 2020 when one and three redds, respectively, were recorded in Dry Creek. Most redds in the Grave Creek population area were recorded in GRV-R3, between the two culverts at 4.5 and 7.8 km, and in HRM-R1 below the Harmer Dam. The first year a

> ***Spawning (Redd) Surveys***
>
> *Spawning (redd) surveys commenced between June 8 and June 15 and continued until July 4 and July 13, depending on the year. Surveys were conducted approximately once every 1 to 2 weeks from 2018 to 2020 and at least once a week in 2021. The surveys covered Grave Creek from the confluence with East Tributary at 10.4 km to the first falls at 1.0 km, the lower 6.3 km of Harmer Creek (from the confluence with Dry Creek) and the lower 1.6 km of Dry Creek from the confluence with South Tributary (Figure 4-3). In 2021, soon after peak spawning, additional surveys were conducted in the lower 0.6 km of South Tributary and the 1.7 km of Harmer Creek above the confluence with Dry Creek. (Source: Thorley et al., 2022)*

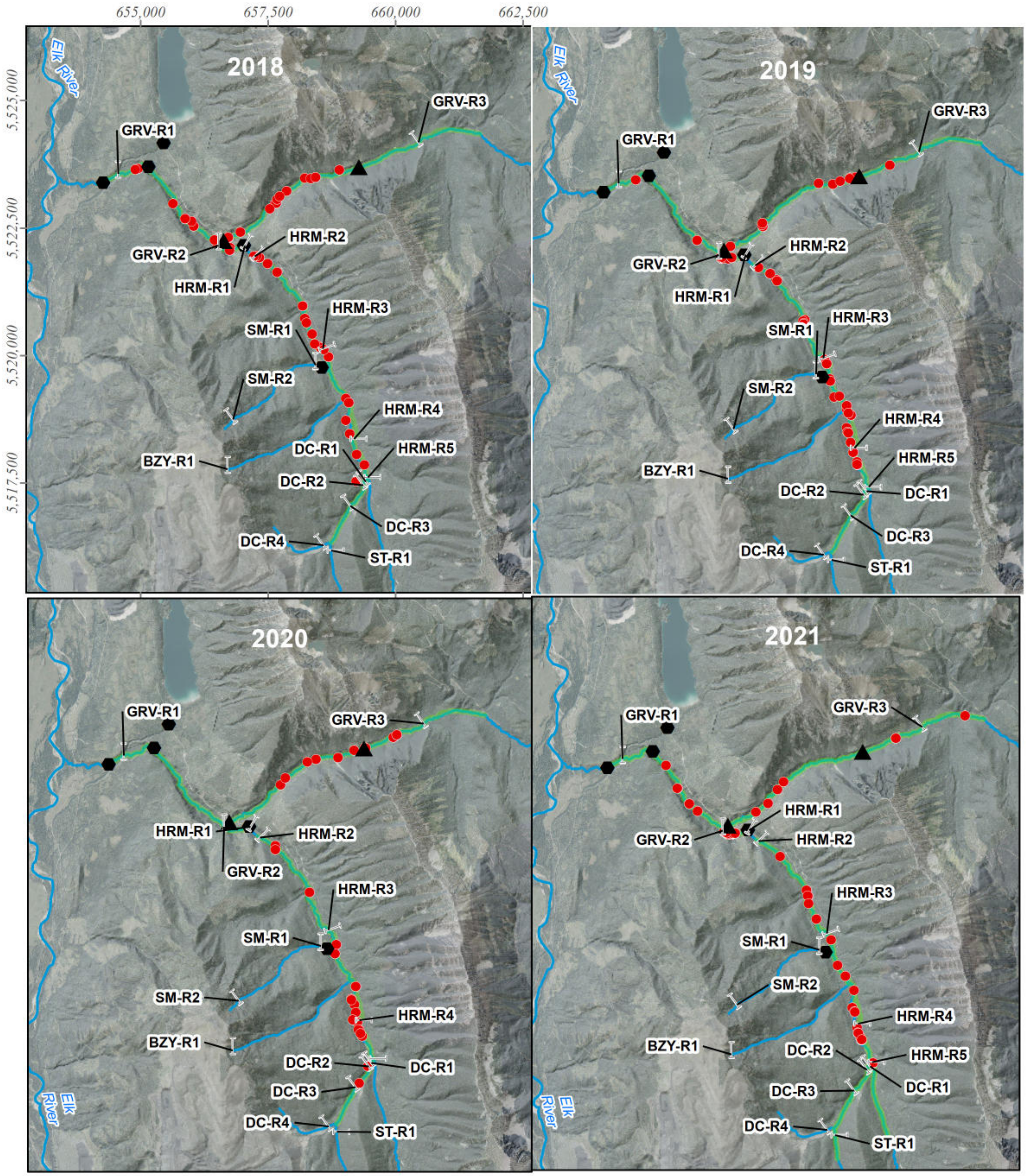
[15] Thorley et al. (2021) used a different model (i.e., the "independent model"). With the additional age-2+ data available as of the 2021 monitoring year, they adopted the life cycle model that uses data from multiple years (i.e., forecasting and backcasting) to provide a more robust estimate of population parameters.

redd was recorded above 7.8 km in Grave Creek was 2021, despite reported surveys since 2018.

The annual total redd counts, estimated using area-under-the-curve methods (see Thorley et al., 2022), were similar for the Harmer Creek and Grave Creek populations in 2018 and 2021, but they were lower in the Grave Creek population in 2019 and 2020, and highest in the Harmer Creek population in 2019 (Figure 4-4). The trend in the redd counts suggests an overall decline in the number of spawning females in both populations over the past 4 years. This trend is consistent with the decline in adults estimated from the electrofishing data by the life cycle model (Section 4.3.2.6).

Figure 4-3 is presented on the following page. Its caption is:

Figure 4-3. The spatial distribution of redds by year



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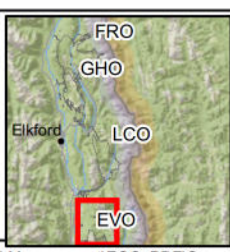

Spawning Locations 2018 -2021

StreamReach	Surveyed Area
Impassble Barrier	Streams
Historical Barrier	Watercourse
Redd Locations	

N

0 625 1,250 2,500 Meters

DATE: 9/19/2022	MINE OPERATION: Elkview
SCALE: 1:100,000	COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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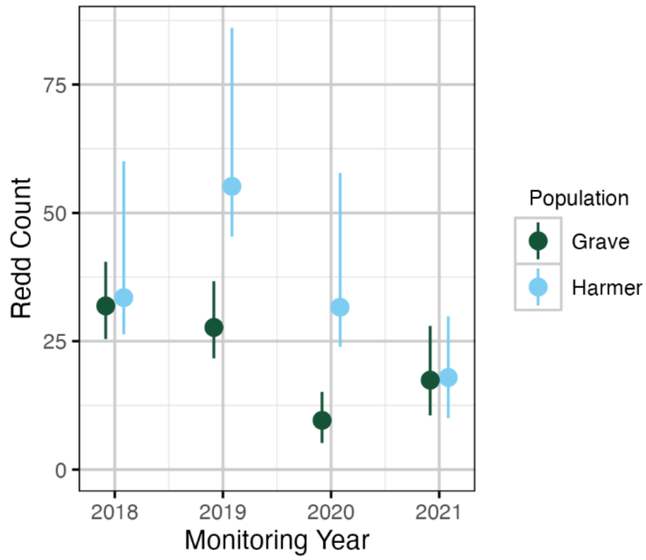


Figure 4-4. Total expected redd count by monitoring year and population estimated using the area-under-the-curve method

The estimate is the total number of unique redds that an average observer would be expected to see if they surveyed each day throughout the spawning period. Error bars represent 95% CIs. Source: Thorley et al. (2022)

4.3.2.2. Fish Length

The length of a fish indicates its likely age, maturity and, for females, fecundity. Length is also an important predictor of overwintering survival for age-0 Cutthroat Trout (Hocking, Whelan & Hatfield, 2022; Coleman & Fausch 2007a, 2007b; Thorley & Branton, 2023). The most common measure of the length of a trout is its fork length, which is the length from the snout to the fork in the tail.

Fish caught by electrofishing in the Harmer Creek and Grave Creek populations are plotted by fork length and life stage in Figure 4-5. Fish in each population were assigned to a life stage based on the distribution of fork lengths for all years. Individuals in the Harmer Creek WCT population less than 45 mm long were considered to be age-0, while those between 45 and 94 mm were considered to be age-1. In contrast, the Grave Creek WCT population individuals with a fork length less than 50 mm were considered to be age-0, while those with fork length between 50 and 99 mm were considered to be age-1. Following Cope and Cope (2020), the previous threshold for a fish to be classified as an adult was 150 mm (Thorley et al., 2021). However, adult fish can grow by 20 mm between the spawning period and the fall when the electrofishing surveys occur. Because females, which determine the egg deposition, tend to mature at a greater length than males (Downs, 1995), the fall adult length threshold was increased to 170 mm. In this report, age-2+ juveniles are individuals that were too big to be age-1 but too small to be adults, i.e., in the fall they were between 95 mm and 169 mm for the Harmer Creek WCT population and between 100 mm and 169 mm for the Grave Greek WCT population.

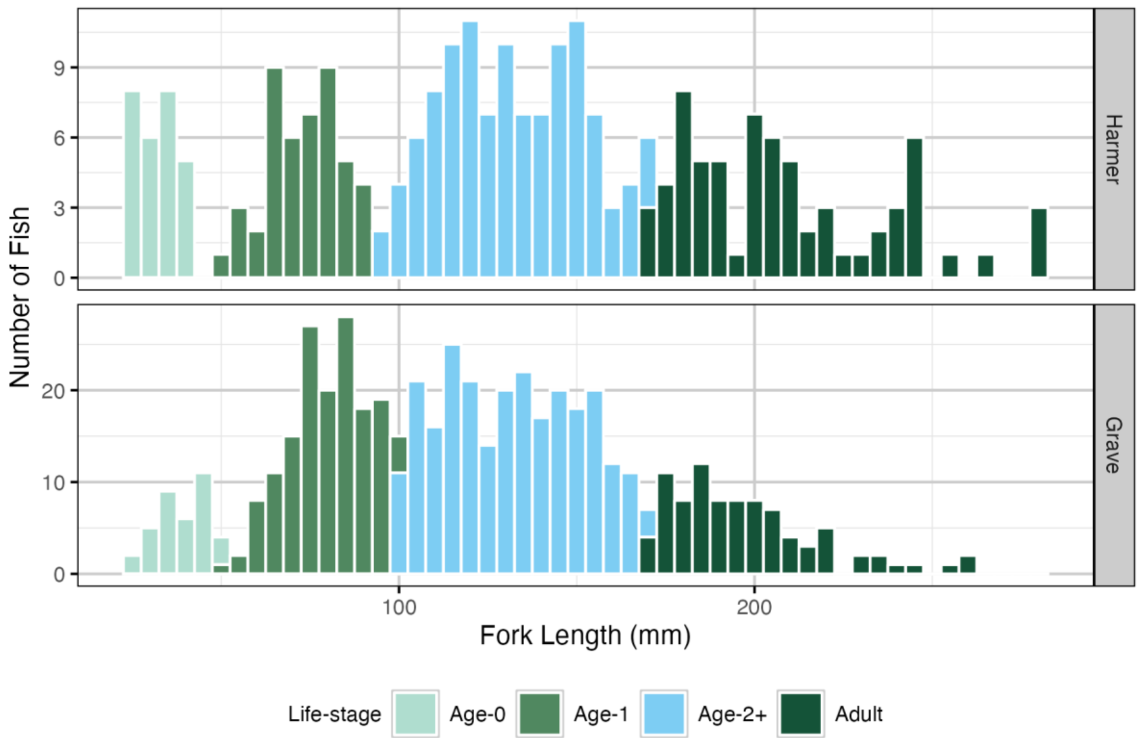


Figure 4-5. Number of fish captured by electrofishing, bank-walk fish captures and observations from the Harmer Creek and Grave Creek population, by fork length and life stage.

Data are from sampling programs in 1996, 2008 and 2013 and from 2017 to 2021 (see 4.3.1 for data sources). Note the y axis scale differs between the graphs. Source: Thorley et al. (2022).

The estimated mean annual fork length of age-0s (adjusted to October 1) in both populations is shown in Figure 4-7 by year. The large inter-annual variation and small sample size for the Harmer Creek and Grave Creek populations mean there is a wide range of probable values for the annual fork lengths. Nonetheless, the estimates of the annual fork lengths of age-0 fish suggest that fish in the Harmer Creek population were smaller than those in the Grave Creek population in 2017, 2018 and 2021. No age-0s were captured in 2019 or 2020 in the Harmer Creek population. (Figure 4-6).

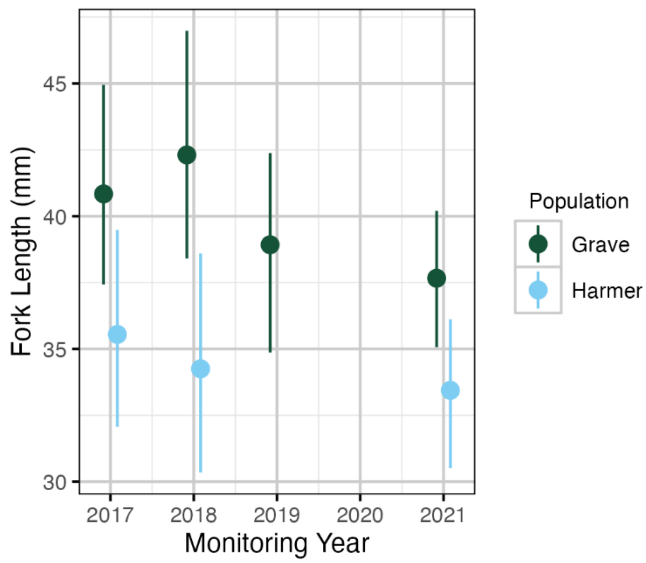


Figure 4-6. Annual average fork length estimates (with 95% CIs) for age-0 Westslope Cutthroat Trout captured by electrofishing in the fall in the Harmer Creek and Grave Creek populations by monitoring year

Source: Thorley et al. (2022)

Adult fish are estimated to be larger in the Harmer Creek population than in the Grave Creek population in an average year, at 209 mm (95% CI[16]; 194–224 mm) vs 196 mm (95% CI; 183–209 mm) (Figure 4-7). The Harmer Creek population adults also show more variation in annual size (range 196–226 mm) than the Grave Creek population adults (range 190–206 mm; Figure 4-6). The larger average size of adults in the Harmer Creek population may be due to a higher proportion of older fish. This could be consistent with fewer recruits entering the adult size class.

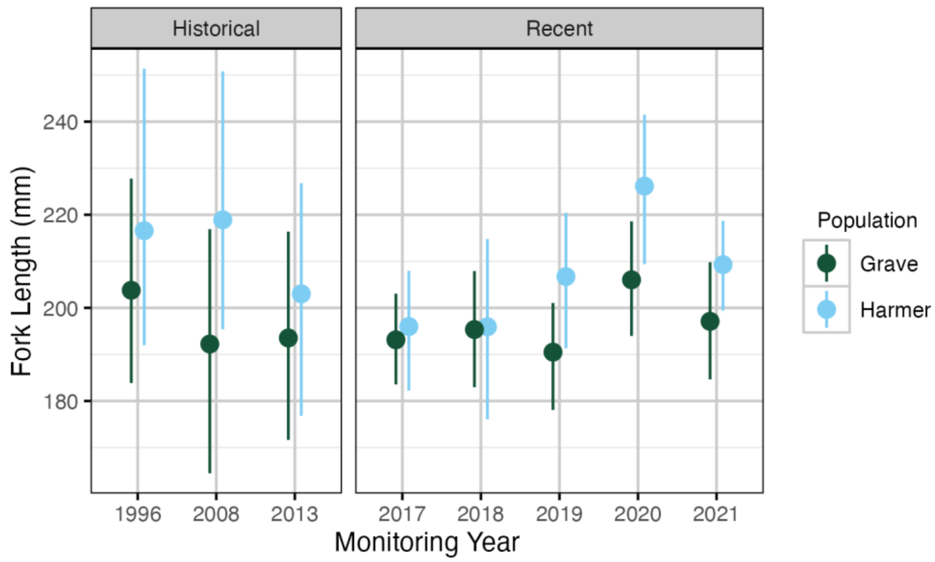


Figure 4-7. Estimated average fork length of adult fish on October 1 (end of growing season), by monitoring year and population

Error bars represent 95% CIs. Source: Thorley et al. (2022)

4.3.2.3. Fecundity

The number of recruits in any given year is partially determined by how many eggs are deposited. Egg deposition, in turn, depends on the number of spawning females, their fecundity, which is the number of eggs each spawner produces, and the presence of suitable spawning habitat (Hocking, Cloutier et al., 2022). Following Ma and Thompson (2021), the fecundity of WCT in the Harmer Creek and Grave Creek populations was calculated from the average fork length (bigger females tend to produce more eggs) for each population, using the relationship in Corsi et al. (2013). Average annual fecundities in

[16] Credibility Intervals (CIs) is a statistical term. The term generally refers to an interval which has a 95% probability of including the true value if the model is correct.

the Harmer Creek population were calculated to be between 185 and 280 eggs per female. Fecundity rates for the Grave Creek population were between 171 and 207 eggs per female (Figure 4-8). There was no apparent decrease in fecundity during the period of Reduced Recruitment compared to the historical period.

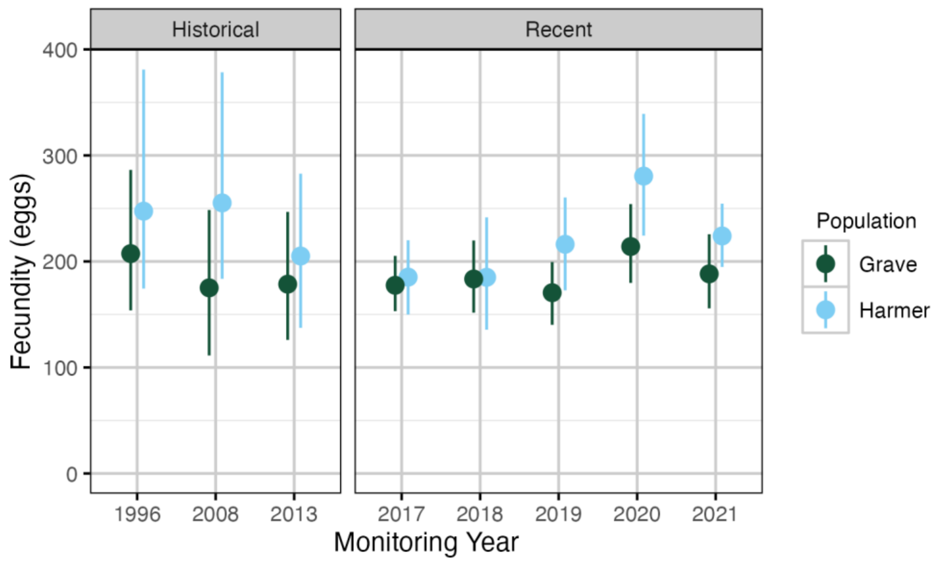


Figure 4-8. The average estimated eggs per female by population and year, based on the lengths of the fish captured during electrofishing

Error bars represent 95% CIs. Source: Thorley et al. (2022)

4.3.2.4. Condition

Fish condition measures an individual's mass relative to its length. All other things being equal, fish with higher body condition would be expected to have more energy stores for growth, reproduction and metabolic processes than fish of a similar length but lower body condition. Condition can be influenced by many factors, including water temperature, food availability, feeding opportunities and predation pressure. The condition of WCT captured in the Harmer Creek and Grave Creek populations was evaluated by Thorley et al. (2022), Wiebe et al. (2022a) and Thorley and Branton (2023). Using different statistical methods they arrived at similar conclusions for the period of Reduced Recruitment, as described below.

Fish less than 65 mm were excluded from all calculations of body condition because the error in the fish's weight measurements was a relatively high proportion of their absolute weight (Thorley et al., 2022; Wiebe et al., 2022a). Thorley et al. (2022) analyzed all the electrofishing data for fish ≥ 65 mm in a single model that accounted for the change in fish shape with increasing size. Their model estimated that fish condition was lowest in 2018 relative to an average year in both the Harmer Creek and Grave Creek populations and that condition was slightly above average in 2020 (Figure 4-9). Wiebe et al. (2022a) analyzed the data for fish 65 - 169 mm and concluded that juveniles in the Harmer Creek and Grave Creek populations were about 4% lighter in 2018 compared to 2017 but similar to 2008 and 2013. They were unable to assess condition for juvenile fish captured from the Harmer Creek population area in 2019 due to the limited number of individuals (Wiebe et al., 2022a). In 2020, condition of juvenile fish from the Harmer Creek and Grave Creek populations was higher by about 6–15%, depending on year, relative to 2017, 2018 and 2019.

The similar patterns in condition between the Harmer Creek and Grave Creek populations suggest that the condition of fish ≥ 65 mm is primarily driven by factors that vary annually at the watershed scale (Figure 4-9).

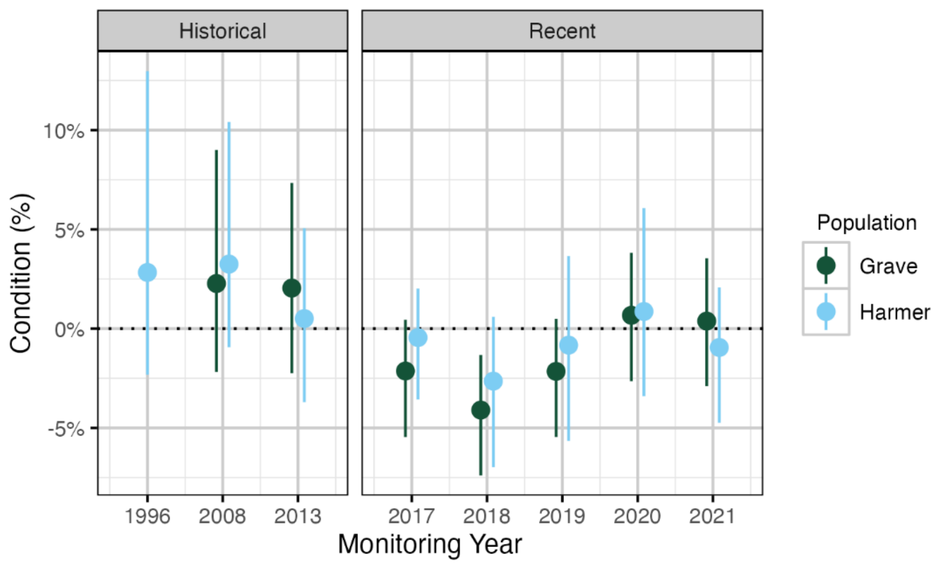


Figure 4-9. The percent change in the body condition (weight) relative to an average year (represented by 0% change) by population and monitoring year for juveniles and adults combined (with 95% CIs)

Source: Thorley et al. (2022)

4.3.2.5. Fish Density

Fish density is a measure of the number of fish in a unit amount of habitat. Conventionally, it is calculated in terms of the number of fish per unit area (m^2). However, the amount of lineal habitat is often a better predictor of fish numbers than the amount of areal habitat when dealing with small, stream-dwelling fish that tend to occupy the margins. For this reason, fish density is calculated here in terms of the number of fish per lineal distance, as fish per 100 m.

The fish density at a particular site relative to other sites depends on the quality of the habitat as well as its connectivity. Consequently, if sampling is biased towards higher quality sites, the local site densities will tend to overestimate the average fish density and can mask temporal trends that would be apparent from more random sampling approaches. Site densities can also be used to evaluate trends in the distribution of fish along the length of a creek relative to other variables, including stressors such as water quality.

Thorley et al. (2022) estimated the lineal density (fish per 100 m) by analyzing the single- and multi-pass electrofishing data for the Harmer Creek and Grave Creek populations by life stage, based on fish length (Section 4.3.2.2). The average lineal raw densities of WCT captured per pass at each location sampled between 1996 and 2021 are summarized in Figure 4-10 by year and age class. A map showing the sample locations is provided in Figure 4-2. A hierarchical Bayesian removal-depletion submodel within the lifecycle model was used to estimate the underlying expected densities of each life stage, by location and year, after accounting for the capture efficiency. The raw capture densities averaged across the first three passes are plotted by life stage and location in Figure 4-10. The expected densities of fish in an average year by life stage and location are shown in Figure 4-11. The purpose of these figures is to show the general, expected spatial distribution of fish. For simplicity, when the Harmer Creek mainstem is discussed below, it refers to the reaches HRM-R3, HRM-R4 and HRM-R5, i.e., it does not include HRM-R2 or HRM-R6. Grave Creek above the confluence of Harmer and Grave Creek is not mine influenced. The results of the lifecycle model indicate that the expected lineal density of adults in Dry Creek is negative 18% (-63% to 119%, 95% CI) of the expected lineal density of adults in Harmer Creek mainstem.

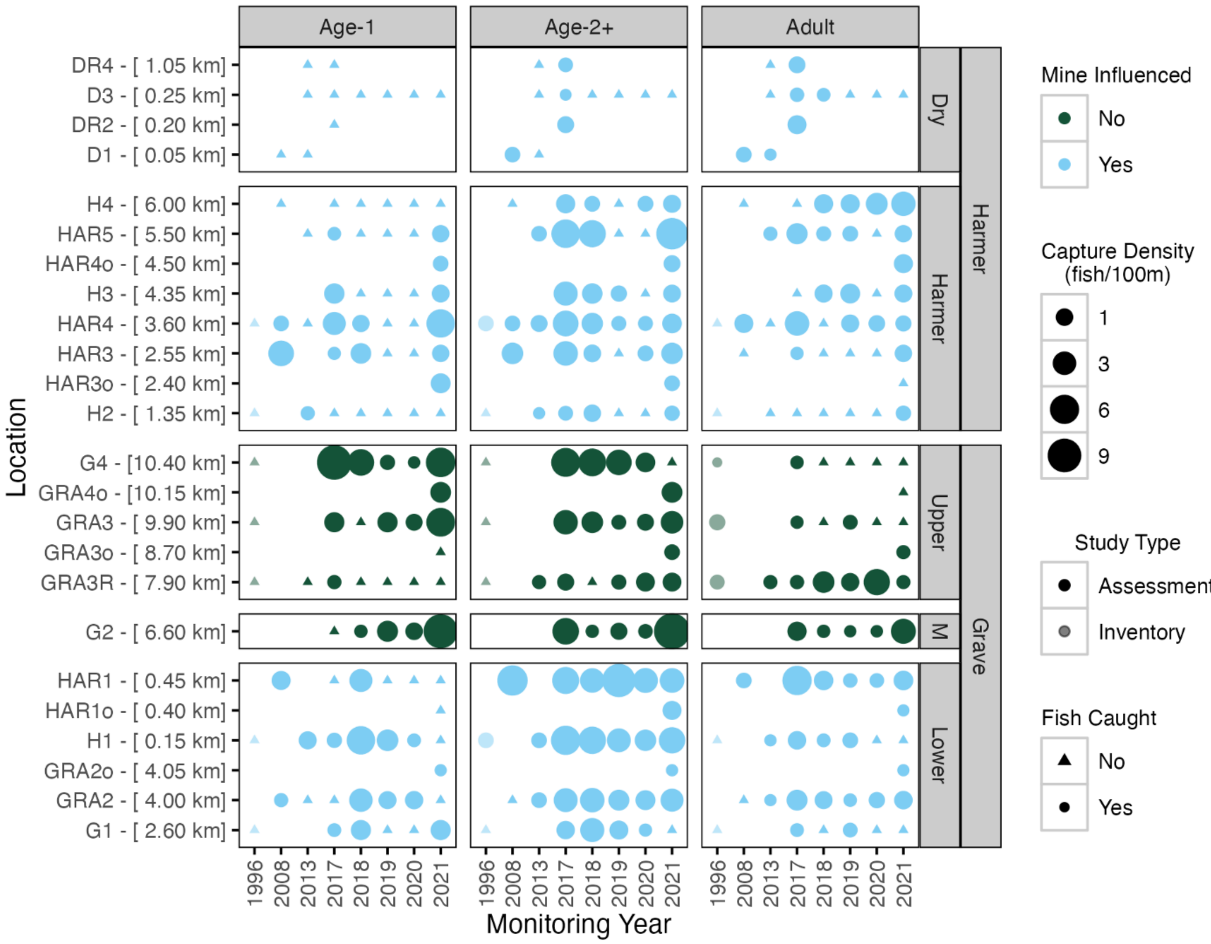


Figure 4-10. The electrofishing capture density averaged across the first three passes by monitoring year, location, life stage, population, channel type and study type

Locations on the y axis are listed in an upstream direction as indicated by the river km in square brackets (refer to Figure 4-2). Large, 300 m open sites are named with a "o" suffix, except for H4 in 2021, which was sampled as a 300 m open site but is not marked with "o." Source: Thorley et al. (2022)

The electrofishing data show that in 2017, 2018 and 2021 age-1 WCT were captured in Harmer Creek mainstem, but they were not captured there in 2019 and 2020 (years which correspond to the 2018 and 2019 spawn years respectively) (Figure 4-10). In contrast, age-1 fish were captured throughout the Grave Creek population area in 2019 and 2020. Age-1

WCT were not captured in HRM-R6 (sample locations HAR6) in any years, although a few adults have been reported in this reach[17].

No age-1 WCT have been captured in Dry Creek, despite the presence of age-2+ juveniles and adults throughout the tributary, including the Dry Creek Sedimentation Pond (Figure 4-10).

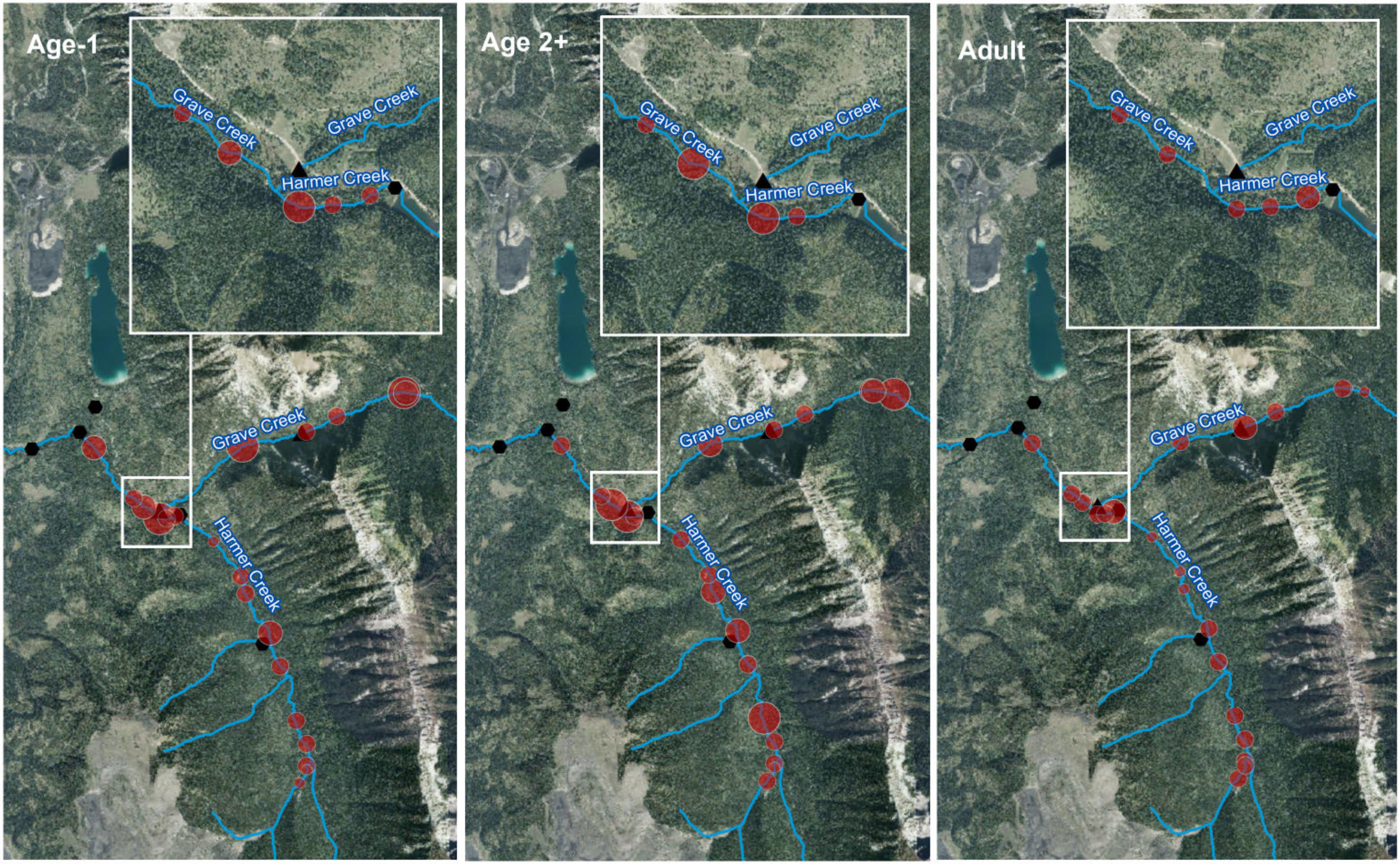
No WCT have been documented in the Harmer Sedimentation Pond (HRM-R2) since 2006. There are records from the Fresh Water Atlas fish observations data of up to four fish in 2006 and one fish in 1975 in the Harmer Creek Sedimentation Pond (BC Ministry of Environment and Climate Change Strategy, 2022).

The expected density of fish in a typical year by life stage and location is shown in Figure 4-11.

Figure 4-11 is presented on the following page. Its caption is:

Figure 4-11. Expected density of fish in an average year by life stage and location

[17] Due to a predominance of groundwater, HRM-R6 has consistently low summer temperatures (~4°C) resulting in poor conditions for WCT growth (see Chapter 3; also see Hocking, Whelan & Hatfield, 2022). Conversely, in winter, water temperatures of ~4°C may be too warm for the fish due to their higher metabolism, and therefore higher energy use, in the relatively warm water.



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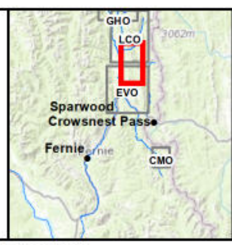


Density of Fish in a Average Year

Density (fish/100m)*

*Estimated lineal density averaged across all years

- 0.65 - 1.00
- 1.01 - 5.00
- 5.01 - 10.00
- 10.01 - 15.00
- 15.01 - 18.00

- Impassble Barrier
- Historical Barrier
- Streams

N

0 625 1,250 2,500 Metres

DATE:	MINE OPERATION:
9/19/2022	Elkview
SCALE:	COORDINATE SYSTEM:
1:100,000	NAD 1983 UTM Zone 11N

Document Path: G:\Data\Projects\FishManagement\EOC_PDF\Electrofishing_Density.mxd

4.3.2.6. Abundance

Annual population abundance was calculated by multiplying the estimated fish density (fish/100 m) at an average site for that year (Figure 4-12, also see Section 4.3.2.5) by the amount of lineal habitat.

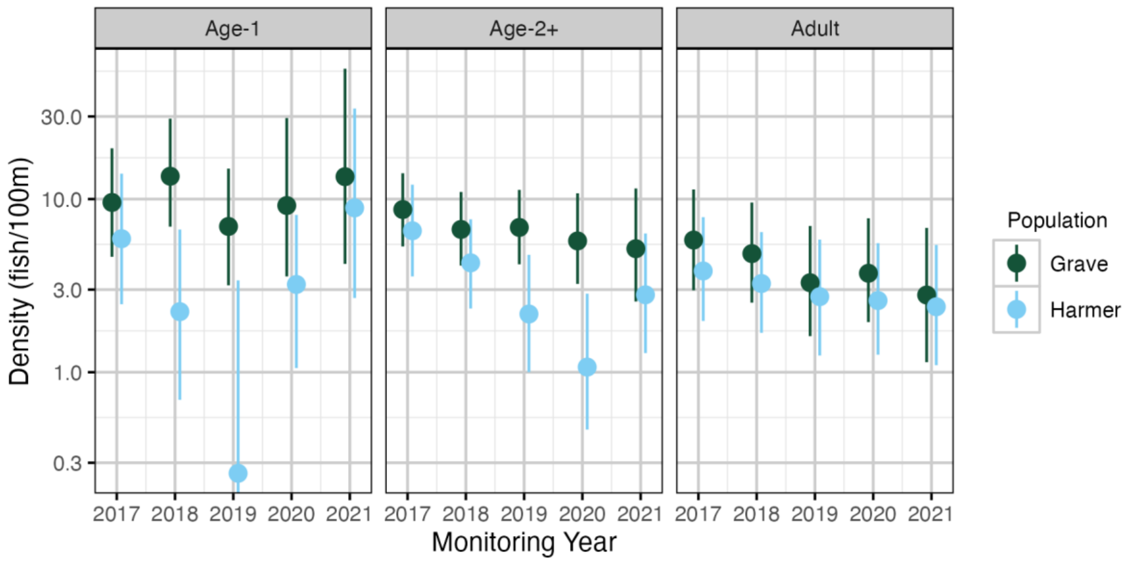


Figure 4-12. The estimated lineal density (on a log scale) at an average site by monitoring year, life stage and population

The abundance calculations were based on 7.3 km of habitat for the Harmer Creek population and 8.8 km of habitat for the Grave Creek population. The only tributary included in the calculations was Dry Creek. No other tributaries for either the Harmer Creek or Grave Creek population areas were included due to their small size and the limited data. The abundance estimates are provided and discussed below.

Density was higher in the Grave Creek population compared to the Harmer Creek population in all years for all life stages (Figure 4-12). Abundance by life stage is discussed below.

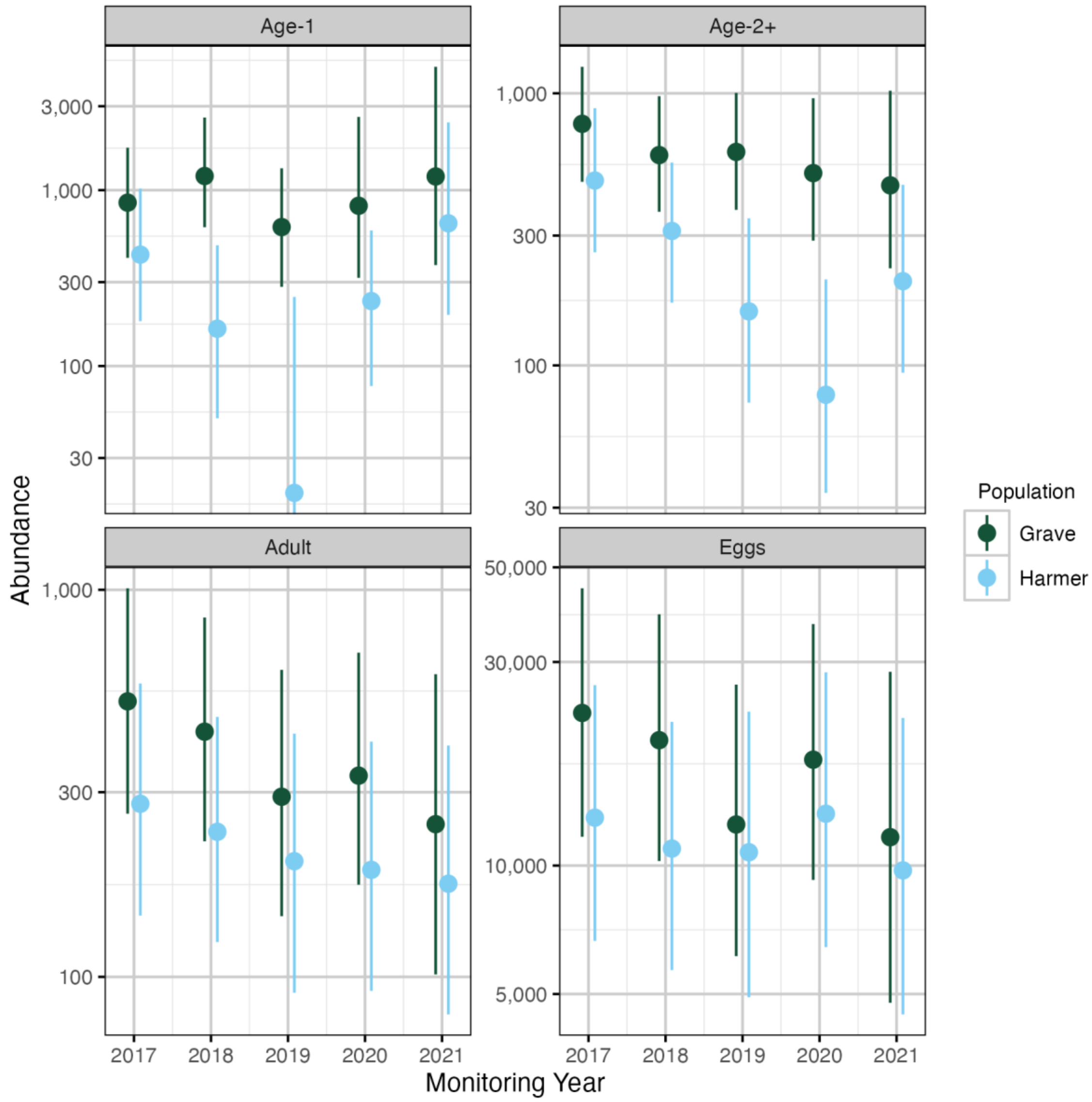


Figure 4-13. The estimated population abundance (on a log scale) by monitoring year, life stage and population

Error bars represent 95% CIs. Source: Thorley et al. (2022)

Age-1 Abundance

Although the estimated abundance of age-1 individuals in both the Harmer Creek and Grave Creek populations has varied, it was more variable and consistently lower in the Harmer Creek population. The estimated abundance of age-1 fish in the Grave Creek population has remained relatively constant at around 1,000 individuals, with 2019 (corresponding to the 2018 spawn year) being lowest. The estimated abundance of age-1 fish in the Harmer Creek population declined from 440 fish in 2017 to 19 in 2019 (95% CI; 0–

320) before increasing to 640 in 2021 (95% CI; 210–2,200). This corresponds to the spawn years 2016 (440 fish), 2018 (19 fish) and 2020 (640 fish) (Thorley et al., 2022). The lower abundances in spawn years 2017 through 2019 correspond to the period of Reduced Recruitment, and the low abundance in the 2018 spawn year corresponds to the Recruitment Failure in the Harmer Creek population.

Age-2+ Abundance

The abundance of age-2+ fish in the Harmer Creek population was consistently lower than that in the Grave Creek population, and both declined over the monitoring period. The estimated abundance of age-2+ fish in the Grave population declined steadily from 790 fish in 2017 (95% CI; 480–1,400) to 470 fish in 2021 (95% CI; 240–1,300). The Harmer Creek population declined from 470 fish in 2017 (95% CI; 280–850) to a low of 76 fish in 2020 (95% CI; 36–270), followed by an increase to 200 fish in 2021 (95% CI; 99–460).

Adult Abundance

The abundance of adult WCT has declined in both populations (Figure 4-13); however, the annual decline in the Grave Creek population (16%) was greater than in the Harmer Creek population (12%). Estimated adult abundances for the Harmer population declined from 280 fish in 2017 (95% CI; 140–550) to 170 fish in 2021 (95% CI; 77–360), and the Grave population declined from 520 fish in 2017 (95% CI; 270–1000) to 260 fish in 2021 (95% CI; 95–610).

Eggs

The estimated egg abundances are the product of the estimated adult abundance and the fecundity (Section 4.3.2.3), under the assumptions of a 1:1 sex ratio and a 50% probability of an adult female spawning in any given year. Estimated egg abundance was consistently lower in the Harmer Creek population compared to the Grave Creek population, reflecting the difference in adult abundance between the two populations. In the Harmer Creek population, the estimated number of eggs declined from 13,000 eggs in 2017 (95% CI; 6,600–25,000) to 9,500 eggs in 2021 (95% CI; 4,300–20,000). In the Grave Creek population, the estimated deposition declined from 23,000 eggs in 2017 (95% CI; 12,000–46,000) to 12,000 eggs in 2021 (95% CI; 4,500–29,000). This decline partly reflects the decline in adult abundance over this time period.

4.3.2.7. Recruitment

The term recruitment is used in the Evaluation of Cause to refer to the number of age-1 fish present in the fall of a given year, which were produced by spawning in the previous year (i.e., the spawn year). For a population to be stable over a long time period, each spawner must, on average, replace itself with another spawner over its lifetime. Rates of recruitment vary naturally and can result in Reduced Recruitment or even Recruitment Failure (i.e., a negligible number of fish added to the population). Recruitment Failure can occur in Cutthroat Trout populations for reasons such as extremely high age-0 mortality during the winter (e.g., Coleman & Fausch, 2007a, 2007b) or natural events such as large floods, like the one that occurred in the Grave Creek watershed in 1995 (Heidt, 2003).

> ***Grave Creek Watershed Flood, 1995***
>
> *"The flood peaked on June 7, 1995, during the spawning season for Westslope Cutthroat Trout, and the resulting bed load movement, heavy siltation and high flows likely reduced egg to fry survival and juvenile/adult survival. In response to this event, the Elk River and its' tributaries were regulated catch and release for 3 years (until 1998/1999) so remaining cutthroat stocks could rebuild" (Heidt, 2003).*

The recruitment of age-1 fish is the product of the number of eggs deposited and the egg to age-1 survival. The egg to age-1 survival rate allows conditions to be compared among populations and years, particularly when the rate is plotted by the egg density (eggs/100 m). Further insight into population stability can be achieved by dividing the egg to age-1 survival rate by the rate required to achieve population replacement. Over time, a stable population would have an average 100% replacement, with some years above 100% and some years below. A literature review suggested that in a typical population an egg to age-1 survival rate of 5% is required for 100% population replacement (Ma & Thompson, 2021), while the life cycle model for the Harmer Creek and Grave Creek populations estimated the value to be 4% (95% CI; 1–11%) (Thorley et al., 2022). At high egg densities when the population is above the habitat's carrying capacity (the maximum number of adult individuals a habitat can sustain in the long term) the replacement rate is expected to be less than 100%, indicating a decreasing population. But when the egg density is low, competition is reduced and this is expected to result in a replacement rate greater than 100%, indicating an increasing population. As the egg densities in the two populations during the period of interest are relatively similar, density-dependence is not expected to explain a substantial proportion of the difference in egg to age-1 survival between the populations or among the years.

The egg to age-1 survival was calculated by spawn year for the Harmer Creek[18] and Grave Creek population areas, as described below, and then plotted by the lineal egg density. First, the adult length, which predicts fecundity, and adult abundance for each year were used to calculate the number of eggs deposited. Age-1 abundance was then divided by the number of eggs deposited to estimate the egg to age-1 survival rate. The egg to age-1 survival rates for the Harmer Creek and Grave Creek populations are plotted by egg density in Figure 4-14. Finally, these rates were divided by the replacement rate of 4% (with uncertainty) which was calculated in the life cycle model, to give the percent replacement, where 100% indicates that the egg to age-1 survival is sufficient for population replacement under typical conditions.

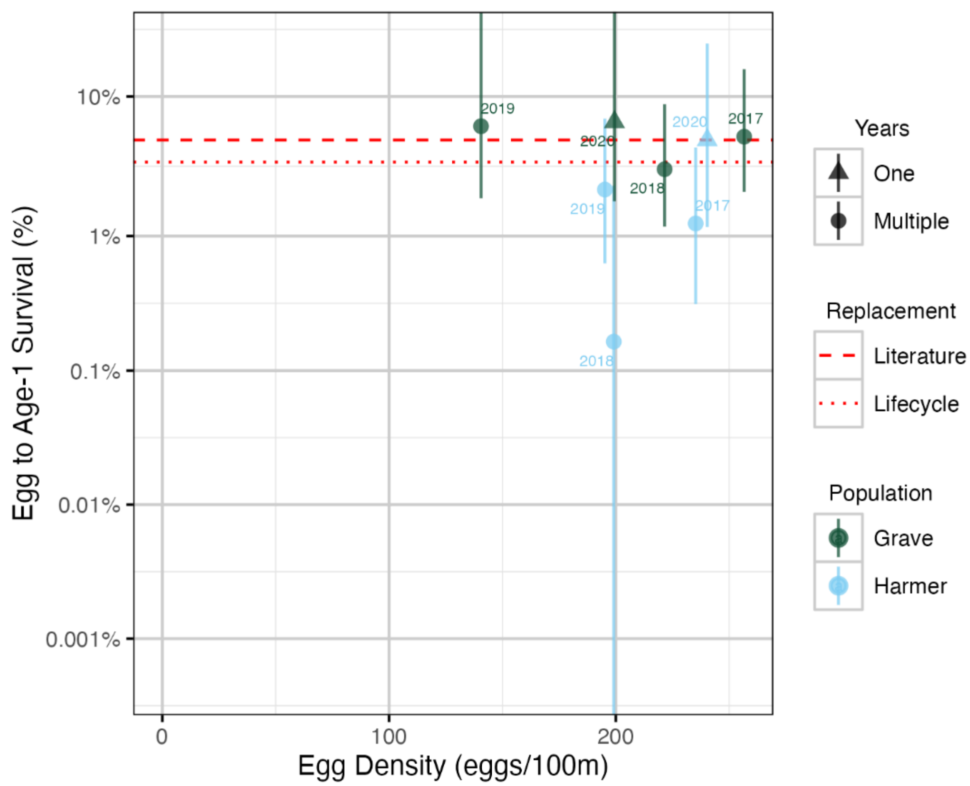


Figure 4-14. The egg to age-1 survival (on a logistic scale) by egg density, spawn year and population

The red lines indicate the egg to fry survival required for replacement, based on the literature (Ma & Thompson, 2021) and the life cycle model. Error bars represent 95% CIs. Year symbols indicate how many years of data were available to use in the model. Source: Thorley et al. (2022)

[18] Egg density was calculated based only on the Harmer mainstem, because almost all Harmer population fish spawn within the mainstem below Dry Creek and not in the 1.8 km of Dry Creek (Thorley et al., 2020).

The replacement rates were then plotted as probability densities, where the width of the density polygon indicates the probability of recruitment for each replacement rate (Figure 4-15).

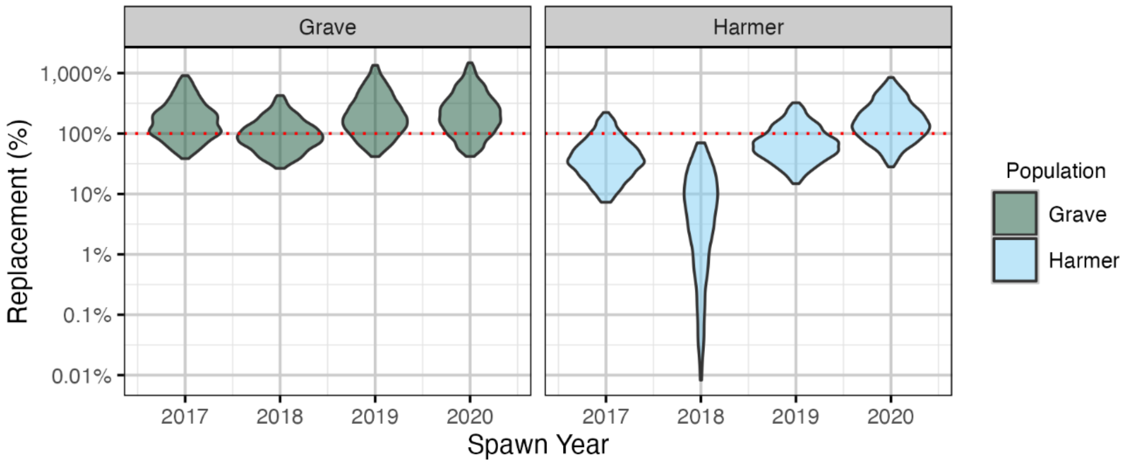


Figure 4-15. The population replacement rate by spawn year and population as a probability density

The broadest part of the shape represents the most likely egg to age-1 survival rate for a given spawn year and population, and the narrower part of the shape indicates a less likely outcome. Only the values in the 95% CI are plotted. The red line indicates replacement. Source: Thorley et al. (2022)

For the Evaluation of Cause, three levels of recruitment were defined: Above Replacement (≥ 100% replacement), Reduced Recruitment (< 100% replacement) and Recruitment Failure (<10% replacement). Spawn years for each population were assigned to the most likely (> 50% probability) level of recruitment. On this basis, there was Reduced Recruitment in Harmer Creek in each spawn year from 2017 to 2019. The magnitude of the Reduced Recruitment in the 2018 spawn year was large enough to meet the definition of Recruitment Failure. By contrast, the 2020 spawn year in Harmer Creek was Above Replacement. Recruitment was Above Replacement for all years in the Grave Creek population, except the 2018 spawn year when there was Reduced Recruitment. These findings suggest that (1) local conditions unique to the Harmer Creek population area (vs the Grave Creek population area) may have contributed to the Reduced Recruitment in the 2017 to 2019 spawn years, and (2) regional conditions may have further contributed to the Recruitment Failure in 2018. The pattern of lower recruitment in both Harmer Creek and Grave Creek populations in 2018 compared to other years suggests that there may have been stressors common to the two population areas that impacted recruitment.

4.3.2.8. Summary of Data Analysis and Results

We considered the role that different WCT life stages play in recruitment and evaluated the available data to determine if there were changes in Harmer Creek individual parameters (e.g., length) or population parameters (e.g., abundance) that indicated which life stage or life stages were likely responsible for the Reduced Recruitment.

Life Stage

There is no evidence that reduced egg deposition was responsible for the Reduced Recruitment. While there were declines in adult abundance and body condition, these declines occurred in both the Harmer Creek and Grave Creek population areas and were slightly greater in the Grave Creek population area. Spawning was documented in the Harmer Creek population area throughout the period of Reduced Recruitment. Adult length, fecundity (calculated based on length) and body condition were similar in both populations and trended together, except for adults in the Harmer Creek population which were longer in 2019 than in other years. Body condition was lower than other years in both the Harmer Creek and Grave Creek populations in 2018. These lines of evidence led us to conclude that the low recruitment was not due to a reduction in the total egg deposition but, instead, occurred between nest construction and the electrofishing surveys the following fall. This period includes the following life stages: embryos (developing in the eggs), alevins (absorbing the yolk sac in the gravels), fry (hiding and feeding) and growth and survival from age-0 through age-1.

Although monitoring occurred in the fall when age-0s would have been present, the electrofishing methods used in monitoring are not effective for collecting very small fish. We do not know, therefore, whether spawning cohorts successfully reared over the summer period. In the Harmer Creek population area, a few age-0 fish were captured in 2017, 2018 and 2021, and in the Grave Creek population area a few were captured in all years from 2017 to 2019 and in 2021. Although the sample sizes were too small to estimate abundance, they indicated that age-0 fish were present, and the data provided some information about size, i.e., that the age-0 fish were consistently smaller in the Harmer Creek population than in the Grave Creek population. This finding is important because the size of a fish going into its first winter strongly influences its survival in the first year (Coleman & Fausch, 2007a, 2007b; Hocking, Whelan & Hatfield, 2022). There is a positive relationship between fish length and overwintering survival, i.e., when fish are bigger, overwintering survival is higher, so the small size of the age-0 fish from Harmer Creek suggests they may have had a greater challenge surviving winter than the somewhat larger fish in Grave Creek. The effects of temperature on growth and survival in Harmer Creek were assessed by Hocking, Whelan and Hatfield (2022), and the effects of length and body condition on survival were estimated by Thorley and Branton (2023).

Timing

For the Harmer Creek population, a level of productivity substantially below replacement indicated that Reduced Recruitment occurred in the 2017 to 2019 spawn years and Recruitment Failure occurred in the 2018 spawn year. Reduced recruitment in the Grave Creek population in the 2018 spawn year suggests that there may have been a common regional stressor influencing recruitment.

Location

Based on density estimates, which are associated with the locations sampled, age-1 WCT were present in all three reaches of the Harmer Creek mainstem in 2017 (2016 spawning cohort) but none were present in Dry Creek. In 2018 (2017 spawning cohort), there were age-1 WCT in HRM-R3 and HRM-R4 (limited data for Dry Creek[19]) and no age-1 WCT in HRM-R5. In 2019 and 2020 (2018 and 2019 spawning cohorts), no age-1 WCT were collected anywhere in the Harmer Creek population area. In 2021 (2020 spawning cohort), recruitment was above replacement and age-1s were caught throughout the Harmer Creek mainstem, though none in Dry Creek. These density estimates are consistent with widespread recruitment in the mainstem of Harmer Creek for the 2016 and 2020 spawning cohorts, with spatially more limited recruitment for the 2017 spawning cohort and with negligible recruitment for the 2018 cohort. The life cycle model estimated that there was some recruitment for the 2019 spawning cohort, but with no captures it is not possible to know how recruitment was distributed. This spatial context is important for understanding the potential relationship between the stressors and the recruitment patterns. Specifically, it suggests that whatever caused the Reduced Recruitment was spatially widespread, because it appears to have impacted age-1 fish throughout the Harmer Creek mainstem. It is notable that in 2017 when there were no age-1 fish in Dry Creek, there was recruitment in all reaches of the Harmer mainstem.

As telemetry studies indicate, WCT in the Grave Creek watershed tend to move relatively small distances (<1 km) (Akaoka & Hatfield, 2022), which suggests that they are vulnerable to stressors in a fairly localized area. Densities were reduced across the length of the Harmer Creek mainstem during the period of interest, which suggests that the primary stressors were not concentrated in a location within the Harmer Creek mainstem.

[19] Although DC-R3 was monitored in 2018, 2019 and 2020, because of the fish salvage in 2017, the monitoring data are not expected to be representative of fish density in absence of the salvage. However, it is useful to note that no age-1 fish were found in DC-R3 in 2018 prior to the Recruitment Failure.

4.4. IMPLICATIONS OF FISH MONITORING DATA

The analyses described in this chapter were used to identify the period of interest and key life stages SMEs needed to consider in their stressor evaluations. Given that recruitment was the focus of this Evaluation of Cause, potential stressors would have had to be present at a sufficient magnitude and for a sufficient duration to have had adverse effects from approximately September 2016 through September 2020 to have contributed to Reduced Recruitment in the 2017 to 2019 spawning cohorts. Available stressor data collected prior to, during and after the period of Reduced Recruitment were used to evaluate these trends. Given that recruitment was lowest in both the Harmer and Grave Creek populations in 2018, but much lower in the Harmer Creek population, we looked for (1) anything that could cause lower recruitment that year in both systems and (2) anything that could cause lower recruitment only in the Harmer Creek population, particularly in 2018. As part of their stressor evaluations, SMEs were also asked to consider the spatial extent of the potential stressors. In their reports, they evaluated stressor impacts for adults and early life stages, focusing on endpoints that could be related to recruitment, including those related to fish growth and survival in their first year.

The life stage of each spawning cohort is depicted visually by calendar year in Figure 4-16. This figure was useful when evaluating temporal patterns in potential stressors because it helped identify the spawning cohorts and life stages that could have been impacted by a given stressor.

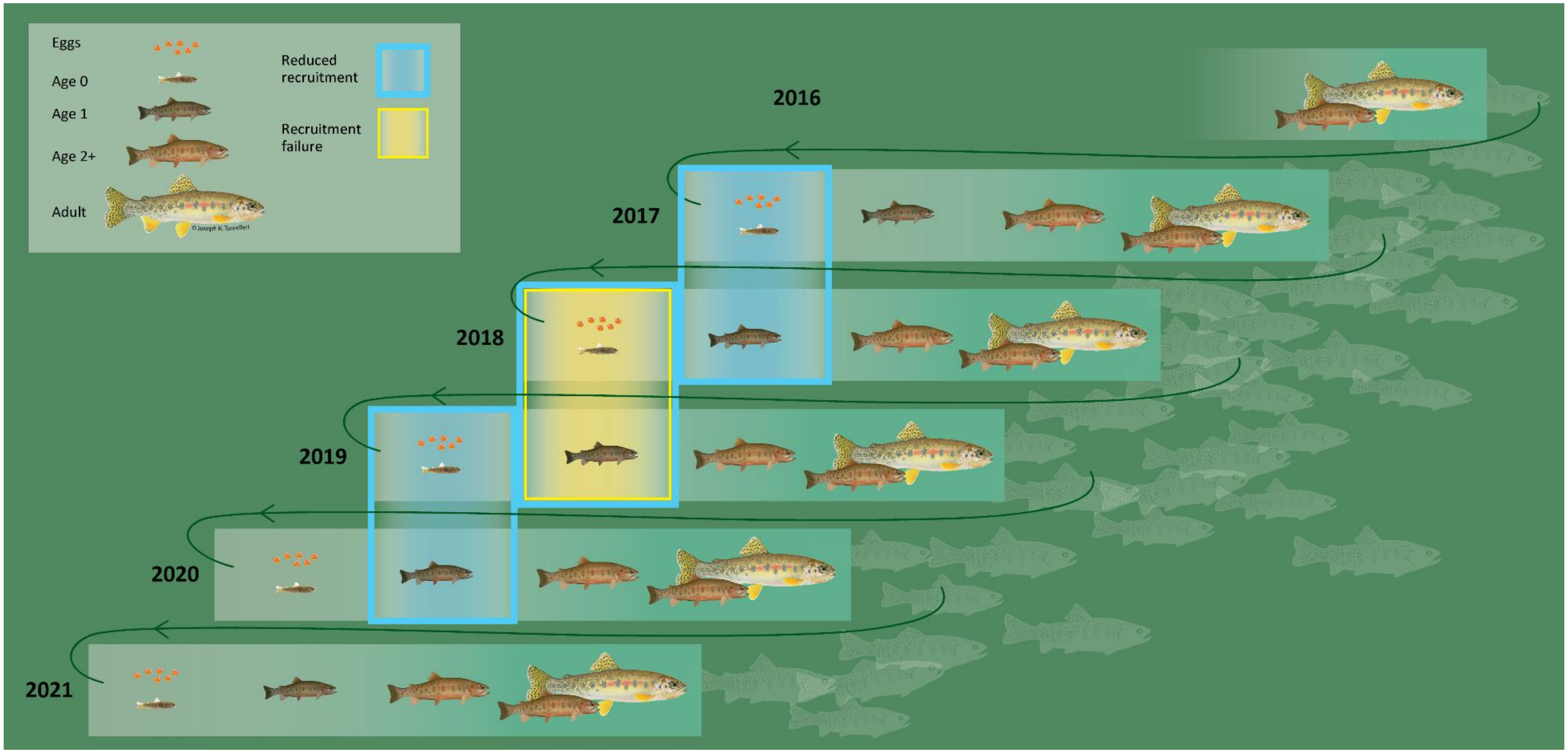


Figure 4-16. Harmer Creek Westslope Cutthroat Trout, 2016–2021 cohorts: Development from spawning through maturity and potential periods of Recruitment Failure and Reduced Recruitment

The periods of WCT Reduced Recruitment and Recruitment Failure in Harmer Creek are shown, together with the life stages from spawning through adult for the 2016–2021 cohorts (spawning cohort year shown in bold). A single fish's life stages through the years can be followed by reading top to bottom. For example, a fish that was an egg/age-0 in 2017, was an age-1 in 2018, age-2+ in 2019 and age-2+/adult in 2020 and 2021. Fish spend more than 1 year as an age-2+ prior to reaching reproductive maturity.

5. Summary of Findings from SME Reports

5.1. CHAPTER OVERVIEW

Teck Coal engaged with the Evaluation of Cause participants (i.e., KNC, government agencies and committees; see Chapter 1.2) to identify a suite of potential stressors that may have contributed to the Reduced Recruitment and Recruitment Failure patterns in the Harmer Creek population. For each potential stressor, SMEs characterized patterns for the Harmer Creek and Grave Creek population areas, compared the differences between the two population areas for the period of Reduced Recruitment and identified differences in the Harmer Creek population area between 2018, when there was Recruitment Failure, and 2017 and 2019 when there was not. The patterns in the stressors were compared with those in WCT endpoints (see Chapter 4). The SMEs evaluated causal pathways by which potential stressors could have impacted WCT and determined if stressors were present at a sufficient magnitude or for long enough to have had an adverse effect on WCT that could impact recruitment.

This chapter summarizes SME conclusions regarding individual stressors, with limited consideration of interactions. Detailed methods and results are documented in the individual SME reports listed in Appendix A, and findings are summarized in Section 5.2. In addition to the stressors covered in these summary sections, the Harmer Creek Evaluation of Cause Team assessed groundwater (Canham & Humphries, 2022), fish movement (using telemetry studies) (Akaoka & Hatfield, 2022), fish capture and handling (i.e., scientific monitoring, angling and salvage; Appendix B) and Ice (Appendix C). Later in this report, the findings are integrated to address the purpose of the Evaluation of Cause (see Chapter 6).

5.2. INDIVIDUAL STRESSOR RESULTS

This section provides summaries of SME stressor reports. It includes overviews of methods, life stages evaluated, findings and uncertainties.

5.2.1. Calcite

Methods

Spatial and temporal trends of calcite in Harmer Creek and Grave Creek were evaluated for four pathways of effect: spawning, incubation, overwintering and invertebrate food supply.

Life Stages

The evaluation considered pathways that are relevant to embryos, juveniles and adults.

Findings

Calcite index and concretion were low and did not change markedly over time during the period of Reduced Recruitment for most of the Harmer Creek and Grave Creek WCT population areas. The Harmer Creek population was exposed to higher levels of calcite than the Grave Creek population. However, this was due to the high calcite index and concretion observed in Dry Creek, which accounts for ~24% of the Harmer Creek population area. The effects evaluation did not indicate a substantial contribution to Recruitment Failure or Reduced Recruitment from any of the four pathways, although partial contribution could not be ruled out, particularly for the spawning pathway. High levels of calcite have persisted in Dry Creek since well before the period of Reduced Recruitment. Calcite, therefore, is a chronic (long-term) stressor to the Harmer Creek WCT population and, in that way, it may have contributed to the observed Reduced Recruitment (2017 to 2019 spawn years). But high effect levels in Dry Creek are predicted to have occurred throughout this period and prior to it, and the levels did not show notable temporal alignment with the single year of Recruitment Failure in the 2018 spawn year.

Uncertainties

Calcite data were available for multiple locations over time, so there is reasonable confidence in the description of physical conditions and changes immediately prior to and during the period of Reduced Recruitment. Likewise, there is broad confidence in the general response relationships between calcite and biological effects; small to modest changes to the response curves would be unlikely to substantively alter the conclusions.

Credit: Poisson Consulting

5.2.2. Dissolved Oxygen

Methods

Dissolved oxygen (DO) measurements collected since 2014 were assessed using the same dataset considered for the water quality assessment (Warner & Lancaster, 2022). Data for DO were most extensive for DC-R2, the outlet of Dry Creek Sedimentation Pond in the Harmer Creek population area, and HRM-R1, which is downstream of the Harmer Dam in the Grave Creek population area. Dissolved oxygen measurements were compared to British Columbia Water Quality Guidelines (BCWQG) and supporting literature regarding the effects of low DO concentrations on salmonids. Spatiotemporal variability in DO concentrations was analyzed using a statistical model.

Life Stages

The analysis distinguished between free-swimming life stages of WCT and buried life stages, because eggs and alevins are more sensitive to low DO concentrations.

Findings

Measurements do not indicate that DO conditions caused acute (short-term) or chronic adverse effects to free-swimming life stages of WCT (fry, juvenile and adults) in the Harmer Creek population area. However, DO conditions in parts of the Harmer Creek population area were sub-optimal for WCT incubation. Specifically, low DO concentrations were occasionally recorded in Dry Creek that were ~2–5% below the instantaneous guideline minimum for the protection of buried life stages (embryos, alevins). An estimated worst-case prediction is that low DO concentrations measured during the Reduced Recruitment period could have reduced the growth of embryos by ~10–35% in Dry Creek (based on length), relative to growth at optimum DO concentrations. This worst-case prediction applies to the 2018 spawn year and is highly precautionary because it assumes that the minimum measurement is representative of DO concentrations throughout the incubation period. There was less potential for chronic effects during other years. Furthermore, a key qualifier is that spawning generally occurs in other parts of the Harmer Creek population area where DO concentrations were above (compliant with) the guideline. Thus, the DO data indicate that the potential for chronic effects to buried life stages in the Harmer Creek population area was negligible or low.

Concentrations of DO in Dry Creek during the WCT incubation period were occasionally below the BCWQG minimum for the protection of buried life stages, including during 2018, 2019 and 2020, with the lowest value measured in August 2018. However, there was no statistically significant difference between DO concentrations measured during the Reduced Recruitment period and DO concentrations measured in prior years. Similarly, available data did not show clear differences in DO concentrations between the two population areas that would account for the spatial differences in recruitment success.

Overall, results do not indicate that low DO concentrations were a substantive cause of the Reduced Recruitment of WCT in the Harmer Creek population area, especially given that the low DO observations were in portions of Dry Creek that had limited use for spawning and incubation. Nevertheless, the occurrence of low DO concentrations in Dry Creek in summer 2018 and 2019 indicates that a partial contribution cannot be rejected.

Uncertainties

Confidence in the conclusions is influenced by several uncertainties. A key uncertainty is the lack of information about the difference between DO concentrations in interstitial waters (most relevant to buried life stages) and surface waters where DO concentrations were measured. Additionally, spatial representation of DO conditions was lacking. Suitable data for the Harmer Creek population area were only available for Dry Creek, and suitable data for the Grave Creek population area were only available for HRM-R1, not the Grave Creek mainstem.

5.2.3. Energetic Status

Methods

A hierarchical Bayesian Integrated Network model (Kéry & Royle, 2016; Carriger et al., 2016; McElreath, 2020; Schaub & Kéry, 2022) was used to quantify the effect of energetic status on the egg to age-1 survival for the Harmer Creek and Grave Creek populations, based on length, body condition and the scaling of standard metabolic rate to the size observed in salmonids. This was used to estimate the relative contributions to the observed Reduced Recruitment and Recruitment Failure patterns of energetic status, fork length, body condition, growing season degree days (GSSD; see textbox in Section 6.3.1) and dietary selenium.

Life Stages

The analysis focused on egg to age-1 survival.

Findings

The analysis estimated that energetic status explained 65% (29–85%, 95% CI) of the Reduced Recruitment and 90% (76–96%, 95% CI) of the Recruitment Failure. Although GSDD was estimated to contribute 34% (4–58%, 95% CI) to the Reduced Recruitment and dietary selenium 8% (3–16%, 95% CI), neither contributed to the Recruitment Failure pattern. Growing season degree days and dietary selenium did not contribute to the Recruitment Failure because they were at similar levels in the Harmer Creek population area in 2018 relative to 2017 and 2019.

Uncertainties

Assumptions include:

- Dietary selenium has the same effect on age-0 Westslope Cutthroat Trout as it has on age-0 Chinook Salmon
- The effect of selenium on length occurs solely via the dietary pathway
- Selenium only affects the length of the age-0 fish
- Age-0 fish have the same condition as age-1 fish
- The effect of dietary selenium in Grave Creek above the confluence with Harmer Creek is negligible
- The estimated average dietary selenium concentration is indicative of the population-level exposure

5.2.4. Food Availability

Methods

Three lines of evidence were examined to evaluate whether food limitations and subsequent starvation may have caused or contributed to the Reduced Recruitment for the 2017 to 2019 spawning year cohorts:

- **First line of evidence.** Body condition of juvenile and adult WCT in the Harmer Creek population in years associated with Reduced Recruitment compared to previous years and compared to WCT from nearby watersheds
- **Second line of evidence.** The abundance of total benthic invertebrates and specific dietary taxa in the Harmer Creek population area during the years of Reduced Recruitment compared to previous years and compared to the Grave Creek population area
- **Third line of evidence.** Total undisturbed and riparian habitat in 2020 compared to 2016, to indicate a potential change in terrestrial invertebrate inputs during the years of Reduced Recruitment

Life Stages

The findings apply to all free-feeding life stages of WCT, but in the context of Reduced Recruitment they are most relevant for WCT in their first year and for spawning adults. Diets of juveniles and adults strongly overlap, although adults can consume larger prey.

Findings

Condition of adults in the Harmer Creek WCT population was not reduced relative to that in the Grave Creek population, other upper Kootenay populations or years prior to the period of Reduced Recruitment. Condition of juvenile WCT from the Harmer Creek population was not reduced relative to Grave Creek in 2017, 2018 or 2020 but was lower (≤10%) in 2018 relative to 2017 and 2020. The amount of juvenile WCT data from the Harmer Creek population in 2019 were insufficient to support comparisons for that year. Additionally, no length or weight data were available to evaluate condition of fish that did not survive to age-1. Regardless, aquatic food availability in the Harmer Creek population area was similar to that in the Grave Creek population area in the years prior to and during the period of Reduced Recruitment. Terrestrial food availability was likely consistent over time, based on landscape disturbance indicators.

Food availability likely contributed negligibly to the Reduced Recruitment observed for the Harmer Creek WCT population, based on an absence of evidence for reduced food quantity/quality or starvation of WCT. However, we expect food to be one factor controlling fish growth, which can ultimately affect survival.

Uncertainties

The key uncertainties associated with the evaluation of food availability include small sample sizes for juvenile WCT captured from the Harmer Creek population in 2019 and the reliability of late summer or early fall fish condition as an indicator of lipid (energy) reserves in winter, when mortalities related to energy deficits often occur. Additionally, no length or weight data were available to evaluate body condition for mortalities that may have perished as a result of energy deficits. Indirect assessment methods were used to evaluate the contributions of aquatic and terrestrial invertebrates to instream drift and diets of WCT, and there are uncertainties associated with each of the steps linking invertebrate production to energy storage in WCT. Nonetheless, the confidence in these findings is considered fair to moderate because data gaps were generally offset by other lines of corroborating evidence.

5.2.5. Ice

Methods

Data for winter conditions were examined to infer anomalous surface, anchor or frazil ice, or rapid formation of ice that could have affected streamflow. Surface and anchor ice, as well as the speed with which ice forms, can affect the amount and quality of available habitat.

Frazil ice can injure free-swimming life stages or cause them to move to different locations and thereby incur energy costs.

The data types examined included:

- Air temperature (1980 to 2020)
- Water temperature (2017 to 2019)
- Snowpack (1983 to 2020)
- Discharge/stage (2010 to 2020)

Life Stages

Juvenile and adult life stages of WCT were not considered separately in the analysis. The ice stressor pathway is considered applicable for all life stages except eggs and embryos, which are only present when there is no ice.

Findings

Data suggest that severe ice conditions occurred in both Grave and Harmer Creeks in February 2019. Regional air temperatures shifted from abnormally warm in January 2019 to abnormally cold in February through early March 2019. The temperature shift occurred when the snowpack was below average and winter streamflow was lower than normal; therefore, relatively thin snow and ice cover was present to buffer swings in water temperature or ice formation. Water temperature and water level/discharge readings at multiple locations in the region indicate that ice formation and ice jams occurred during the cold period. Although we lack direct observations of ice during this period, we infer that effects to fish habitat quantity and quality or direct effects to fish were possible, which may have affected recruitment from the 2018 spawn year throughout the watershed.

Spatial and temporal trends of air and water temperatures indicated that ice may have contributed to Reduced Recruitment, especially in the year of Recruitment Failure.

Uncertainties

Ice conditions during the period of interest were not directly observed; rather, they were inferred from air temperature, snow water equivalents, water temperature and stream discharge data. Likewise, fish behaviour or survival were not directly observed during the period of assumed ice effects, so effects were inferred based on available literature.

Credit: Westslope Fisheries

5.2.6. Sediment Quality

Methods

Potential effects to WCT from elevated concentrations of metals, metalloids and polycyclic aromatic hydrocarbons in sediment were evaluated by:

- Comparing sediment chemistry data (i.e., all available data from 2013 to 2020) from the Harmer Creek and Grave Creek population areas to lower and upper British Columbia Working Sediment Quality Guidelines (BC WSQG)
- Comparing sediment chemistry data for constituents with concentrations greater than the lower or upper BC WSQG to regional reference area normal ranges
- Identifying constituents of potential concern (COPCs) based on concentrations greater than the upper BC WSQG and reference area normal ranges in the Harmer Creek population area during the period of Reduced Recruitment

- Evaluating trends in particle sizes, organic carbon and COPC concentrations over time in areas with two or more years of data
- Evaluating exposure pathways, bioavailability, species sensitivity and differences relative to the Grave Creek population area for COPCs in the Harmer Creek population area to identify key constituents of interest

Life Stages

The findings apply to all life stages of WCT but, in the context of Reduced Recruitment, they are most relevant for spawning adults and WCT in their first year.

Findings

Concentrations of cadmium, nickel, selenium, chrysene, dibenz(a,h)anthracene, fluorene and phenanthrene in the Harmer Creek population area were greater than the upper BC WSQG and reference area normal ranges from 2013 to 2020. However, from 2017 to 2020, the only constituents with concentrations greater than the upper BC WSQG and reference area normal ranges were cadmium, nickel and selenium in Dry Creek upstream and downstream from the Dry Creek Sedimentation Pond. In the Harmer Creek Sedimentation Pond, only the selenium concentration was greater than the alert concentration (treated as an upper BC WSQG) and reference area normal range. Cadmium, nickel and selenium were therefore identified as COPCs.

Concentrations of cadmium and nickel in bulk sediments from Dry Creek likely overpredict the bioavailable fractions of these constituents. This is because these metals were likely to have been at least partially incorporated into the calcite matrix at that location.

Habitats used by WCT in the Harmer Creek population area are primarily erosional, overall, with few patchy deposits of fine sediments. Ranges of selenium concentrations in sediments of the Harmer Creek and Grave Creek population areas overlapped, but concentrations increased by 525% in Harmer Creek Sedimentation Pond between 2013 and 2019. The increase in selenium concentrations within the pond could reflect changing conditions upstream, for which data were limited. However, given the spatial patterns of selenium speciation, and selenium concentrations in water and benthic invertebrate tissue, it is likely that sediments collected from the Harmer Creek Sedimentation Pond reflect speciation conditions and processes within the pond (de Bruyn et al., 2022).

While the results of the sediment quality evaluation indicate that selenium should be considered a key constituent of concern, the potential effects of selenium on fish are most reliably evaluated by analyzing tissue selenium concentrations in fish themselves, followed by concentrations in benthic invertebrate prey (an indicator of dietary exposure), rather than by evaluating sediment concentrations. Temporal and spatial differences in benthic invertebrate and WCT tissue chemistry, as they relate to the Reduced Recruitment, were assessed in detail in the Water Quality report prepared by Warner and Lancaster (2022). Because of the complexity of selenium behaviour and effects in aquatic systems, a separate, selenium-focused supplemental evaluation was also completed to support the Evaluation of Cause (de Bruyn et al., 2022).

The role of sediment quality as a contributing factor in the Reduced Recruitment for the Harmer Creek WCT population is considered low, based on scarcity of fine sediment in erosional habitats frequented by WCT, limited use of the Harmer Creek Sedimentation Pond by WCT and the absence of effects on benthic invertebrate communities during the years of Reduced Recruitment compared to previous years and compared to Grave Creek.

Uncertainties

The limited spatial and temporal coverage of the data set prevented statistical comparisons between the Harmer Creek and Grave Creek population areas and among years at some locations (e.g., within Dry Creek). Similarly, there is uncertainty around whether sediment constituent concentrations in the ponds reflect conditions in the nearby lotic habitats. Other key uncertainties in the evaluation included:

- Whether sediments that were collected in 2020 using different methods from those employed in previous years of sampling can be considered representative of recent (i.e., in 2020) deposits
- The bioavailability of COPCs in sediment samples
- The sensitivity of WCT to the identified COPCs

However, data gaps were either offset by other lines of corroborating evidence (i.e., benthic invertebrate community data) or, in the case of selenium, they were addressed as part of focused assessments (de Bruyn et al., 2022; Warner & Lancaster, 2022).

5.2.7. Selenium

Methods

Monitoring data were summarized to evaluate selenium concentrations in water, sediment, benthic invertebrates and WCT from the Harmer Creek population area. These data indicated two exposure scenarios, and these were evaluated separately:

- **Scenario 1**. Monitoring data from the period of Reduced Recruitment indicated that concentrations of aqueous and tissue selenium were generally consistent with data collected between 2012 and 2020.
- **Scenario 2.** Monitoring data from 2021 indicated higher concentrations in biota than previous years and were interpreted to reflect relatively high generation of organoselenium in the Dry Creek Sedimentation Pond in 2021. Although similarly high concentrations were not observed during the period of Reduced Recruitment, it could not be ruled out that conditions similar to 2021 might have occurred in other years.

Potential effects to WCT were evaluated by comparing estimated exposures of embryos, alevins, and fry under each exposure scenario to concentrations associated with effects on embryo survival, larval development and growth. Where exposures in an area indicated a potential for effects, the potential contribution to Reduced Recruitment was further evaluated by considering spatial extent and use of the area by WCT.

Life Stages

Findings apply to sensitive early life stages of WCT, including embryos, alevins, and fry (age-0).

Findings

Monitoring data from the period of Reduced Recruitment indicated potential 5–10% effects on fry growth from dietary selenium in most areas of the Harmer Creek population area used for juvenile rearing. Aqueous, dietary and WCT tissue selenium concentrations from the period of Reduced Recruitment did not indicate potential effects on larval development or survival of embryos or fry. Monitoring data from Harmer Creek in 2021 indicated potential 14–20% effects on fry growth from dietary selenium and potential 28% effects on embryo-larval survival, but they did not indicate potential effects on fry survival.

- The potential role of selenium as a factor contributing to Reduced Recruitment in the Harmer Creek WCT population differed between the two exposure scenarios. Monitoring data from the period of Reduced Recruitment indicated a low-level effect on growth. This effect would not usually be interpreted to indicate a potential for changes at the population level, but it could contribute to overwintering mortality when combined with other factors that limit the growth of fry.
- Monitoring data from 2021 indicated larger potential effects on fry growth and potential effects on embryo-larval survival and, as a result, a greater potential contribution of selenium if similar conditions occurred during the period of Reduced Recruitment.

Credit: Minnow Environmental Inc

Uncertainties

Confidence in these findings is difficult to characterize because of the marked difference between the two exposure scenarios. Prior to receiving 2021 data, confidence in the evaluation of data from the period of Reduced Recruitment was moderate: there were abundant monitoring data in several areas that generally aligned, and toxicity information to interpret these data was available. Data were unevenly distributed in space and time, and overall conclusions required estimation, resulting in moderate confidence.

However, data collected in 2021 showed that selenium speciation and tissue selenium concentrations in the Harmer Creek population area can be highly variable, and this reduces confidence that the available data fully characterize selenium exposures during the period of Reduced Recruitment. This uncertainty is somewhat reduced by the observation that 2021 had a distinctly warmer and earlier summer than previous years, which could explain the increase in organoselenium generation in that year. By comparison, monitoring data from the period of Reduced Recruitment did not indicate conditions that would be expected to have increased generation of organoselenium (e.g., warm summer, low flow, high nutrient availability).

5.2.8. Small Population Size

Methods

Single nucleotide polymorphisms were used to quantify allelic richness, diversity and effective population size for the Harmer (n=15) and Grave (n=34) Creek populations in 2016.

Life Stages

Inbreeding depression (expression of harmful recessive alleles) or maladaptation (insufficient genetic diversity to respond to changing environmental conditions) could contribute to reduced early life stage growth (and possibly survival) in both systems.

Findings

- Allelic richness of 1.4 alleles/loci for Harmer Creek vs 1.6 for Grave Creek and a genetic diversity of 9% for Harmer Creek vs 12% for Grave Creek (with little differentiation). These population differences are unlikely to have had more than a negligible contribution to Reduced Recruitment in the Harmer Creek population relative to the Grave Creek population.
- The effective genetic population size in the Harmer Creek population area was estimated to be 23 individuals. It indicates that the genetic diversity in the Harmer Creek population would have declined from 9% to 8.9% over the period of interest. This difference would have caused a negligible contribution to Recruitment Failure in the Harmer Creek population in 2018 relative to 2017 and 2019.

Uncertainties

This analysis is based on just 49 fish from a single year. After conducting the analyses for this report, we discovered that in 2016 the Grave Creek fish were divided into three distinct populations by culverts. This discovery increased our confidence in the findings, because when the genetic data were collected the Grave Creek population was physically subdivided into three populations. These populations would have been expected to have lower allelic richness, genetic diversity and effective population size than the estimated overall Grave Creek population.

5.2.9. Streamflow and Inferred Habitat Availability

Methods

Streamflow influences a wide range of possible pathways that relate to aquatic habitat quantity and quality and, thereby, to WCT recruitment. Streamflow data from sites within the Grave Creek watershed and from Water Survey of Canada (WSC) reference sites outside the watershed were assessed to evaluate general characteristics and identify anomalies in the hydrologic record and anomalies in ecologically relevant flow statistics. The outcome of these analyses provided important context for SMEs to consider when undertaking further analysis of each individual pathway.

Life Stages

Streamflow analysis was performed for WCT activity periods: overwintering, spawning, incubation (assuming early and late spawning) and summer rearing.

Findings

Overall, streamflow was similar before and during the period of Reduced Recruitment, with two notable exceptions:

- The spring freshet of 2016 occurred earlier than average at all gauges analyzed, which resulted in early recession of flow and very low flows in June and July that year. Flows were the lowest on record at some but not all stations.
- Over the past decade, the 2018 to 2019 water year (October to October) had the lowest average annual streamflow at monitoring locations EV_DC1, EV_HC1 and reference streams. Lower than normal streamflow occurred from late summer 2018 through spring of 2019. Low streamflow during this period, combined with ice formation during severe winter air temperatures in February and March 2019, are inferred to have reduced available habitat relative to normal conditions.

When results were examined by activity period, they did not indicate notable differences in streamflow prior to and during the Reduced Recruitment, except for

- The spawning period of 2016, when average daily streamflow was the lowest on record at EV_DC1 and the WSC Elk River near Natal reference station
- Streamflow during the early incubation period and the rearing period of 2016 was also the lowest on record at EV_DC1, but it was not the lowest at EV_HC1 and WSC reference stations

- The overwintering period of 2018/2019, when average streamflow was lowest on record at the Dry Creek hydrometric station (EV_DC1) and very low at the Harmer Creek (EV_HC1) and WSC reference stations: This period coincided with winter conditions in February and early March 2019 that were inferred to have resulted in anomalous ice conditions.

The hydrometric record implies that streamflow possibly contributed to Reduced Recruitment, particularly during the period of Recruitment Failure.

Uncertainties

There are large spatial and temporal gaps in the flow record at locations within the Grave Creek watershed that limit the assessment. The data provide moderate certainty that reductions in streamflow during the summer of 2016 and the winter of 2018/2019 affected availability of fish habitat in the Harmer Creek population area. The continuous data record within the watershed is short and, therefore, it is difficult to compare to historical conditions. There were no continuous streamflow data for Grave Creek for comparison; however, the observed trends in Harmer Creek watershed were similar to trends at other regional monitoring locations.

5.2.10. Total Suspended Solids

Methods

Records for total suspended solids (TSS) from the Grave Creek watershed since 1981 were analyzed using the severity of ill effects (SEV) models for all life stages. Results from the Harmer Creek population area for the period of interest were compared against previous data from Harmer Creek and concurrent data from the Grave Creek population area. Where high SEV scores were observed, the results were evaluated for temporal alignment with WCT life stages.

Life Stages

Three SEV models — eggs/alevins, juveniles and adults — were used in the assessment, noting that earlier life stages are more sensitive to TSS. The analysis focused on early life stages but remained open to possible effects to adults and juveniles, because stress to these life stages can reduce the energy that individuals can invest in reproduction.

Findings

In the Harmer Creek population area during the period of interest, SEV measures were generally similar to or indicated less severity than in previous periods and were better than in Grave Creek. One anomalous event in Dry Creek in September 2018 had higher TSS, but the datum is possibly unreliable (i.e., it applied to a single site on a single day and corresponded poorly with turbidity observations). Even if this observation is reliable, exposure of a small portion of the egg cohort in a single year could not fully explain Reduced Recruitment or Recruitment Failure. Therefore, this event is considered insufficient to have caused Reduced Recruitment on its own, but it may have been contributory.

During the period of interest, TSS was sufficient to have acted as a stressor that could have interacted with other stressors, even though TSS and SEV data did not indicate an increase relative to the historical data (pre-2016) or relative to Grave Creek data.

Uncertainties

The temporal coverage of TSS data is low resolution (often monthly) and has multi-year gaps at most stations, such that higher or lower TSS events may have gone unsampled. Data are primarily from sedimentation pond outlets, which are expected to have lower TSS concentrations than upstream locations because TSS settles out in the sedimentation ponds.

Credit: Minnow Environmental Inc.

5.2.11. Water Quality

Methods

The water quality assessment evaluated potential direct, acute and chronic effects of mine-influenced water quality on WCT and potential indirect effects from nutrient enrichment[20]. The assessment examined when potential effects may have occurred and if these conditions occurred at locations where sensitive life stages of fish could have been present. The water quality data, tissue selenium data and acute and chronic toxicity testing data evaluated in this assessment were interpreted in the context of information about WCT life history, movement and habitat use that was developed in other SME reports.

Surface water quality data from the Harmer Creek and Grave Creek population areas were screened to identify the potential for acute or chronic effects to aquatic life. The first step was to identify constituents that could have contributed toward causing stress to aquatic life. Available water quality data collected before and during the period of interest (2016 to 2020) were screened against available water quality guidelines for the protection of aquatic life. The second step was a more refined assessment conducted for constituents identified in the preliminary screening as potential stressors. This was done using species-specific and site-specific information to characterize potential effects on the most sensitive life stages of WCT. The refined assessment relied on screening values and benchmarks for potential effects to WCT from published toxicological data. For many constituents this was based on laboratory testing with sensitive early life stages of standard test species such as Rainbow Trout.

Measured concentrations of total phosphorus and orthophosphate were evaluated in the context of federal nutrient management frameworks and site-specific screening values that indicate the potential for adverse effects on habitat quality.

Life Stages

The evaluation considered pathways that are relevant to embryos and juveniles (considered sensitive early life stages of WCT) and adults.

Findings

- The nutrient evaluation did not indicate a potential for enrichment effects to have contributed to the Reduced Recruitment.

[20] A detailed evaluation of DO is provided in the DO SME memo (Abell et al., 2022) and is summarized in Section 5.2.2.

- Screening water quality data in the period of interest did not indicate a potential for acute effects from mine-related constituents at any site in the assessment area. Acute toxicity testing results also indicated that mine-influenced water at the point of release from Dry Creek Sedimentation Pond did not cause acute effects in test species.
- Sulphate, total dissolved solids (TDS, of which sulphate and its counter-ions are the major components) and selenium were identified as potential chronic stressors. They were carried forward in the refined assessment.
- Maximum sulphate and associated TDS concentrations in Dry Creek indicated a potential for effects on survival and development (indicated by swim-up) of sensitive early life stages in the years before and during the period of interest. Available information indicates that early life stages of WCT are unlikely to have been present in relevant reaches of Dry Creek. Moreover, the potential for effects to WCT from sulphate and TDS concentrations in Dry Creek in 2017 to 2019 (years with Reduced Recruitment) were similar to 2020 (when Reduced Recruitment was not observed). Concentrations of sulphate and TDS in Harmer Creek and its tributaries and in Grave Creek were not associated with potential effects to WCT.
- Maximum aqueous selenium concentrations during the period of interest indicated potential effects on WCT reproduction and juvenile growth in Dry Creek. Concentrations in Dry Creek were greater in 2017 and 2018 than in previously recorded years. It cannot be ruled out that bioaccumulated selenium in WCT in the lower reaches of Dry Creek may have contributed to Reduced Recruitment, although the interpretation of potential effects to WCT from aqueous selenium concentrations is uncertain. Selenium exposure did not indicate the potential for effects in Harmer Creek and its tributaries, the area representing most of the habitat used by the Harmer Creek WCT population. However, recognizing the complexity of the selenium exposure dataset and the range of potential pathways for selenium effects, a separate evaluation of selenium was conducted by de Bruyn et al. (2022) to supplement the screening-based water quality assessment.

Conditions were not met for water quality stressors (specifically, sulphate and TDS) to have been a factor contributing to or having caused Reduced Recruitment of WCT in the Harmer Creek population. Bioaccumulated selenium in WCT in the lower reaches of Dry Creek may have been a minor contributor to Reduced Recruitment and was further evaluated in de Bruyn et al. (2022). Water quality was considered a negligible contributing or causal factor to the Harmer Creek Recruitment Failure in spawning year 2018.

The quantity of data within the Harmer Creek population area limited the robustness of the spatial and temporal analyses. Teck Coal has addressed this uncertainty through additional sampling efforts in Dry, Harmer and Grave Creeks (data not available for this report). Confidence in the conclusions of the water quality evaluation is moderate to high.

Uncertainties

Available data used in this assessment provide a reasonable characterization of water quality in the Harmer Creek and Grave Creek population areas. Although there are creek reaches and years with few or no monitoring data, conditions in these reaches and years can reasonably be inferred from the long monitoring record in Dry Creek, the primary source of mine-influenced water to Harmer Creek.

5.2.12. Water Temperature

Methods

Water temperature data previously collected for Cope and Cope (2020) were reanalyzed to generate several metrics for water temperature suitability. The metrics analyzed included:

- Mean monthly water temperature
- Mean weekly temperature
- Exceedances of daily mean temperature thresholds
- Rate of water temperature change (hourly)
- Growing season degree days

These metrics were then compared to optima derived from scientific literature and the BCWQG. Additional scenario explorations were undertaken to compare growth and survival based on GSDD at different water temperature stations in the Grave Creek watershed, and to compare possible interactions with other stressors like water quality, severe winter conditions or other factors.

Life Stages

We expect that cold water temperature would have greatest effect on embryos (by prolonging incubation) and newly emerged fry (by allowing for less time to grow prior to winter) but that it may also limit growth and reproduction of older age classes.

Findings

The Grave Creek watershed is a cold water system. All locations rarely warm beyond the upper threshold of WCT optima. Water temperature in upper Grave Creek and upper Harmer Creek (except Dry Creek) was characterized by low summer peak temperatures, short and cool growing seasons (measured by GSDD) and low July mean water temperature. Lower-elevation stations were warmer in the summer but still cool overall. The colder stations were less suitable for recruitment than the warmer stations due to lower GSDD.

Locations elsewhere in the watershed, including Dry Creek, had temperatures that were appropriate for spawning, incubation and fry rearing.

Small differences in GSDD are thought to be biologically meaningful, because GSDD in the whole watershed is near the lower threshold for recruitment. Therefore, small differences among locations and years may result in quite different probabilities of recruitment. In the Grave Creek population area, GSDD was found to be more appropriate for recruitment than in the Harmer Creek population area, but there was no strong indication that water temperature alone was responsible for the Recruitment Failure in 2018. A role in both Reduced Recruitment and Recruitment Failure is nevertheless plausible, particularly if there were interactions with other stressors.

Uncertainties

There is broad confidence that the existing water temperature data accurately represent both the point locations where sensors were deployed and the trends in water temperature at those locations. However, the data are spatially and temporally limited and, therefore, may not adequately represent conditions in a broader area. For example, new data from 2021 suggest that upper Grave Creek may be warmer than previously assumed from station G3. These newer data suggest Grave Creek may be even more suitable for recruitment relative to Harmer Creek than was originally assessed using G3 as being representative of the temperature regime in upper Grave Creek. Likewise, there is broad confidence in the general effect of water temperature on the duration of incubation and on fry size at the end of the rearing period, based on considerable literature. However, when applying literature-based relationships there is uncertainty between fry size and overwintering mortality to WCT in the Grave Creek watershed.

Credit: Minnow Environmental Inc.

6. Integrated Findings

6.1. CHAPTER OVERVIEW

This chapter integrates our understanding of the patterns of recruitment and key fish metrics for the Harmer Creek and Grave Creek WCT populations for the 2017 to 2019 spawn years with individual stressor patterns and causal effect pathways. Intrinsic conditions in the Harmer Creek population area (e.g., a short, relatively cold growing season) result in the fish being very small. These fish are particularly susceptible to other factors which can decrease their growth or increase their overwintering mortality but which may have little or no effect on larger fish. The integration considers how potential stressors may have contributed individually or interacted to affect recruitment.

Having evaluated numerous lines of evidence, the Evaluation of Cause Team developed an integrated hypothesis about the most likely combination of stressors that contributed to the Reduced Recruitment and Recruitment Failure in the Harmer Creek population. We consider it likely that the overall recruitment patterns were primarily caused by low overwintering survival, due to age-0 WCT having had insufficient energy to survive their first winter. Several stressors were identified that influence growth and energy balances. These are related to both natural conditions in the watershed (as measured by GSDD and impacts associated with mining (including chemical constituents, namely selenium). Other potential causal pathways that were unrelated to energy also likely contributed to the recruitment patterns. For example, dietary selenium in Dry Creek was high enough to have been able to cause reproductive effects, thereby contributing to the reduction in recruitment rate for the Harmer Creek population. As another example, Recruitment Failure for the 2018 spawn year may have been related to anomalous conditions in the winter of 2018/2019 which may have led to direct age-0 mortality, through habitat loss and ice-related conditions, and to increased energetic costs.

The datasets used in the Evaluation of Cause were collected under a variety of programs that were not designed specifically to answer Evaluation of Cause questions. Using these data and supporting information from the published scientific literature, the Evaluation of Cause Team developed the integrated hypothesis discussed in this chapter. This hypothesis represents our understanding of the Reduced Recruitment and Recruitment Failure in the Harmer Creek population. Uncertainties that were identified and discussed in individual SME reports were also relevant to this integration and were considered.

Information used to develop this integrated hypothesis is presented in this chapter. The chapter is structured as follows:

- Section 6.2 summarizes key findings from the population monitoring data that are relevant to WCT recruitment patterns.
- Section 6.3 reviews conditions in the watershed prior to the period of development, during development and during the period of Reduced Recruitment, with a focus on conditions believed to have had the most influence on recruitment patterns.
- Section 6.4 reviews the mechanisms that could have resulted in Reduced Recruitment and Recruitment Failure.
- Section 6.5 describes the integrated hypothesis for each recruitment pattern.
- Section 6.6 describes actions that we understand Teck Coal is taking in response to the findings.

6.2. RECRUITMENT PATTERNS

The Evaluation of Cause was initiated based on the results of an analysis of fish population monitoring data collected in the Harmer Creek population area from 2017 to 2019. The analysis indicated that there was low abundance of juvenile WCT, attributed to apparent Recruitment Failure (Cope & Cope, 2020). A summary of key results regarding recruitment patterns follows, including the life stages involved and the timing and spatial scale of the Reduced Recruitment in the Harmer Creek population area, which were described in Chapter 4. The nearby Grave Creek population was used as a reference area for the Evaluation of Cause (see text box).

> ***Grave Creek Reference Area***
>
> *The Grave Creek population area (including HRM-R1 and Grave Creek upstream of the waterfall at rkm 2.1) was used as a reference for the Harmer Creek population area for some analyses in the Evaluation of Cause. The Grave Creek and Harmer Creek populations were a single population until 1971 when they were separated by a dam that prevents upstream movement into the Harmer Creek population area (Chapter 2). In addition to their common genetic background, the areas the two populations occupy are similar in size and have similar conditions, such as elevation and climate. The areas also differ in important ways, including water temperature and extent of mine influence. Over the period of record, recruitment rates have been higher in the Grave Creek population than the Harmer Creek population.*

Recruitment refers to the number of fish surviving from one life stage to another. In this case, we focused on the number of fish recruiting to the age-1 life stage. The estimated recruitment of age-1 fish to the Harmer Creek and Grave Creek WCT populations for the 2017 to 2020 spawn years is shown in Figure 6-1. Egg to age-1 survival, measured in the fall of the spawning cohort's second year, was used to express recruitment patterns (see Chapter 4). Although fluctuating patterns in recruitment are expected to occur in fish populations, for a population to be stable, the long-term average egg to age-1 survival rate needs to be at replacement.

For the 2017 to 2019 spawn years, the egg to age-1 survival rate was likely below replacement in the Harmer Creek population (Figure 6-1) and, therefore, it meets the definition of Reduced Recruitment[21] (Section 1.1). In 2018, the egg to age-1 survival rate was even lower than in 2017 and 2019, and it was below replacement. This is the Recruitment Failure pattern. The Grave Creek population's 2018 spawning cohort also had lower recruitment than its 2017 and 2019 cohorts, and it met the definition of Reduced Recruitment. This recruitment pattern suggests that a common stressor might have influenced recruitment for the 2018 spawning cohort in both population areas. These are the recruitment patterns we investigated in the Evaluation of Cause. In 2020, there was little difference in the egg to age-1 survival rate between the populations[22], and both were above the level of replacement.

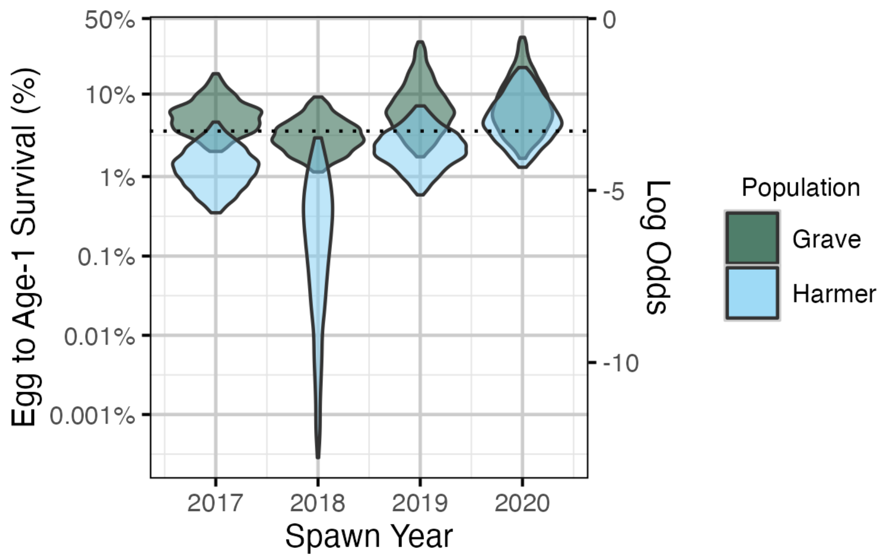


Figure 6-1. The probability density for the egg to age-1 survival rate by spawn year and population[23]

The dotted line represents the estimated level of egg to age-1 survival necessary for each spawner to replace itself over its lifetime. The broadest part of the shape represents the most likely egg to age-1 survival rate for a given spawn year and population. Where the shape is narrower, it indicates a less likely outcome. Where the shapes for Harmer and Grave overlap, it indicates the likelihood of similar recruitment rates, and where they do not overlap it indicates the likelihood of differing recruitment rates (Chapter 4; Thorley et al., 2022).

[21] Reduced Recruitment describes a probability of > 50% that annual recruitment was < 100% of that required for population replacement.

[22] Note that the 2020 spawn recruitment rates are more uncertain than other years because they are estimated based only on age-1 abundance in 2021. For other years the recruitment rates were estimated using monitoring data from 2 years (i.e., age-1 and age-2+, see Chapter 4).

[23] Recruitment rates could not be calculated for the 1996, 2008 and 2013 spawn years using the life cycle model because only a single year of data was available, and the recruitment calculation requires estimates of the number of eggs deposited and the egg to age-1 survival rate the following year (Chapter 4; Thorley et al., 2022).

The population monitoring results indicated that Reduced Recruitment in the Harmer Creek population was unlikely to be due to changes in the total number of eggs deposited by adults. This is because, even though adult abundance had been declining in both populations from 2017 to 2020, body condition and fecundity were similar in both and redds were documented in the Harmer Creek population area throughout the period of Reduced Recruitment (Chapter 4). This led us to conclude that low recruitment of age-1s was probably due to low survival that occurred between fertilization and when their low abundance was documented in the electrofishing surveys the following fall.

Given the understanding of the recruitment patterns, we focused on stressors that could have impacted the 2017 to 2019 spawning cohorts between egg deposition and census in the fall of their age-1 year. For Recruitment Failure of the 2018 spawning cohort, the stressor (or stressors) would have to have been sufficiently widespread to impact WCT throughout the population area. In 2017 and 2019, the stressor(s) could either have been more localized, potentially having large impacts in a small area, or widespread, but with a smaller magnitude of effect over a larger area.

The life stages of each spawning cohort by calendar year are depicted in Figure 6-2. Using this figure, temporal patterns in potential stressors can be compared with recruitment patterns. For instance, for a stressor to have an impact on egg to age-1 survival in the 2017 spawn year, the stressor could have impacted adults in 2016, directly impacted eggs and age-0 fish in 2017 and/or impacted age-1s through the winter of 2017/2018 and the summer of 2018.

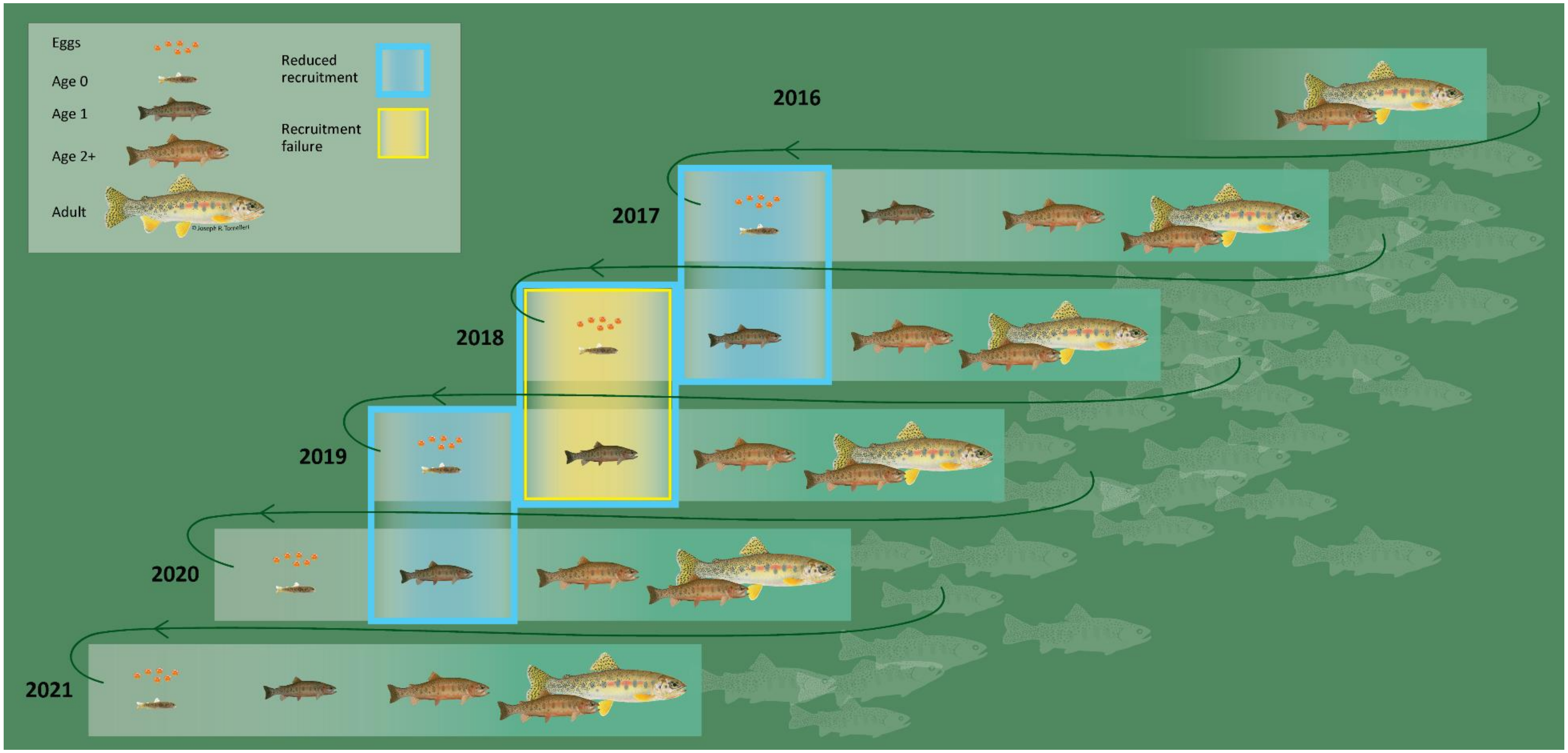


Figure 6-2. Harmer Creek Westslope Cutthroat Trout, 2016–2021 cohorts: Development from spawning through maturity and potential periods of Recruitment Failure and Reduced Recruitment

The periods of WCT Reduced Recruitment and Recruitment Failure in Harmer Creek are shown, together with the life stages from spawning through adult, for the 2016–2021 cohorts (spawning cohort year shown in bold). A single fish's life stages through the years can be followed by reading top to bottom. For example, a fish that was an egg/age-0 in 2017 was an age-1 in 2018, age-2 in 2019 and adult in 2020 and 2021. Fish spend more than 1 year as an age-2+ prior to reaching reproductive maturity.

6.3. WATERSHED HISTORY

When considering the recruitment patterns in the Harmer Creek WCT population, several characteristics of the Grave Creek watershed, in general, and the Harmer Creek population area, in particular, are relevant. These include conditions intrinsic to the population area and conditions that may have changed due to development in the watershed (see also Chapter 2). When reviewing the conditions and stressors that may have affected recruitment, three periods in the history of the watershed are distinguished in this section:

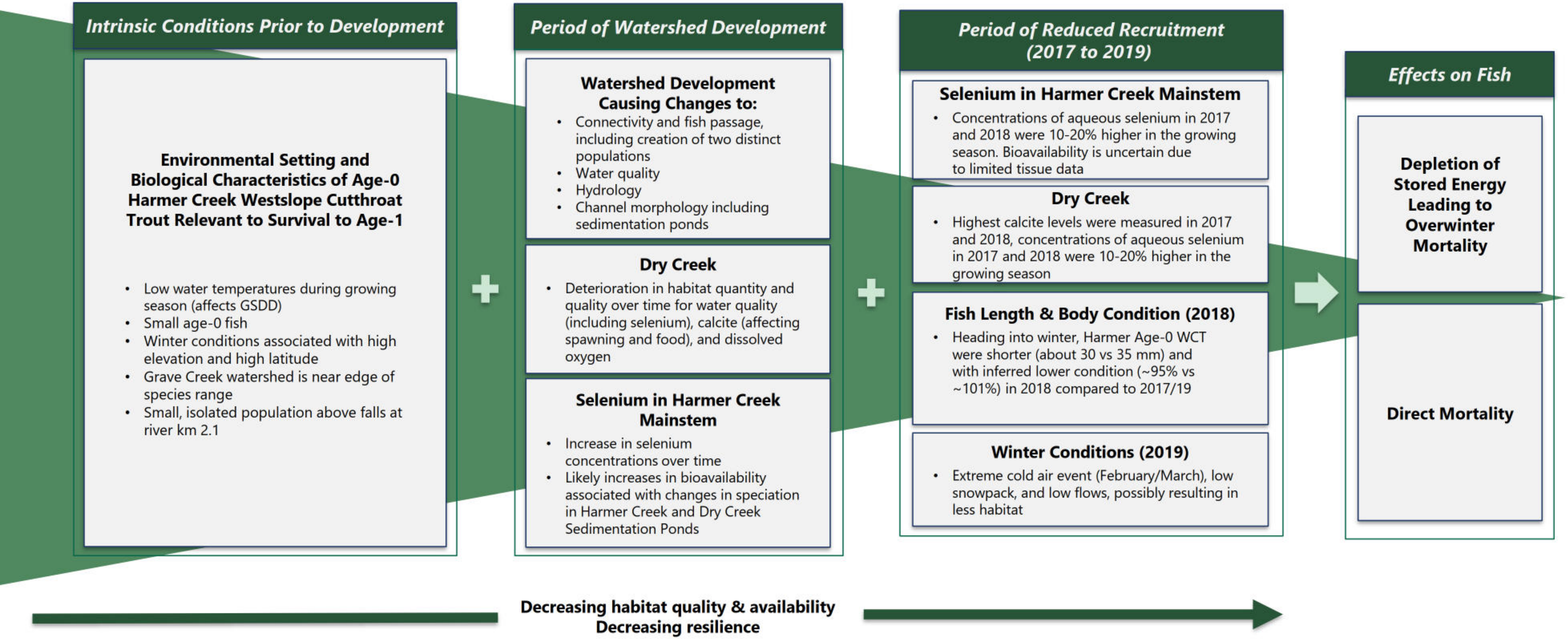
- Intrinsic conditions pre-development (before 1950s)
- Development period (after 1950s)
- Period of Reduced Recruitment (2017 to 2019 spawn years)

A summary of key stressors in each of these periods is provided in **Error! Reference source not found.** and discussed in the following sections. The "+" between the periods in Figure 6-3 indicates that conditions and stressors with the potential to have influenced recruitment patterns in one period were also present in the subsequent period. In addition, Dry Creek and selenium in the Harmer Creek mainstem are listed in two periods. Habitat and water quality in Dry Creek deteriorated during the period of development in the watershed, and evidence suggests conditions were incrementally worse during the period of Reduced Recruitment. Similarly, selenium reduced water quality in the Harmer Creek mainstem, which followed a similar pattern of deterioration during the period of development in the watershed and became incrementally worse during the period of Reduced Recruitment. The potential for those differences to be biologically meaningful is discussed below, in the supporting SME reports (e.g., Abell et al., 2022; de Bruyn et al., 2022; Hocking, Cloutier, et al., 2022; Warner & Lancaster, 2022) and in Chapter 5 of this Evaluation of Cause.

Figure 6-3 is presented on the following page. Its caption is:

Figure 6-3. Stressors and conditions present in the Harmer Creek Population Area prior to development, during watershed development and specific to the period of Reduced Recruitment

These stressors and conditions are believed to have contributed to the observed recruitment patterns for Westslope Cutthroat Trout.


Intrinsic Conditions Prior to Development
Environmental Setting and Biological Characteristics of Age-0 Harmer Creek Westslope Cutthroat Trout Relevant to Survival to Age-1
Low water temperatures during growing season (affects GSDD)
Small age-0 fish
Winter conditions associated with high elevation and high latitude
Grave Creek watershed is near edge of species range
Small, isolated population above falls at river km 2.1
Period of Watershed Development
Watershed Development Causing Changes to:
Connectivity and fish passage, including creation of two distinct populations
Water quality
Hydrology
Channel morphology including sedimentation ponds
Dry Creek
Deterioration in habitat quantity and quality over time for water quality (including selenium), calcite (affecting spawning and food), and dissolved oxygen
Selenium in Harmer Creek Mainstem
Increase in selenium concentrations over time
Likely increases in bioavailability associated with changes in speciation in Harmer Creek and Dry Creek Sedimentation Ponds
Period of Reduced Recruitment (2017 to 2019)
Selenium in Harmer Creek Mainstem
Concentrations of aqueous selenium in 2017 and 2018 were 10-20% higher in the growing season. Bioavailability is uncertain due to limited tissue data
Dry Creek
Highest calcite levels were measured in 2017 and 2018, concentrations of aqueous selenium in 2017 and 2018 were 10-20% higher in the growing season
Fish Length & Body Condition (2018)
Heading into winter, Harmer Age-0 WCT were shorter (about 30 vs 35 mm) and with inferred lower condition (~95% vs ~101%) in 2018 compared to 2017/19
Winter Conditions (2019)
Extreme cold air event (February/March), low snowpack, and low flows, possibly resulting in less habitat
Effects on Fish
Depletion of Stored Energy Leading to Overwinter Mortality
Direct Mortality
Decreasing habitat quality & availability
Decreasing resilience

6.3.1. Intrinsic Conditions in the Grave Creek Watershed Prior to Development

Intrinsic conditions prior to development in the Grave Creek watershed and conditions specific to the Harmer Creek population area provide context for the recruitment patterns evaluated in the Evaluation of Cause.

The Grave Creek watershed ranges in elevation from 1,173 m to 2,494 m above sea level. While post-glacial dispersal barriers influence current WCT distribution, few WCT populations occur farther north. This suggests the Grave Creek watershed is near the latitude and elevation where habitat transitions from being suitable for supporting WCT populations in the long term to habitats that are less suitable. Westslope Cutthroat Trout are able to persist in cold, unproductive environments, although these conditions may affect their physiological performance (e.g., growth, fecundity and survival) and potentially affect the population's abundance and distribution. Even though WCT are adapted to local conditions in the Elk River watershed, conditions in relatively small streams like Harmer and Grave Creeks may be near or beyond an individual fish's tolerance.

Cold Water Temperatures During Growing Season

In the Grave Creek watershed, the growing seasons are short and the winters are long. In addition, summer water temperatures in Harmer Creek are cold, due to groundwater influence in the upper reaches of the creek. Consequently, the water warms later in Harmer Creek than it does in much of the Grave Creek population area. We expect that this would also have been the case prior to watershed development. We expect, too, that water temperatures similar to those currently seen in HRM-R3 likely extended to the confluence with Grave Creek, because there would have been no warming from the Harmer Creek Sedimentation Pond. The current warm summer water temperatures in Dry Creek are likely related to habitat alterations associated with mining activities. These alterations include the broader and shallower channel, the terraced channel morphology from calcite, and the Dry Creek Sedimentation Pond. Water temperatures prior to watershed development are expected to have been lower. Likewise, the water temperatures immediately downstream of the Dry Creek and Harmer Creek confluence may have been lower pre-development than at present because Dry Creek is currently a source of warmer water.

Fish generally grow more slowly in cooler conditions and have less time to grow in short growing seasons (see text box, below, and Section 6.4.1). We would therefore expect that age-0 fish in the Harmer Creek mainstem would have been smaller than those in Grave Creek, historically, particularly in the upper reaches where water is cooler in summer due to the groundwater influence. This is consistent with recent observations. Given that smaller fish have lower overwintering survival, challenging winter conditions and low water temperatures prior to development in the area likely influenced recruitment for the Harmer Creek WCT.

Growing Season Degree Days

The accumulation of thermal energy during the growing season influences fish growth. The accumulation of thermal units (e.g., growing season degree days – GSDD) is determined both by the length of the growing season and the water temperatures during the growing season. The longer the growing season and the warmer the water, the more thermal units accumulate. Cooler water and a shorter growing season are expected to result in longer incubation for fry, which therefore emerge later, have less time to grow and begin the overwintering period at a smaller size. Growth is also slower when water temperature is lower. Small age-0 size at the onset of winter has been linked to poor overwintering survival in other interior Cutthroat Trout populations. Studies indicate that age-0s below a critical size threshold have reduced overwintering survival (Coleman & Fausch, 2007a, 2007b).

For additional discussion about GSDD and the relationship between GSDD and fish size and survival, see Hocking, Whelan & Hatfield (2022).

Winter Conditions

Based on what we know about winter conditions in the Grave Creek watershed (Cope & Cope, 2020) and on recent water temperature data (Hocking, Whelan & Hatfield, 2022), it is likely that winter conditions prior to watershed development would have had both similarities and differences compared to today. Conditions in the Harmer Creek mainstem upstream of what is now the Harmer Creek Sedimentation Pond were likely similar to today (i.e., from upstream to downstream there was likely open water transitioning to surface ice, then anchor and frazil ice) (MacDonald et al., 2022). Before the Harmer Creek Sedimentation Pond was constructed, winter conditions in and downstream of this area were likely different because stream habitat would have been uninterrupted. Frazil and anchor ice conditions would likely have continued to the confluence with Grave Creek and below, where anchor and frazil ice have been documented in recent years (Cope & Cope, 2020).

Restricted Distribution

The waterfall at rkm 2.1 in Grave Creek (Figure 2-4) isolates WCT in the Grave Creek watershed by preventing fish in the Elk River from migrating upstream (Chapter 2). Prior to development, there was a single WCT population above the waterfall comprised of fish from both Grave Creek and Harmer Creek. However, given the limited fish-bearing habitat, the total population size would have been small[24]. Small, isolated populations are inherently at risk of extirpation (becoming locally extinct) as a result of fluctuations in abundance, lack of rescue from adjacent populations (immigration) and potential loss of genetic diversity that leads to inbreeding depression or maladaptation over the long term (Frankham, 1995; McElhany et al., 2000; Wang et al., 2002; Reed et al., 2003; COSEWIC, 2019; Thorley et al., 2022). In the absence of immigration to the Grave Creek watershed, negative effects from either local or regional influences may affect a larger portion of the population than would be the case in a population that occupies a larger area.

6.3.2. Development Period – What Changed

Several ongoing conditions in the Harmer Creek population area are associated with the period of development but are not specific to the period of Reduced Recruitment. These are:

- Habitat alteration, loss and connectivity
- Constituents of concern

Habitat Alteration, Loss and Connectivity

Open pit steelmaking coal mining at Elkview Operations began in 1969. Open pit mining and waste rock deposition have affected 11% (i.e., 3.54 km^2) of the Harmer Creek sub-watershed and 23% of the Dry Creek sub-watershed that drains the northern end of Elkview Operations (see Chapter 2). Compared to pre-development, spatial distribution of physical impacts from forestry and road building in the Harmer Creek

[24] A small population, as defined by the 50/500 rule of population genetics, is one with an effective population size of less than 500 individuals. A very small population is one with an effective population size of less than 50 individuals (Hastings et al., 2008).

population area are minimal (~1.4%). During the period of development, there has been no consumptive water use in this watershed. Non-consumptive water licences have been issued for treating sediment via construction and operation of sedimentation ponds. Mining activities in the Harmer Creek population area have resulted in elevation loss at higher elevations and elevation gain at lower elevations. In Dry Creek, several spoiling slumps and landslides have occurred, broadening the channel and, in some parts, making it shallower (Chapter 2). Due to the morphological changes in Dry Creek and the apparent lack of groundwater influence that would moderate stream temperature, summer temperatures are warmer and winter temperatures are colder in Dry Creek than in other parts of the Harmer Creek population area (Hocking, Whelan & Hatfield, 2022). If Dry Creek had warmer summer temperatures than the Harmer Creek mainstem prior to the period of development, it may have produced larger age-0s better able to survive winter.

Calcite deposition and concretion have the potential to negatively affect aquatic habitat by changing stream sediment characteristics (Barrett et al., 2016; Hocking et al., 2020). Calcite formation occurs naturally, but downstream of mining spoils it can increase in magnitude and extent (Teck Coal, 2019), and this has occurred in Dry Creek. As a result, Dry Creek developed the pooled and terraced channel morphology typical of a calcified creek (Lorax Environmental Services, 2019; Figure 2-8). The high levels of calcite in Dry Creek had likely reduced WCT spawning for some time prior to the period of Reduced Recruitment (Hocking, Cloutier, et al., 2022). In contrast, only low levels of calcite have been documented in the Harmer Creek mainstem, and they have had little influence on spawning suitability. Calcite impacts on benthic invertebrate habitat may also have reduced food availability in Dry Creek relative to pre-development (Wiebe et al., 2022a).

Assuming that prior to the period of development Dry Creek would have supported adult (i.e., reproductively mature) WCT to the Harmer Creek population in proportion to its length, which is about 23% of the length of the Harmer Creek population area, poor habitat quality in Dry Creek could have resulted in a proportionate loss in recruitment (i.e., approximately 23%) for the Harmer Creek population. The Grave Creek population area does not have an equivalent area to Dry Creek with impacted habitat.

In 1971, the Harmer Dam was constructed in lower Harmer Creek to create Harmer Creek Sedimentation Pond, thereby limiting downstream movement of fine sediment inputs from mining activities at EVO, and to comply with provincial water quality regulations. The dam is a barrier to upstream fish movement and affects habitat connectivity by isolating the Harmer Creek WCT population from the Grave Creek population (Chapter 3). The creation of Harmer Creek Sedimentation Pond converted stream habitat to pond habitat. Similarly, construction of the Dry Creek Sedimentation

Pond converted stream to pond habitat. In addition, creating these sedimentation ponds facilitated changes in selenium speciation, which is discussed in the following section.

Constituents of Concern

For the period of development in the watershed, the most comprehensive record for constituents of concern is from water sampling (Warner & Lancaster, 2022). This record extends back to 1996 in the Harmer Creek Sedimentation Pond (HRM-R2) and 1991 in the Dry Creek Sedimentation Pond (DR-R2). These data show that concentrations of aqueous sulphate, TDS and selenium have been increasing since data collection began and were higher in the Dry Creek Sedimentation Pond than in the Harmer Creek Sedimentation Pond. In Dry Creek, concentrations of sulphate, TDS and selenium were sufficient to cause chronic effects on survival and development of the sensitive early life stages of WCT (Warner & Lancaster, 2022).

During the period of development in the watershed, the Harmer Creek mainstem was also influenced by mining related constituents through its tributary Dry Creek. However, concentrations were diluted in the mainstem and did not indicate the potential for chronic or acute effects from sulphate or TDS. In the mainstem, aqueous selenium concentrations were above BCWQG but below Elk Valley specific benchmarks (Warner & Lancaster, 2022).

Selenium, specifically organoselenium, is a bioaccumulative substance that disproportionately accumulates in biota relative to concentrations in water. The degree to which an increase in total aqueous selenium alone translates into higher organoselenium concentrations is uncertain because inter-annual differences in pond productivity are likely to cause year-to-year variability in organoselenium concentrations. Tissue selenium concentrations in fish or fish diet are better indicators of exposure than aqueous concentrations (see de Bruyn et al., 2022). Few fish muscle or benthic invertebrate (dietary) data are available for the Harmer Creek population area prior to 2020. However, the data that are available indicate that dietary selenium was high enough to have been able to cause reduced growth and reproductive effects in fish that were feeding in the lower reaches of Dry Creek or in the Harmer Creek Sedimentation Pond (de Bruyn et al., 2022). In contrast, the data that are available for this time period indicate that dietary and muscle concentrations were not high enough in the Harmer Creek mainstem to have caused adverse reproductive effects.

Changes in selenium speciation are relevant because they can result in increased bioaccumulation. It is likely that changes in selenium speciation have been enhanced due to the creation of the Harmer Creek and Dry Creek Sedimentation Ponds. Under conditions that favour algal growth and microbial activity (e.g., warm temperatures, low streamflow and high nutrient levels), selenium speciation in pond habitat changes, resulting in higher levels of bioavailable selenium (de Bruyn et al., 2022). However, the study of factors that affect selenium speciation in the Elk Valley is relatively new, and there are too few data prior to the period of Reduced Recruitment to further assess this potential effect of these sedimentation ponds.

6.3.3. Period of Reduced Recruitment (2017 to 2019) and Recruitment Failure (2018): What Was Different?

In this section, we identify stressors and conditions in the Harmer Creek population area that were different during the period of Reduced Recruitment in general or different in the 2018 spawn year specifically, when Recruitment Failure occurred. Recruitment status is defined relative to replacement, as described in Section 1.1. We do not have sufficient information on recruitment prior to 2017 to determine what the patterns were or how they related to stressor levels. Nevertheless, understanding temporal patterns is useful because stressors are more likely to be identified as contributors to Reduced Recruitment if they have generally worsened over time.

Reduced Recruitment (2017 to 2019)

No new stressors were introduced to the Harmer Creek population area during the period of Reduced Recruitment, but the magnitude and extent of some of the existing stressors changed or indicated an increasing trend. Specifically, aspects of the poor habitat quality in Dry Creek worsened and selenium concentrations in the Harmer Creek mainstem increased. The nature of those changes and the likelihood for them to have resulted in measurable changes in recruitment are discussed below. We also report WCT length data (Chapter 4; Thorley et al., 2022) because there are important differences in fish length between the Harmer Creek and Grave Creek populations.

Selenium in the Harmer Creek Mainstem

Data for selenium concentrations in water, sediment and tissue (muscle and dietary) were used to assess trends in exposure in the Harmer Creek population area. Most aqueous and sediment selenium data were collected in the Dry Creek and Harmer Creek Sedimentation Ponds (Warner & Lancaster, 2022; Wiebe et al., 2022b). We relied on aqueous data from Dry Creek and lower Harmer Creek to infer trends in selenium concentrations in the Harmer Creek mainstem. This was based on de Bruyn et al. (2022), who reported that selenium concentrations in Dry Creek are diluted below the confluence with the Harmer Creek mainstem but follow similar temporal patterns.

Concentrations of selenium have increased in recent years in both water and sediment. The concentrations of aqueous selenium in the Harmer Creek population area were about 10–20% higher in the 2017 and 2018 growing seasons than in years before and after. This magnitude of change in aqueous selenium, alone, was unlikely to have presented a material change in effects to fish. However, if the bioaccumulative form, organoselenium was present, the potential for effects on fish at these concentrations exists. We know that there was organoselenium in the Harmer Creek population area, but there is insufficient information to infer tissue concentrations in 2017 and 2019. The benthic invertebrate and fish tissue data from 2018 do not indicate a strong organoselenium signal that year but, as evidenced by the range of tissue concentrations in the 2021 data, it is possible that there were higher exposures in 2018 that were not captured in those monitoring data (de Bruyn et al., 2022). Based on 2 years of data (2013 and 2019), the concentration of selenium in sediment increased substantially in the Harmer Creek Sedimentation Pond. However, it is not clear if that increase was associated with inputs from upstream or with conditions in the pond itself (Wiebe et al., 2022b).

Dry Creek

Conditions described for Dry Creek during the period of development also apply to the period of Reduced Recruitment. Concentrations of aqueous sulphate, TDS and selenium in Dry Creek were sufficient to have been able to cause chronic effects on survival and development, particularly for fish living or feeding in lower Dry Creek (de Bruyn et al., 2022; Warner & Lancaster, 2022). Dissolved oxygen was also lowest in Dry Creek during this time and had the potential to negatively impact incubation if there were redds present (Abell et al., 2022).

In 2017, the maximum concentration of aqueous selenium was above the level 2 benchmark for reproduction in Dry Creek for the first time (Warner & Lancaster, 2022). We cannot preclude the possibility that there were increased adverse effects associated with these higher concentrations of selenium; however, as discussed in Warner & Lancaster (2022), increased adverse effects are considered unlikely, given the already high concentrations of aqueous selenium prior to 2017.

Based on calcite monitoring, the spawning suitability in Dry Creek was lowest during the period of Reduced Recruitment, with the highest calcite levels measured in 2017 and 2018 (Hocking, Cloutier, et al., 2022). However, given already low suitability prior to 2017 and the very low level of spawning activity in Dry Creek (Chapter 4), the decrease in spawning suitability would likely have had little additional effect. To the extent that an increase in calcite would further reduce the abundance of benthic invertebrates, food availability could have been reduced (Wiebe et al., 2022a). Hocking, Cloutier, et al. (2022) concluded that high levels of calcite in Dry Creek represented a chronic stressor to the Harmer Creek WCT population that may have reduced the reproductive output of fish attracted to Dry Creek to spawn, and, therefore, may have contributed to the observed Reduced Recruitment for the 2017 and 2018 spawning cohorts.

Selenium and calcite exposure in Dry Creek during and prior to the period of Reduced Recruitment likely had adverse effects on fish. Nonetheless, it is unlikely that the relatively small changes in direct exposure in Dry Creek would have resulted in meaningful changes in recruitment for the Harmer Creek population area from 2017 to 2019 compared to the period of development in the watershed, because recruitment in Dry Creek was likely already impacted (see Section 6.3.2).

Length of Age-0 Fish

Water temperature influences the duration of incubation and the length of the growing season, which in turn strongly influence the size of age-0 fish at the onset of their first winter (Coleman & Fausch, 2007 a, b). Age-0 WCT in the Harmer Creek population area, as shown in Figure 6-4, were shorter on October 1 than those in the Grave Creek population area for all years with data. The length of age-0 fish at the end of the growing season has a strong influence on the probability of a fish surviving through the winter (Huusko et al., 2007). Body size also governs the size of prey that a WCT can capture, as well as the potential for it to be preyed upon. Smaller WCT have a smaller gape or mouth size, which restricts their ability to consume large food items (Christensen, 1996; Mihalitsis, 2017). These smaller WCT are also potentially more susceptible to predation by conspecifics (Griffith, 1974; Rosenfeld, 2014).

Too few data are available to compare the length of fish over time in the Harmer Creek population. However, for all years with data, fish in the Harmer Creek population were shorter than fish in the Grave Creek population area where recruitment rates were higher (Figure 6-4).

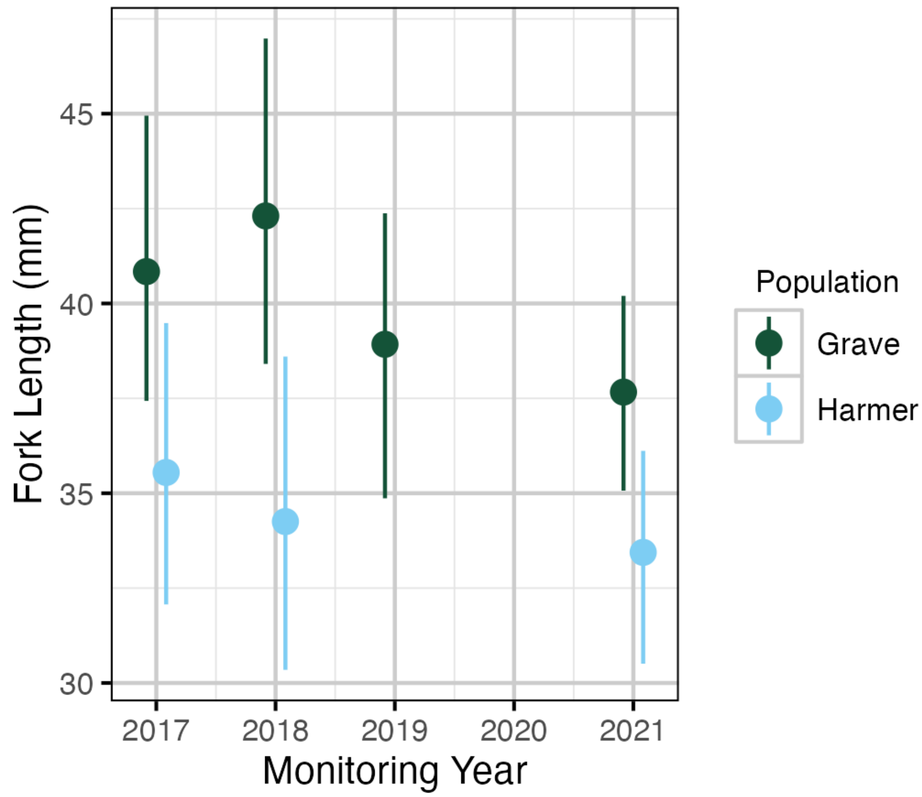


Figure 6-4. Estimated average fork length of age-0 fish on October 1 (end of growing season) by year and population.

Error bars represent 95% CIs. Source: Thorley et al. (2022)

Recruitment Failure

In this section, we consider data collected as part of the population monitoring programs that provide information about the physical status of each spawning cohort. We identify conditions that could have influenced recruitment in the Harmer Creek population area and that were different in magnitude and/or extent for the 2018 spawn year compared to the 2017 and 2019 spawning years when recruitment was higher. We also discuss, where relevant, conditions common to both the Grave and Harmer Creek population areas in 2018, because both had lower recruitment in 2018 than in other years.

Body Condition and Length

In the fall of 2018, the body condition of juvenile fish (65–169 mm) was lower than it was in the other years with data, in both the Harmer Creek and Grave Creek populations (Figure 6-5) (Thorley & Branton 2023; Wiebe et al., 2022a). Collecting data on age-0 fish is challenging because of difficulties in sampling (finding them) and because their small size causes measurement error when collecting weight data. Weight data are used to calculate body condition and, without it for age-0s, we assumed that the low body condition of larger juveniles measured in 2018 indicated lower age-0 body condition going into winter. Age-0 WCT in the Harmer Creek population area were also shorter in 2018 than in any other year, while in the Grave Creek population area they were longer (Figure 6-4). Lower body condition and shorter lengths indicate lower energy reserves, which influence overwintering survival. Fish with more energy reserves (e.g., higher body condition and longer lengths) have better survival than fish with lower reserves, all else being equal (Biro et al., 2004). The relationship between energy and egg to age-1 survival is discussed in detail in Section 6.4 and in Thorley and Branton (2023).

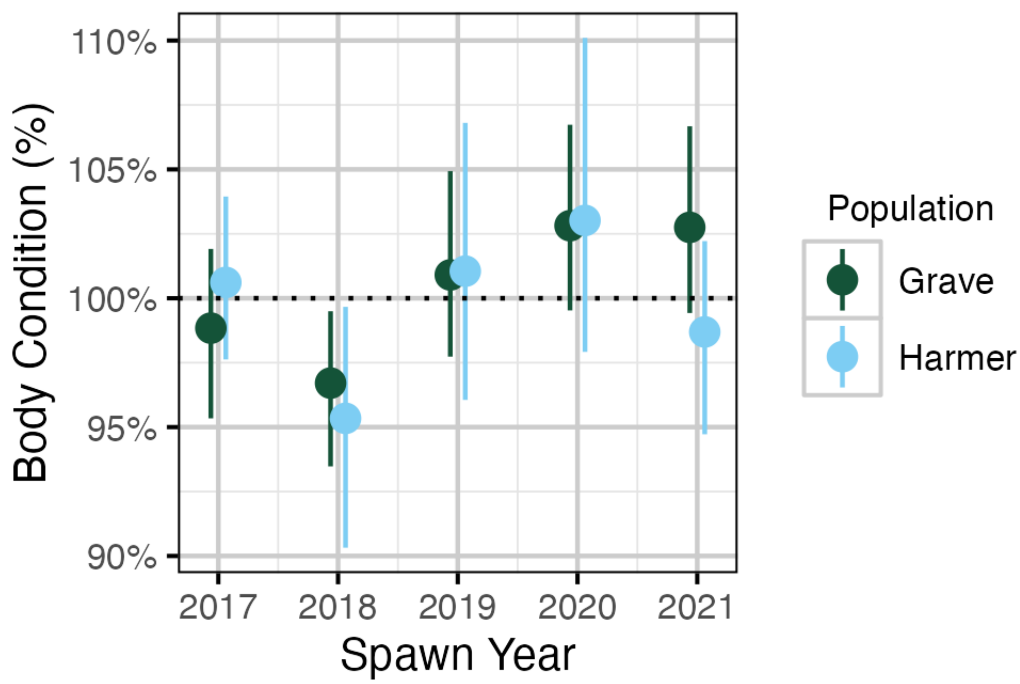


Figure 6-5. The estimated juvenile body condition as the percent difference in body mass on October 1 relative to a typical year, by year and population

Error bars represent 95% CIs. Source: Adapted from Thorley and Branton (2023).

Winter Conditions

Several aspects of winter were different in 2018/2019 compared to 2017/2018 and 2019/2020.

Air Temperature. The Elk Valley, including the Grave Creek watershed, had an anomalously cold period in February and March 2019 relative to the historical temperature record and, specifically, compared with the winters of 2017/2018 and 2019/2020. Hocking, Whelan & Hatfield (2022) characterized the drop in air temperature in February 2019 as remarkable for its magnitude and suddenness. Records from the nearby Environment Canada weather station at Sparwood show that this was the second-most sudden and severe weather transition since 1980. It was preceded by unseasonably warm temperatures and was followed by a period of sustained cold through early March. Daily maximum air temperatures did not exceed 0°C until mid-March. In comparison, air temperatures in February 2018 were similarly cold, but these temperatures occurred for days rather than weeks, and warmer temperatures — around the long-term median — returned between the intense cold periods (Hocking, Whelan & Hatfield, 2022).

Snowpack. In February 2019, snow water equivalents (SWE; a measure of the snowpack based on weight of accumulated snow) were the lowest in the historical data set from 1983 to 2020. Other recent years were within the 25–75th percentile range, although, for a period in January and February 2017, there was also an unusually low SWE. The low SWE conditions occurred on the same dates as the abnormally cold air temperatures, suggesting there was little snow cover on the surface ice to act as a buffer to air temperatures, which would have allowed for more rapid cooling of stream water during periods of especially cold weather (see Hocking, Whelan & Hatfield, 2022).

Streamflow. Streamflow data indicated that 2018/2019 was a low water year in this region, with persistent winter low flow relative to other years recorded at stations in the Grave Creek watershed and at other nearby reference streams (Wright et al., 2022). Wright et al. (2022) inferred that low flows could have negatively affected the quantity and quality of fish habitat.

Ice. While several cold periods were observed in the record, the conditions for ice formation during February 2019 were severe and rare (Hocking, Whelan & Hatfield, 2022; Appendix C). It is hypothesized that an unusually cold period in February and March combined with preceding warm conditions, a low snowpack and lower than usual river flows, led to ice conditions that were different during the winter of 2018/2019.

The middle section of Harmer Creek (HRM-R4) was characterized as typically having stable surface ice (Cope & Cope, 2020). This is likely the optimal winter habitat condition when compared to open water or frazil and anchor ice (see Section 6.4). The longer than usual warm period during the winter of 2018/2019, followed by intense and suddenly cold air temperatures was less likely to have provided conditions for stable surface ice than in other years. It is possible that there was more open water prior to the cold snap in February and more frazil and anchor ice produced during the cold snap than in other years (Appendix C). Open water conditions and frazil and anchor ice formation could have led to fish using more energy, which could have then led to starvation prior to the end of winter. These conditions could also have led to increased predation due to crowding or movement to areas without sufficient cover refuge. And severe ice conditions could have caused fish mortality directly through injury, crushing and/or freezing.

Winter conditions would have been broadly similar in both the Harmer Creek and Grave Creek population areas in 2018/2019. Grave Creek above the confluence with Harmer Creek has been characterized as typically having stable surface ice (Cope & Cope, 2020). But if ice did not form as usual in the early part of winter of 2018/2019, as discussed above, fish may have used more energy and/or been subject to more direct mortality from ice than in other years. Ice conditions may, therefore, have played a role in the Reduced Recruitment in the Grave Creek population and the Recruitment Failure in the Harmer Creek population. While there were no observations of fish or of ice conditions within the Grave Creek watershed during this period, inferences from available data indicate that conditions may have caused fish mortality and may have reduced individuals' ability to cope with other natural or anthropogenic stressors (Hocking, Whelan & Hatfield, 2022).

A desktop study was conducted to evaluate the potential mechanisms governing ice formation in Harmer Creek (MacDonald et al., 2022; Appendix C). It focused on understanding what the potential timing and distribution of ice cover might have been like in 2018/2019. The uppermost reach of Harmer Creek (HRM-R6) is groundwater dominated. That influence continues below the confluence with Dry Creek, but it diminishes in a downstream direction to the bottom of HRM-R3, just above the Harmer Creek Sedimentation Pond where groundwater makes up a lower proportion of total streamflow. It is important to consider that the influence of atmospheric conditions on stream temperature and ice formation increases as the proportion of groundwater to total streamflow decreases. Therefore, extreme atmospheric conditions like those observed in the winter of 2019 likely did result in the development of frazil and subsequent anchor and surface ice that could have begun farther upstream in the Harmer Creek mainstem relative to years with more moderate conditions.

6.4. MECHANISMS THAT COULD HAVE LED TO THE OBSERVED RECRUITMENT PATTERNS

This section explores how recruitment patterns for the 2017, 2018 and 2019 spawning cohorts could have occurred. Most of the causal pathways identified as likely contributing to the recruitment patterns in the Harmer Creek population area influence energy accumulation and/or depletion. Energy for age-0 fish comes initially from the yolk sac and then, after swim-up, from food intake. This energy fuels basal metabolism and activity (e.g., foraging) in the growing season. When there is surplus energy, it is allocated to growth. Fish first allocate energy to growing longer, which reduces their chances of gape-limited predation (Biro et al., 2005). Then, prior to winter, they also allocate energy to lipid storage (Giacomini & Shuter, 2013; Biro et al., 2021). If fish have less surplus energy during the growing season, they may have less lipid stores going into winter. Salmonids continue to feed in winter, but the efficiency with which they acquire and digest food is reduced in cold water (Cunjak et al., 1987; Elliot, 1972; Finstad et al., 2004; Watz & Piccolo, 2011). The energy they require in winter for basal metabolism and movement therefore comes primarily from stored lipids (Cunjak & Power, 1987). As a result, stored lipids are critical to overwintering survival (Biro et al., 2004, 2021; Berg et al., 2011).

In addition to energy-related causal pathways, we identified pathways that are related to direct mortality and which can also lead to Reduced Recruitment. A representation of the relationships between stressors, energy and or/egg to age-1 survival is provided in Figure 6-6. These relationships are summarized in Table 6-1 and discussed in the subsections that follow. Each subsection relates to a labelled arrow in Figure 6-6.

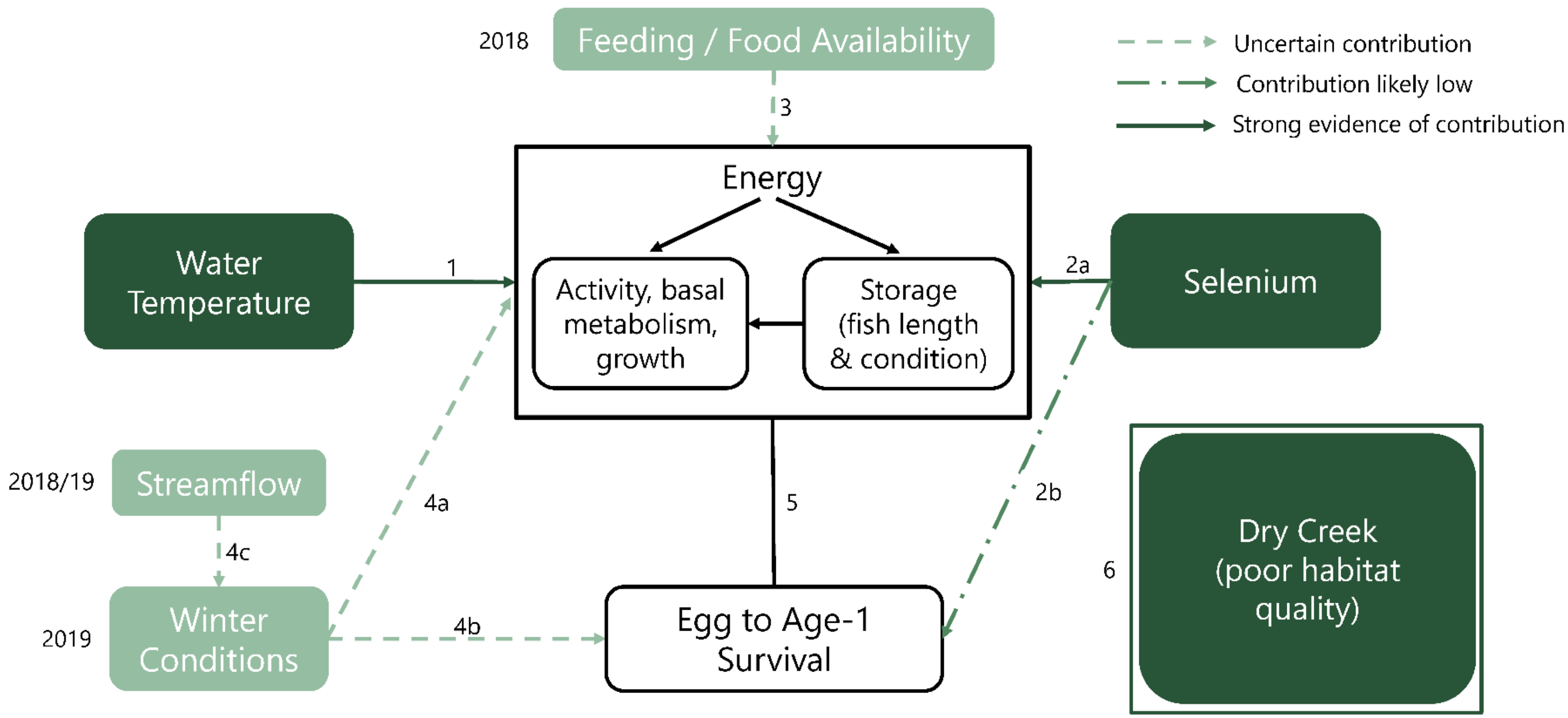


Figure 6-6. Representation of relationships between stressors that may have contributed to Reduced Recruitment and/or Recruitment Failure

A brief description of each pathway to energy or to egg to age-1 survival is provided in Table 6-1. Stressors in the dark green boxes would have contributed to Reduced Recruitment in all years. Stressors in the light green boxes were identified as potentially contributing to Recruitment Failure in 2018.

Table 6-1. Summary of mechanisms related to each numbered Pathway in Figure 6-6 and described in Section 6.4.1

	Mechanism
1	**Water Temperature** Fish grow bigger (longer, fatter/heavier) when growing season is longer and water temperatures are warmer (but below the lethal temperatures). Bigger fish have more energy stores and more efficient metabolism. Water temperature in any season affects fish metabolism (metabolism is higher with warmer temperatures). Seasonal changes between growing season temperatures and cooler fall and winter temperatures trigger physiological changes that are energetically costly, resulting in higher mortality rates during these temperature and physiology transitions.
2	**Selenium** **2a.** Reduction in growth rate of fry (age-0) is associated with dietary exposure to selenium. **2b.** Increased embryo-larval deformity and/or mortality are associated with maternal transfer (ovary/egg) of selenium.
3	**Feeding/Food** The food availability SME report concluded that there is no evidence of reduced food availability during the period of Reduced Recruitment in Harmer Creek, and there is no other information related to food or feeding available. However, data were limited, and food consumption is expected to be an important determinant of total energy intake for fish. Feeding/food availability is therefore shown in this figure. If fish have to increase foraging movements because food availability is low, food quality is poor, and/or there are issues associated with assimilation of nutrients, they may use more energy and/or be more exposed to predation.
4	**Winter Conditions and Streamflow** Conditions in winter 2018/2019 did not favour formation of early stable surface ice, and more extensive frazil and anchor ice were possible in February to March 2019 relative to

	Mechanism
	other years. However, there were no measurements of ice during that period, so the specific conditions are unknown and the implications for fish recruitment are therefore uncertain. **4a.** Frazil and anchor ice formation may lead to higher than usual energy usage through various mechanisms, for example fish movement, to avoid ice, stress associated with gill function in the presence of frazil ice or fish movement to avoid crowding if habitat availability is lower due to ice. **4b.** Ice may impact overwintering survival of age-0 fish directly if they suffocate (frazil ice) or get entombed (anchor ice). **4c.** Lower than usual winter streamflow, as occurred in 2018/2019, can act cumulatively with winter conditions (ice) to reduce habitat availability, potentially leading to increased crowding and predation.
5	**Energy Depletion** If fish have insufficient energy from feeding or energy stores (lipids and structural tissue) to support basal metabolism, starvation and mortality will occur. This is most likely to occur during the overwintering period when fish rely almost exclusively on stored energy.
6	**Dry Creek** Several stressors (e.g., water quality, calcite) are present in Dry Creek at higher levels than in the rest of Harmer Creek. These conditions likely resulted in very low or no recruitment in Dry Creek itself, even prior to and during the period of Reduced Recruitment. To the extent conditions were worse during the period of Reduced Recruitment, they would likely have had little additional effect on recruitment patterns in the Harmer Creek population.

6.4.1. Water Temperature

Fish grow bigger (longer, heavier) when the growing season is longer and water temperatures are warmer, i.e., when the GSDD is higher. The probability of age-0 trout surviving winter is strongly influenced by their length at the end of the growing season (Huusko et al., 2007) and by their lipid content (Biro et al., 2004, 2021; Berg et al., 2011).

Based on laboratory and field studies, Coleman & Fausch (2007a) wrote that their "data suggest that Cutthroat Trout fry need to reach a minimum of 30–35 mm (total length [28–33 mm fork length]) by the onset of winter to allow recruitment to age-1 in temperature regimes like those of the streams we studied in the southern Rocky Mountains." This specific size threshold may differ somewhat in the Grave Creek watershed; however, we expect the general relationship of size-dependent overwintering survival to be similar. Assuming the general relationship holds, Figure 6-4 shows that the age-0 fish in the Harmer Creek population are consistently shorter than those in the Grave Creek population, as would be predicted by the lower GSDD (Hocking, Whelan & Hatfield, 2022). Age-0 WCT in the Harmer Creek population area are, on average, very close to the threshold for survival identified by Coleman and Fausch (2007a, 2007b). Consequently, they are likely more susceptible to overwintering mortality than the larger age-0s, such as those in the Grave Creek population area.

Low water temperatures in winter can also induce physiological stresses in fish, likely because cold temperatures alter metabolic rates and cellular processes at a time when fish are reliant on energy stores (de Bruyn et al., 2022). The transition to the drop in water temperature is physiologically taxing, and a spike in mortality of age-0 trout has been observed at the start of winter (Cunjak et al., 1987; Coleman & Fausch, 2007 b). This is likely because fish energy depletion is greater during fall when water temperature and day length decline rapidly than it is later in the winter when low temperatures have stabilized (Cunjak et al., 1987; Metcalfe & Thorpe, 1992; Handy, 1997; Koljonen et al., 2012; see also de Bruyn et al. 2022).

6.4.2. Selenium

There are several causal pathways by which exposure to selenium could plausibly impact recruitment. Two of these were identified as potentially contributing to the recruitment patterns in the Harmer Creek population (de Bruyn et al., 2022): dietary exposure resulting in reduced growth and maternal exposure resulting in increased embryo-larval deformity and/or mortality. To assess these two pathways, we relied on measured selenium concentrations in biota from (1) data collected during the period of Reduced Recruitment (2017 to 2019) and (2) extensive data collected in 2021. It is uncertain how representative the 2021 selenium concentrations are for the period of Reduced Recruitment (de Bruyn et al., 2022). Nevertheless, the 2021 concentrations of selenium, which were higher than those measured in 2018, were included in the assessment to capture the upper range of exposure concentrations that have been measured.

Growth. Once yolk sacs are depleted, age-0 fish rely on ingested food to grow and develop. If selenium in dietary items is present above concentrations required for normal growth, it can cause reduced growth and survival (Hamilton et al., 1990; de Bruyn et al., 2022) by causing oxidative stress and altered lipid metabolism (Knight et al., 2016; Berntssen et al., 2017; de Bruyn et al., 2022). The available data indicate a potential effect of dietary selenium on fry growth as a mechanism by which selenium could have contributed to Reduced Recruitment in the Harmer Creek WCT population (de Bruyn et al., 2022). The effect of exposure to dietary selenium on growth was estimated to be 5 to 10%, based on data from the period of Reduced Recruitment and to be 14 to 20% based on data collected in 2021. A reduction in growth of less than 10% would not usually be interpreted as indicating a potential for population-level changes (US EPA,1999, 2013; Suter et al., 1995; Mebane, 2010). However, in the context of the length of age-0 WCT in the Harmer Creek population area (Figure 6-4), a small reduction in length associated with selenium could have a disproportionate effect on recruitment if many fish are close to the size threshold for overwintering survival.

Embryo-larval toxicity. Selenium toxicity via maternal transfer (from mother to egg) is the second causal pathway by which exposure to selenium could plausibly impact recruitment (de Bruyn et al., 2022). Observed effects that are associated with egg/ovary concentrations of selenium include embryo-larval mortality, teratogenesis and larval edema (Nautilus and Interior Reforestation, 2011; Covington et al., 2018).

Selenium concentrations in WCT and benthic invertebrates are higher in lower Dry Creek and the Harmer Creek Sedimentation Pond compared to elsewhere in the watershed, resulting in modelled effects of greater than 50% on embryo-larval survival in these areas for all years (de Bruyn et al., 2022). Thorley and Branton (2023) evaluated these localized exposures to estimate how they could have contributed to the Reduced Recruitment in the Harmer Creek population. They estimated that if no adults were exposed to dietary selenium in Dry Creek (using 2021[25] exposure data), it would have reduced the difference in recruitment between the Harmer Creek and Grave Creek populations by 4%. This finding is consistent with the relatively small area of elevated tissue selenium concentrations associated with the Dry Creek Sedimentation Pond. In the Harmer Creek mainstem, selenium concentrations in WCT and benthic invertebrates were lower than the EC10[26] for embryo-larval toxicity between 2012 and 2020 (based primarily on data from HRM-R3), resulting in an average modelled effect of less than 1% on embryo-larval survival. In 2021, they were near (HRM-R5 and -R4) or higher than

[25] 2021 was the year with the highest selenium tissue concentrations in the Harmer Creek mainstem (de Bruyn et al., 2022).

[26] The EC10 is the concentration at which 10% of the individuals tested show effects.

(HRM-R3) the EC10 for embryo-larval toxicity resulting in an average modelled effect of 28% on embryo-larval survival. These two outcomes are expected to bound the range of possible embryo-larval effects that occurred in most parts of the watershed during the period of Reduced Recruitment, with the former (<1%) more consistent with available data.

6.4.3. Food/Feeding

Food consumption, which is the primary source of energy intake, is an important determinant of growth for fish (Railsback & Rose, 1999). A prolonged period of reduced caloric energy intake may result in starvation. During such a period of reduced caloric energy intake, the energy obtained from food is less than the amount of energy required to carry out basic biological processes and, in extreme cases, maintain life (Wiebe et al., 2022a). In addition to food having a direct effect on fish via energy, it can have indirect effects. If fish spend more time foraging due to factors such as low visibility, low food availability, poor food quality and/or issues associated with assimilation of nutrition, they may use more energy and/or be more vulnerable to predation than when they forage less (Biro et al., 2005; Finstad et al., 2010). Competition between individuals and subsequent local reductions in food quantity can lead to greater predation risk for smaller fish (i.e., they may need to spend more time in areas where they are more likely to be detected and eaten by larger fish), and this is considered to be one of the primary factors limiting the abundance of trout populations (van Poorten et al., 2018).

There were limited data available to assess feeding and food availability. Based on available data, there was no evidence of reduced food availability during the period of Reduced Recruitment in the Harmer Creek population area (Wiebe et al., 2022a), and there is no other direct information available related to food or feeding during this period. However, we cannot rule out the possibility of a food-related influence (including feeding or assimilation) on available energy for age-0 fish. We do, however, have indirect indicators that age-0 fish in the Harmer Creek population had little surplus energy to allocate to growth. In the 2018 spawn year, fish were shorter (Figure 6-4) and were assumed to have a lower body condition[27] (Figure 6-5) than fish in other years, resulting in the modelled energy stores being lower (Thorley & Branton, 2023).

[27] Weight data is used to calculate body condition and, without it for age-0s, we assumed that the measured low body condition of juvenile and adult fish in 2018 also suggested lower age-0 body condition (Section 6.3.3).

6.4.4. Winter Conditions and Streamflow

Open water, stable surface ice, frazil ice and anchor ice have different implications for fish. Under surface ice, fish lose less energy than they lose under open water winter conditions (Finstad, 2004), because they are provided cover by the ice, and conditions tend to be more hydraulically stable, which allow increased food consumption and a lower metabolic expenditure. Movement in winter is energetically costly to fish. Frazil and anchor ice often require fish to move to different locations (as reviewed in Hocking, Whelan & Hatfield, 2022). Fish are also known to move in response to ice intruding into their overwintering location (e.g., Roussell et al., 2004; Whalen et al., 1999), which can also lead to fish crowding into fewer areas. Whether this displacement occurs in response to ice or crowding or both, energy expenditure would occur at a time when fish are trying to conserve energy, or when they are weaker and more susceptible to other stressors. Frazil and anchor ice can also impact water velocity, reduce available habitat and limit access to interstitial cover (Hocking, Whelan & Hatfield, 2022; Appendix C).

An unusually cold period in February and March, combined with preceding warm conditions, a low snowpack and lower than usual river flows, led to ice conditions that were different during the winter of 2018/2019 (Hocking, Whelan & Hatfield, 2022; Appendix C, this report). These conditions could have led to greater energy use for fish in both the Harmer Creek and Grave Creek populations, not only during open water conditions but also while frazil and anchor ice were forming. And this could have led to higher mortality from starvation or predation (Hocking, Whelan & Hatfield, 2022). Adult abundance was seemingly unaffected, which could indicate that fish displacement did not occur or that adults and fry may have been impacted differently. Lower than usual winter streamflow, as occurred in 2018/2019, can act cumulatively with winter conditions (ice) to reduce habitat availability, potentially leading to increased crowding and predation.

Ice could also have physically entombed fish, particularly in shallow areas in the stream margins where smaller fish are more likely to take refuge. Fish could have been injured directly and suffocated due to frazil ice. Examples of frazil and surface ice accumulations intruding into as much as 80% of a stream cross-section or a deep pool were provided by Cunjak et al. (1998).

6.4.5. Dry Creek Habitat Quality

Several stressors were either different in Dry Creek or present in Dry Creek at higher levels than in the rest of the Harmer Creek population area. These stressors include:

- Concentrations of sulphate, TDS and selenium above benchmarks for adverse chronic effects to early life stages
- Concentrations of DO below thresholds required for incubation, and
- Substrate with low spawning suitability due to calcification (see Section 5.2.1).

These stressors were documented at levels sufficient to have caused adverse chronic effects, such as toxicity and reduced spawning suitability, for many years prior to the period of Reduced Recruitment (e.g., Hocking, Cloutier, et al., 2022; Warner & Lancaster, 2022). Therefore, although the concentrations of aqueous selenium and the levels of calcite in Dry Creek were higher in 2017 and 2018 than in previous years, given the already poor water quality and concretion in Dry Creek they would likely have had little additional effect on fish over the period of Reduced Recruitment. However, to the extent that the Harmer Creek population is smaller due to the loss of recruitment in Dry Creek, it would have had implications for the overall productivity of the population.

The available data indicate that the concentration of dietary selenium was high enough to have been able to cause reproductive effects in fish feeding in Dry Creek (de Bruyn et al., 2022). Considering embryo-larval survival in Dry Creek, Thorley and Branton (2023) estimated that maternal exposure to selenium could explain 4% (1.8% – 11% 95% CI) of the difference in recruitment between the Harmer Creek and Grave Creek populations.

6.4.6. Energetic Status

Energetic status, defined here as the ratio of relative energy stores to relative metabolic requirements, of age-0 WCT is a primary determinant of overwintering survival (e.g., Biro et al., 2004). Thorley and Branton (2023) used an energetic model to estimate the proportion of the Reduced Recruitment and Recruitment Failure in the Harmer Creek WCT population that could be explained by the energetic status of age-0 WCT at the onset of winter. They estimated energetic status from length, body condition and the scaling of standard metabolic rate to the size observed in salmonids. They then estimated the relationship between energetic status and recruitment (egg to age-1 survival rate) and used the resultant relationship to predict how the recruitment would have changed if factors that influence energetic status were the same in both populations in all years. The factors considered were length, body condition, energy, GSDD and selenium. Growing season degree days and selenium act on length and length and body condition influence energetic status. For Reduced Recruitment (2017 to 2019), the amount of the difference in recruitment between the Harmer Creek population and the Grave Creek population explained by each factor was estimated. For

Recruitment Failure, the amount of the difference in recruitment between 2018 compared to 2017 and 2019 in the Harmer Creek population explained by each factor was estimated.

The model makes a number of key assumptions including that (1) dietary selenium has the same effect on age-0 WCT as has been observed in a study on age-0 Chinook Salmon, (2) the effect of selenium on length occurs solely via the dietary pathway, (3) selenium only affects energetic status via the length and (4) age-1 condition is a representative proxy of age-0 condition. The model does not include other stressors (e.g., physical impact of ice) that could increase direct mortality and which may explain some of the remaining variation in the egg to age-1 survival. Although the model does not explicitly include other stressors that could affect energy inputs or outputs such as food consumption, predator avoidance and ice avoidance, these potential causal pathways are captured in the model in a general sense. The reason is the model estimates the relationship between the energetic status at the onset of winter and the survival from egg to age-1, as opposed to just estimating the overwintering survival. For more information on these and other assumptions see Thorley and Branton (2023) and de Bruyn et al. (2022).

Model estimates are provided below for how much the recruitment patterns can be explained by each factor one at a time[28].

- For the Reduced Recruitment pattern observed over the 2017 to 2019 period, GSDD explains[29] ~36% (5–58%, 95% CI) of the difference in egg to age-1 survival between the Harmer Creek and Grave Creek populations. Dietary selenium was estimated to explain ~7% (2–14%, 95% CI) of the difference. Energy, driven solely by length, was estimated to explain ~66% (29–87%, 95% CI).
- For the Recruitment Failure, GSDD and dietary selenium were estimated to be at similar levels in 2018 as they were in 2017 and 2019 in the Harmer Creek population area. As a result, they did not explain the difference in egg to age-1 survival between those years. However, the age-0 fish from the 2018 spawning cohort were shorter and had lower body condition (Figure 6-5) at the onset of winter than those from the 2017 and 2019 spawning cohorts, meaning that they were skinnier for

[28] Each of the stressors were evaluated independently, as were body condition, fish length and energy. However, most of these are inter-related, and energy captures several inputs at once. For example, while differences in energy reserves can explain 66% of the difference in recruitment between the Harmer Creek and Grave Creek populations for 2017 to 2019, energy is driven by both condition and length, and length is driven by both GSDD and selenium. Unknown factors also influence both body condition and length.

[29] That is, if the GSDD is the same in both population areas in all years, the modelled difference in recruitment between the two populations for this period decreases by 36% (5–58%, 95% CI%).

their length. Body condition alone was estimated to explain ~58% (43–78%, 95% CI) of the difference in recruitment rates in 2018 compared to 2017 and 2019 and, together with length, measured as energy, it explained ~92% (78–97%, 95% CI) of the difference in egg to age-1 survival. The remaining variation for both Reduced Recruitment and Recruitment Failure could be explained by other stressors including those that may also affect the energy pathway (e.g., increased movement due to ice; effects of selenium on lipid metabolism). These were not evaluated because relationships between quantitative exposure and energy use have not been established.

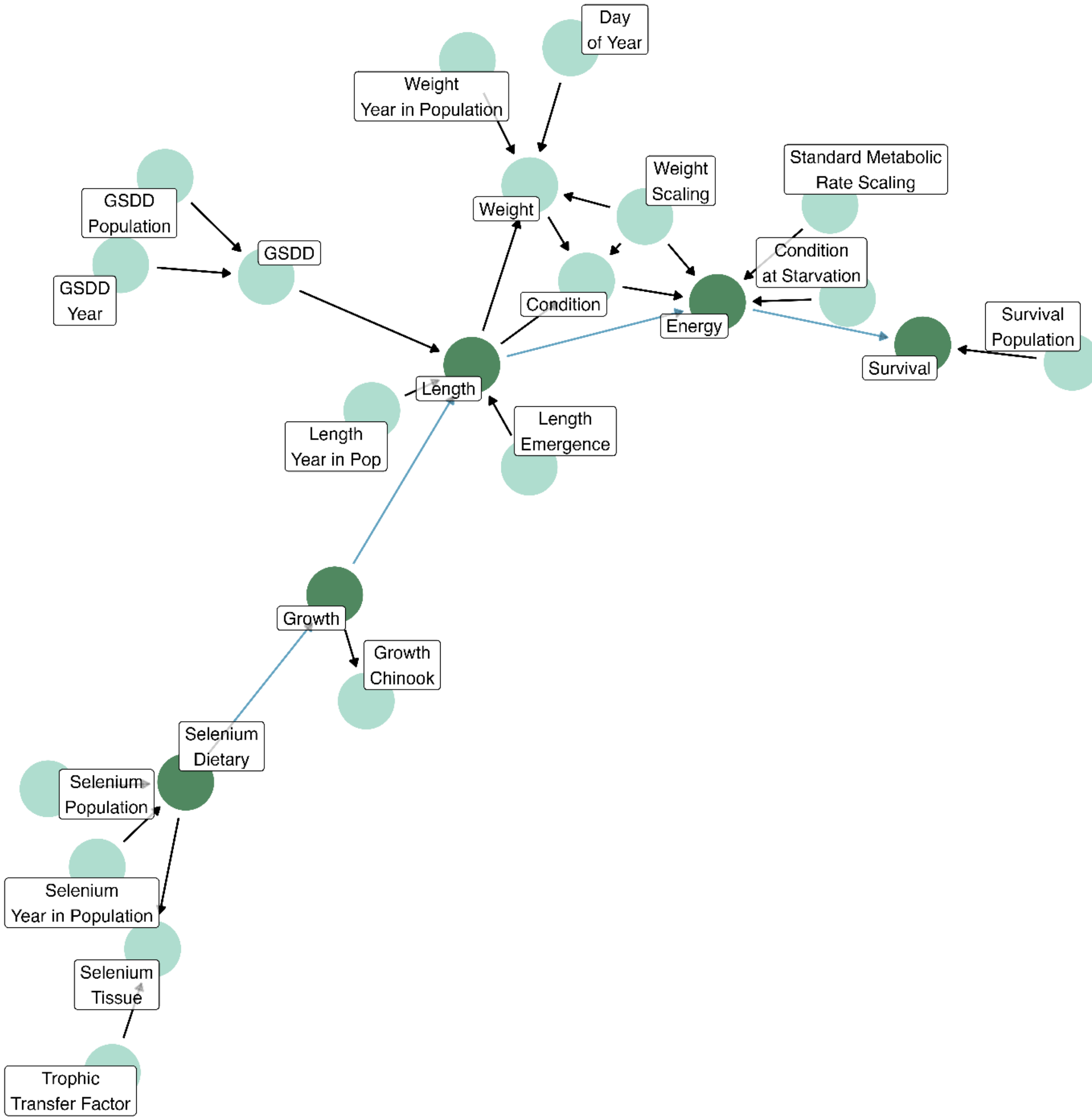


Figure 6-7. Depiction of the statistical model used in the assessment of energetic status.

The dark green circles represent one of the pathways evaluated in the model; the light green circles represent other factors that are included in the model.
Source: Thorley and Branton, 2023

6.5. PUTTING IT ALL TOGETHER

Reduced Recruitment for the 2017 to 2019 spawning cohorts. Low GSDD, exposure to selenium and Dry Creek habitat conditions were the primary stressors identified by the Evaluation of Cause Team as contributing to Reduced Recruitment from 2017 to 2019 in the Harmer Creek population. Because age-0 WCT in the Harmer Creek population were small, they were susceptible to overwintering mortality. Their small size was likely related in part to factors intrinsic to the population area, such as low GSDD due to the short growing season and low water temperature (Hocking, Whelan & Hatfield, 2022), and in part to reduced growth due to selenium exposure (de Bruyn et al., 2022). Based on modelling that estimated recruitment with different levels of these stressors, both of which can affect the energetic pathway, GSDD was found to have had a larger effect on recruitment than selenium exposure had, but both were at levels that could have contributed to reduced growth in fish in their first growing season. Because fish in the Harmer Creek population are intrinsically small, a relatively small reduction in length associated with selenium could have a disproportionate effect on recruitment.

The potential contribution of habitat conditions in Dry Creek itself was also evaluated. Water and habitat quality in Dry Creek deteriorated during the period of development. This largely precluded spawning due to calcite formation in the substrate, and concentrations of sulphate and selenium have been sufficient to affect early life stage development and survival since at least 2010. A lack of reproduction in Dry Creek has likely reduced the size of the Harmer Creek population. The available data indicate that dietary selenium was high enough to have been able to cause reproductive effects in fish that were feeding in Dry Creek. While there are no data to indicate how many adult fish may have been exposed to selenium in Dry Creek, a conservative estimate was that this would explain about 4% of the difference in recruitment between the Harmer Creek and Grave Creek populations.

Recruitment Failure in 2018 spawning cohort. In the Harmer Creek population area, GSDD, selenium and Dry Creek habitat conditions were similar in 2018 compared to 2017 and 2019. Therefore, while they likely acted on recruitment as described above, they did not explain the Recruitment Failure. The Evaluation of Cause Team hypothesizes that Recruitment Failure for the 2018 spawning cohort was related to (1) lower body condition and shorter body length of age-0 fish in fall 2018, which indicate low energy reserves entering the 2018/2019 winter, and (2) challenging winter conditions in winter 2018/2019 that could have resulted in increased energy use and/or direct mortality due to ice-related effects. We do not have direct evidence that explains why fish were shorter in the Harmer Creek population in 2018 than other years, or why body condition was low in 2018 in both the Harmer Creek and Grave Creek populations, but we believe it could be related to factors that reduced energy intake and/or energy assimilation in the summer of 2018.

6.6. MANAGEMENT RESPONSE AND THE WAY FORWARD

Work on the Evaluation of Cause spanned a two-year period, from the fall of 2020 to the fall of 2022. Over that time, several projects were ongoing to understand and improve conditions within the watershed. These included, for example, studies related to Dry Creek Sedimentation Pond removal and improvements in monitoring water quality, water temperature and fish population status. In addition, some key data gaps identified in the Evaluation of Cause process were addressed in ongoing studies. As a result, the recruitment patterns that led to the Evaluation of Cause and the results of the Evaluation of Cause's analyses have already resulted in changes to monitoring of water quality, fish populations, sediments and benthic invertebrates.

The Evaluation of Cause identified gaps and opportunities for improvement in monitoring programs that were addressed in real time by Teck Coal's contractors and consultants. Examples are:

- Teck Coal worked with the KNC and agencies to update the approach to fish monitoring (Thorley et al., 2022), which will improve the quality of information used to manage these fish populations. Significant changes to the fish monitoring program include changes to fish sampling methods and temperature monitoring.
- Starting in 2021, additional sampling areas in Dry, Harmer and Grave Creeks were added to the Regional Aquatic Effects Monitoring Program to address gaps in our understanding of selenium speciation and concentrations in water, sediment and tissues of benthic invertebrates and fish. In addition, intensive sampling was undertaken in Dry Creek and Harmer Creek Sedimentation Ponds under the Elk Valley Selenium Speciation Monitoring Program to investigate the seasonality of selenium speciation changes, the spatial extent of those changes and the mechanisms underlying those changes.

In both examples, the Evaluation of Cause Team used the additional data generated to develop the findings presented herein.

Looking into the future of this watershed, our understanding is that Teck Coal is working with the KNC and agencies to develop fish recovery actions to promote the long-term viability of this WCT population. This includes:

- Developing recovery actions which include improvements to fish habitat
- Restoring stream connectivity, specifically sedimentation pond deconstruction in Harmer Creek
- Reducing the potential for speciation changes that enhance bioavailability, specifically via sedimentation pond bypass and/or removal (both Dry Creek and Harmer Creek)
- Enhancing monitoring programs for fish populations, selenium speciation, water temperature and effects monitoring to address gaps identified throughout the Evaluation of Cause process
- Re-evaluating mine plans and mitigation options, which includes water management and treatment considerations.

Glossary

Term	Description
adfluvial-migratory	WCT populations that migrate between spawning/rearing tributaries and adult-rearing lakes
accumulated thermal unit	used to track the cumulative effect of temperature on fish over time
acute toxicity	the adverse effects of a substance on an organism that result from either a single exposure or from multiple exposures in a short period of time
age-0	fish are considered to be age-0 when they emerge from the gravels to December 31 of their first calendar year (see also alevin, fry)
age-1	fish become age-1 approximately 4 months after they emerge from the gravels, on January 1 of their second calendar year (see also juvenile)
age-2+	fish are considered age-2+ from January 1 of their third calendar year until maturity, this age-class includes multiple cohorts (see also juvenile)
adult	maturity until death due to senescence
age-length	the relationship between the age and length of fish
alert concentration	"a concentration below the guideline but above which there may be a risk to some environments and/or species that are particularly sensitive to selenium bioaccumulation. If alert concentrations are exceeded, a series of actions may be triggered to evaluate whether impacts may be occurring and if necessary, mitigate the effects of selenium" (Beatty & Russo, 2014)
alevin	a newly spawned salmon or trout still carrying the yolk
allele	a variant form of a gene
allelic richness	a measure of genetic diversity that indicates a population's long-term potential to adapt and persist; refers to the number of alleles

alluvial	relating to or composed of clay, silt, sand, gravel etc., deposited by running water
aquatic organisms / aquatic life	animals (invertebrates, amphibians, fish, birds, etc.) that live in or depend on an aquatic environment
ammonia	chemical compound made of nitrogen (N) and hydrogen (H), which has the formula NH_3
anchor ice	ice attached to the beds of streams, lakes and shallow seas
anoxic	greatly deficient in oxygen
anthropogenic	of, relating to, or resulting from the influence of human beings on nature
bankfull	the width of the stream that corresponds to the depth where water fills a main channel to the point of overflowing
baseline	current or existing conditions that serve as a reference point for comparing future conditions
bedrock	solid rock underlying unconsolidated surface materials
benchmark	a standard or point of reference against which things may be compared or evaluated
benthic invertebrates	small organisms that lack backbones, live in or on the sediments at the bottom of rivers, streams and lakes, and include the larvae of aquatic insects, as well as clams, snails, mussels, crayfish and various other kinds of aquatic worms
bioaccumulation	the build-up of substances, both toxic and benign, within the body tissues of an organism
bioconcentration	the process by which a chemical concentration in an aquatic organism exceeds that in water, as a result being exposed to a waterborne chemical
cadmium (Cd)	chemical element with atomic number 48

calcite	– a hard mineral that can form on streambeds and is the same as the build-up that forms in tea kettles or water heaters in homes with hard water – occurs naturally, but its formation can be accelerated by runoff water from mines – is not a human health concern, but excessive calcite build-up can change the characteristics of streambeds by cementing rocks together and affecting habitat for fish and invertebrates
calcite concretion	– a hard, compact mass of calcite formed by the precipitation of mineral cement within the spaces between particles – is found in sedimentary rock or soil – occurs naturally, but its formation can be accelerated by runoff water from mines
calcite index	– a numeric expression of the extent and degree of calcite formation – typically given as a range from 0 to 3
carrying capacity	the maximum number of individuals a habitat can sustain
cascade	a steep, usually small fall of water
causal effect pathway	– the causal linkage(s) between exposure to stressors and effects – the linkages may be specific physical, ecological or physiological mechanisms, or they may be conceptual
channel	the bed where a natural stream of water runs
channel migration	the geomorphological process that involves the lateral migration of an alluvial river channel across its floodplain
chronic toxicity	the adverse effects of a substance on an organism that result from long-term exposure
chrysene	a polycyclic aromatic hydrocarbon (see definition)
coal seam	a bed of coal occurring between layers of rock
compliance point	a water monitoring station immediately downstream from a Teck Coal mine operation in the Elk Valley
condition	a measure of fish health based on the ratio of fish weight to length

conditions (in the context of stressors and conditions)	– entities that can be identified as contributing to an adverse response – can be either natural or mine related
confidence/compatibility/credible interval (CI)	statistical terms which all generally refer to an interval which, if the model is correct, all other things being equal, has a 95% probability of including the true value
conspecifics	belonging to the same species
constituent	an element or ionic compound that may pose a threat to ecological or human health when present at sufficient concentrations
counter-ions	an ion having a charge opposite to that of the substance with which it is associated
culvert	a transverse drain
cumulative effects	changes to the environment caused by combinations of stressors with other past, present and future human actions (see also stressor interaction)
cyanobacteria	a division of microorganisms related to bacteria but capable of photosynthesis
dibenz(a,h)anthracene	a polycyclic aromatic hydrocarbon (see definition)
dissolved oxygen	the amount of oxygen present in water
early life stages	eggs and age-0 WCT
ecosystem	a community of organisms and its environment functioning as an ecological unit
electrofishing (also electro-shocking)	a common scientific survey method used to sample fish populations by using a direct electric current to temporarily immobilize fish
Elk River watershed	the area that includes the Elk River and all its tributaries
endemic (organism)	an organism that is restricted or peculiar to a locality or region
ephemeral stream	a temporary flow for a brief period as a direct result of precipitation
evaporation	the process of becoming vapour
fault(ed)	planar or gently curved fracture in the rocks of Earth's crust, where compressional or tensional forces cause relative displacement of the rocks on the opposite sides of the fracture

fecundity	– the number of eggs produced by a spawning female fish in a single year – is predicted by fish length and condition
floodplain	level land that may be submerged by floodwaters
fluorene	a polycyclic aromatic hydrocarbon (see definition)
fluvial	of or found in a river
fluvial-resident	headwater stream WCT populations that live above barriers and complete their life cycle within a very restricted distribution and remain relatively small (i.e., < 200 mm long) due to the cold, nutrient-poor nature of these small streams
fluvial-migratory	migratory WCT populations that move between small spawning/rearing tributaries and larger, more productive, adult-rearing rivers
fold(ed)	– in geology, undulation or waves in the stratified rocks of Earth's crust stratified rocks were originally formed from sediments deposited in flat horizontal sheets, but in some places the strata are no longer horizontal and have been warped into folds
fork length	the most common measure of the length of a trout (length from the snout to the fork in the tail)
fourth-order stream	– geomorphology and hydrology use stream order to indicate where in a watershed drainage system a certain stream segment lies – fourth-order streams are in the middle reaches of a watershed system
fragmented WCT population	a population of WCT for which downstream movement is possible but upstream movement is not possible for any life stage or at any flow
frazil ice	soft or amorphous ice formed by the accumulation of ice crystals in water that is too turbulent to freeze solid
freshet	the flood of a river caused by heavy rain or melted snow
fry	– age-0 fish that were just spawned – age-0 become age-1 fish in January of the year after they were spawned – fry are capable of feeding themselves but have not yet developed scales or fully formed fins

gape-limited predation	a morphological constraint where the size of prey a fish can eat is limited to the size of their body (e.g., mouth and throat)
gaining reach	a reach that receives water from groundwater, which adds to its overall surface flow
genera (singular: genus)	a group of animals or plants that share some characteristics in a larger biological group
genetically pure	without hybridization (see definition for hybridize)
geologic unit	a rock formation that is generally described by its age, lithology and thickness
glacial	of, relating to, or produced by glaciers
glide	a river or stream habitat type where the flow is characterized by slow-moving, nonturbulent flow
Grave Creek watershed	– a watershed that flows into the Elk River upstream of Sparwood, BC – the entire drainage area of 89.3 km^2 includes the Harmer Creek sub-watershed (30.3 km^2), which drains the Dry Creek sub-watershed (7.3 km^2)
growth	occurs when calorific intake exceeds the energetic demands and gamete production
growing season degree days	– the sum of mean daily temperatures (in Celsius) that are above a threshold to meet a milestone in fish development – the start of the growing season is the beginning of the first week that average stream temperatures exceed and remain above 5°C for the season – the end is the last day of the first week that average stream temperature drop below 4°C (Coleman & Fausch, 2006)
groundwater	water that flows beneath the water table, in soils and geologic formations
hanging valleys	a tributary valley whose mouth is set above the floor of the main valley, usually as a result of differences in glacial erosion
Harmer Creek mainstem	refers to Harmer Creek Reaches 3–5
Harmer Creek population area	includes Harmer Creek Reaches 2–6, Dry Creek and its south tributary, Sawmill Creek, Balzy Creek and unnamed tributaries

Harmer and Grave Creeks study area	– or Grave and Harmer Creeks study area – the area encompassed by both the Grave Creek and the Harmer Creek population areas
headwater	the source of a stream
hierarchical Bayesian (methods)	a method of statistical modelling
hybridize (of an animal or plant)	breed with an individual of another species or variety
hydraulic	of or relating to water or other liquid in motion
hydrophobic	lacking affinity for water
hyporheic	denoting an area or ecosystem beneath the bed of a river or stream that is saturated with water and that supports invertebrate fauna that play a role in the larger ecosystem
hyporheic exchange	the mixing of surface and shallow subsurface water through porous sediment surrounding a river
inbreeding depression	loss of population fitness due to a lack of genetic diversity caused by inbreeding
incubation	the process of maintaining an embryo under conditions favourable for hatching
insectivorous	an animal or plant that eats insects
inbreeding depression	the reduced biological fitness in a population as a result of inbreeding, or breeding of related individuals
interburden	material that lies between two or more coal seams
interstitial (of minute animals)	living in the spaces between individual sand grains in the soil or aquatic sediments
introgression	transfer of genetic information from one species to another
instream flow	water flows and levels in a stream or other waterbody
juvenile	– fish that are age-1 (i.e., spawned the previous year) and age-2+ (i.e., > age-1) but not yet reproductively mature – can include multiple age-cohorts.
laminar flow	flow in which the fluid travels smoothly or in regular paths
latent heat	energy absorbed or released by a substance during a change in its physical state (phase) that occurs without changing its temperature

large woody debris	fallen trees, logs and stumps, root wads and piles of branches along the edges of streams/rivers, which provide habitat to fish and other organisms
lipid	– a class of organic compounds that are fatty acids or their derivatives and are insoluble in water but soluble in organic solvents – they include many natural oils, waxes, and steroids
losing reach	– a reach that loses water as it flows downstream – the water infiltrates into the ground, recharging the local groundwater, because the water table is below the bottom of the stream channel
locus (plural: loci)	a specific, fixed position on a chromosome where a particular gene or genetic marker is located
lotic	of, relating to, or living in actively moving water
mainstem	the main course of a river or stream
maladaptation	failure to adjust adequately or appropriately to the environment or situation
meltwater	water derived from the melting of ice and snow
mesohabitat	a medium-sized habitat
metalloid	an element that has properties that are intermediate between those of metals and nonmetals
Mist Mountain Formation	a geologic formation present in the southern and central Canadian Rockies
moraine	any accumulation of unconsolidated debris (e.g., rock) that occurs in both currently and formerly glaciated regions and that has been previously carried along by a glacier or ice sheet
moraine-dammed lakes	occurs when the terminal moraine has prevented some meltwater from leaving the valley
morphology	the external structure of rocks in relation to the development of erosional forms or topographic features
neutral reach	a reach with a lack of a gain or loss of streamflow
nickel (Ni)	chemical element with atomic number 28
nitrate	a chemical with the formula NO_3, that helps plants grow

nitrite	a chemical with the formula NO_2^-
North American Plate	a major tectonic division of the Earth's crust
observer efficiency	the ratio of the number of fish tags observed to the number of tags present in the survey area, used to estimate the proportion of fish the snorkel team observed
open pit mining	a surface mining technique that extracts minerals from an open pit in the ground
orographic precipitation	rain, snow or other precipitation produced when moist air is lifted as it moves over a mountain range
orthophosphate	a chemical compound in the phosphate family
orographic	relating to mountains, especially with regard to their position and form
osmotic	of or relating to the diffusion of fluid through semipermeable membranes into a solution where solvent concentration is higher, to equalize the concentration of solvent on each side of the membrane
osmoregulation	the maintenance of constant osmotic pressure in the fluids of an organism by the control of water and salt concentrations.
outlet plunge height	distance from the culvert invert (the interior bottom elevation of pipe) to the water surface in the pool below
overburden	materials overlying the coal resource
overwintering	the process by which some organisms pass through or wait out the winter season, or pass through that period when "winter" conditions (cold or sub-zero temperatures, ice, snow, limited food supplies) make normal activity, or even survival, difficult or near impossible
periodicity	the quality, state or fact of recurring regularly or having periods
permeability	a measure of the ability of the rock to transmit water
phenanthrene	a polycyclic aromatic hydrocarbon (see definition)
phosphorus	– a nonmetallic element with atomic number 15 that is essential for life in all known organisms – often found in combination with other elements as phosphates

polycyclic aromatic hydrocarbon	– any of a class of hydrocarbon molecules that have multiple carbon rings – a class of chemicals that occur naturally in coal, crude oil and gasoline
pool	an area of the stream characterized by deep depths and slow current
potential stressor	– used in a general way to describe the main cause of a causal effect pathway, such as water quality or calcite – potential stressors can be natural or anthropogenic
radio tag	a tag used in telemetry studies
reach	a section of a stream that is typically 100 metres long or more
rearing	– the times of year when fish are most likely to be feeding and growing (accumulating somatic or reproductive tissue) – during the rearing period, fish may be undertaking life history activities such as reproduction, migration and maintenance of territories – this period contrasts with the overwintering period when such activities are limited or absent
recruitment	– refers to the addition of new individuals to a population through reproduction – for the Evaluation of Cause, recruitment is documented during the fall fish monitoring (i.e., late September/early October) the year after the fish is spawned (i.e., recruitment is the number of age-1 fish in the fall produced by spawning in the previous year)
recruitment above replacement	for the Evaluation of Cause, a probability of > 50% that annual recruitment is > 100% of that required for population replacement
Recruitment Failure	for the Evaluation of Cause, a probability of > 50% that annual recruitment is < 10% of that required for population replacement
redd	the spawning ground or nest of various fishes
Reduced Recruitment	a probability of > 50% that annual recruitment was < 100% of that required for population replacement

reference area	– an area with similar conditions except for the factor(s) being evaluated – the Grave Creek population area (including HRM-R1 and Grave Creek upstream of the waterfall at rkm 2,1) was used as a reference for the Harmer Creek population area for some analyses in the Evaluation of Cause (see Chapter 6 text box)
removal-depletion	– an electrofishing method where a section of stream is sampled repeatedly and the fish captured are temporarily removed – because each sampling pass should remove fewer fish, the total population can be estimated by extrapolating the decreasing number to 0 (see Chapter 4 textbox)
replacement	for a population to remain stable and be at replacement, i.e., to neither increase nor decrease, on average, every spawning fish (spawner) would need to produce one spawner over its lifetime
resistance	represents the magnitude of abundance decline following disturbance
resilience	a measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables
recovery	the magnitude or rate of population increase after a disturbance abates
reproduction	can be affected by changes in fecundity and/or spawning frequency (fish may not spawn every year), which in turn can affect the number of fertilized eggs in any given year
riffle	an area of stream characterized by shallow depths with fast, turbulent water
riparian zone	the area of terrestrial habitat adjacent to and most directly influenced by a river or stream
river kilometre	a measure of distance in kilometres along a river from its mouth
Rocky Mountain Foreland Belt	– one of the five morphogeological belts that ultimately define the geologic setting in British Columbia from east to west – the Foreland Belt consists of sedimentary rock
run	an area of stream characterized by moderate current, continuous surface and depths greater than riffles

run	an area of stream characterized by moderate current, continuous surface and depths greater than riffles
runoff	releases of mine-influenced water that are not written into a permit with a specified location, and/or water that flows over land due to gravity
Salmonidae	a family of fish that includes salmon, trout, chars, freshwater whitefishes and graylings, which collectively are known as the salmonids
salvage	a fish salvage involves collecting fish from an isolated/unsuitable area and relocating them
screening value	a benchmark or numeric value used to identify constituents or other stressors that merit further evaluation
secondary productivity	the generation of biomass of consumer organisms in a system
sedimentation ponds	used for reducing sediment loadings to streams/rivers from mine operations when other erosion/sediment control methods are insufficient.
sedimentary rock	rock formed through deposition and solidification of sediment, like the sediment transported by water or ice
selenium (Se)	the chemical element of atomic number 34 and a constituent (see definition) in the Grave Creek watershed
sensible heat	thermal energy whose transfer to or from a substance results in a change of temperature
sexual dimorphism	distinct difference in size or appearance between the sexes of an animal, in addition to difference between the sexual organs themselves
single nucleotide polymorphisms	a DNA sequence variation occurring when a single nucleotide (adenine, thymine, cytosine, or guanine) in the genome (or other shared sequence) differs between members of a species or between paired chromosomes in an individual
sinuosity	a measure of the degree of meandering within a river, defined as the ratio of stream length to valley length
skid trail	temporary roads or trails used by logging equipment to remove logs from a timber stand
slump	downward intermittent movement of rock debris
snow water equivalent	the amount of water in the snowpack if you melted the snow

solute	the minor component in a solution, dissolved in the solvent
spawn/spawning	to produce or deposit (eggs) — used of an aquatic animal
spawning (year) cohorts	the spawning (year) cohort for a particular year are those fish that were spawned in that year. For example, the spawning year cohort for 2018 refers to those fish that were spawned in 2018.
speciation	as in selenium. Chemical speciation refers to the distribution of an element among defined forms of a chemical (species) in a system
Special Concern (COSEWIC)	a wildlife species that may become threatened or endangered because of a combination of biological characteristics and identified threats
spoil/spoiling	the overlying material that is removed during mining, in order to access the desired material below
sportfish	a type of fish prized for the sport it gives the angler
snorkel survey	a technique used for the underwater observation and study of fish in flowing waters
stranding	when fish become trapped due to a sudden decrease in water levels caused by natural or anthropogenic events
stressor interactions	the outcome of stressors working in an additive, synergistic and/or antagonistic manner
subfamily	a category in biological classification
sublethal	a negative effect that is less than lethal, such as effects on growth and reproduction
sublimation	the process of passing directly from the solid to the vapour state
suboxic	a zone of water in which the concentration of oxygen is very low
subspecies	a category in biological classification that designates a population of a particular geographic region that is genetically distinguishable from other populations of the same species
sulphate	in water (aqueous phase), sulphate is a negatively charged ion composed of one sulphur atom with four oxygen atoms surrounding it

survival	of any WCT life stage is determined by an interaction between factors such as predation risk, food limitation, energetic demands, physiological stress and disease
swim-up	when alevins have consumed their yolk sacs, they will emerge as fry from the gravel and begin to search for food
tailings	the waste materials remaining after the target mineral or product is extracted or separated from ore
tailout	a shallow, flat section at the end of a pool before the water spills over into another riffle
telemetry	the science or process of collecting information about objects that are far away and sending the information somewhere electronically
tributary	a river, stream or creek flowing into a larger river or lake
topography	the physical appearance of the natural features of an area of land, especially the shape of its surface
total suspended solids	particles larger than 2 microns and found in the water column
total dissolved solids	the amount of material, such as metals, minerals and ions, dissolved in a particular volume of water (typically measured in milligrams per litre)
transpiration	the process of water moving through a plant and evaporating from aerial parts, such as leaves, stems and flowers
trophic status	trophic relates to nutrients/nutrition, so trophic status refers to a classification based on the amount of available nutrients in a system
U-shaped valley	valleys formed by the process of glaciation with steep, straight sides and a flat or rounded bottom (like a "U")
ultimate upper incipient lethal temperature	the temperature at which 50% of a population survives for 60 days
unproductive	as in ecological productivity, where productivity refers to the rate of generation of biomass in an ecosystem
upgradient	a location that is the source groundwater for another location; similar to upstream
upwelling	an upward movement from a lower source

water quality guideline	generic values intended to identify constituents that could contribute to acute (short-term) or chronic (long-term) stress to aquatic life
watershed	the area that drains to a single stream or river; frequently referred to as a river basin
waste rock	the rock excavated during mining to expose the coal seams (also referred to as spoil)

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Appendices

Appendix A: Stressor List and Evaluation of Cause Team Members

Table A-1. Subject Matter Expert Report and Stressor List

Focus	Citation
Harmer Creek Evaluation of Cause report	Harmer Creek Evaluation of Cause Team. (2023). *Evaluation of Cause - Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited.
Calcite	Hocking, M. A., Cloutier, R. N., Braga, J., & Hatfield, T. (2022). Subject Matter Expert Report: *Calcite. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Dissolved oxygen	Abell, J., Yu, X., Braga, J., & Hatfield, T. (2022). Subject Matter Expert Report: *Dissolved Oxygen. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Energetic Status	Thorley, J. L. & Branton, M. A. (2023). Subject Matter Expert Report: *Energetic Status at the Onset of Winter Based on Fork Length and Wet Weight. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Poisson Consulting Ltd and Branton Environmental Consulting/Azimuth Associate.
Food availability	Wiebe, A., Orr, P., & Ings, J. (2022a). Subject Matter Expert Report: *Food Availability. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Minnow Environmental Inc.

Groundwater	Canham, E., & Humphries, S. (2022). Evaluation of Groundwater as a Potential Stressor to Westslope Cutthroat Trout in the Harmer and Grave Creek Watersheds. Memo prepared for Teck Coal Limited. Prepared by SNC-Lavalin Inc.
Habitat availability (instream flow)	Wright, N., Little, P., & Hatfield, T. (2022). Subject Matter Expert Report: *Streamflow and Inferred Habitat Availability. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Sediment quality	Wiebe, A., Orr, P., & Ings, J. (2022b). Subject Matter Expert Report: *Sediment Quality. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Minnow Environmental Inc.
Selenium	de Bruyn, A., Bollinger, T., & Luoma, S. (2022). Subject Matter Expert Report: *Selenium. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by ADEPT Environmental Sciences Ltd, TKB Ecosystem Health Services and SNL PhD, LLC.
Small population size	Thorley, J. L., Hussein, N., Amish, S. J. (2022). *Subject Matter Expert Report: Small Population Size. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Poisson Consulting and Conservation Genomics Consulting, LLC.
Telemetry analysis	Akaoka, K., & Hatfield, T. (2022). Harmer and Grave Creeks Telemetry Movement Analysis. Memo prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Total suspended solids	Durston, D., & Hatfield, T. (2022). Subject Matter Expert Report: *Total Suspended Solids. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout*

	Population. Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Water quality	Warner, K., & Lancaster, S. (2022). Subject Matter Expert Report: *Surface Water Quality. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by WSP-Golder.
Water temperature and ice	Hocking, M., Whelan, C. & Hatfield, T. (2022). Subject Matter Expert Report: *Water Temperature and Ice. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.

Table A-2. Evaluation of Cause Team

Name	Affiliation	University Degree(s)	Professional Designation(s)	Years of Professional Experience (since last degree)	General Area of Practice
Trent Bollinger	TKB Ecosystem Health Services	HBSc DVM DVSc	Professor	28+	Epidemiology and fish pathology
Maggie Branton	Azimuth Consulting Group (Associate) & Branton Environmental Consulting Ltd.	BSc MES PhD	PAg	21+	Ecological risk and impact assessment
Adrian de Bruyn	ADEPT Environmental Services Ltd.	BSc MSc PhD	RPBio. Adjunct Professor	21+	Environmental toxicology
Emma Canham	SNC-Lavalin	MSc	PGeo	18+	Hydrogeology
Todd Hatfield	Ecofish Research	BSc MSc PhD	RPBio	25+	Aquatic ecology
Ryan Hill	Azimuth Consulting Group	BSc MRM	RPBio	27+	Ecological risk assessment
Morgan Hocking	Ecofish Research	PhD	RPBio Adjunct Professor	17+	Applied Ecology
Sam Luoma	Samuel N Luoma PhD LLC, Principal	BS MS PhD	Research Ecologist	47+	Aquatic bioavailability and ecological effects of metals and metalloids (e.g., selenium)

Name	Affiliation	University Degree(s)	Professional Designation(s)	Years of Professional Experience (since last degree)	General Area of Practice
Ryan MacDonald	MacHydro	PhD	PAg Adjunct Professor	10+	Hydrology and cumulative effects
Beth Power	Azimuth Consulting Group	BSc MSc	RPBio P Biol CSAP^{RISK}	32+	Ecological risk assessment and process facilitation
Mike Robinson	Lotic Environmental	MSc	RPBio	20+	Aquatic ecology
Joseph Thorley	Poisson Consulting	BSc PhD	RPBio	22+	Computational biology
Kara Warner	WSP-Golder	BA MS PhD	RPBio	16+	Environmental toxicology
Amy Wiebe	Minnow Environmental Inc.	BSc MSc	RPBio	9+	Aquatic science

Appendix B: Fish Handling

COULD CAPTURE AND HANDLING OR ANGLING HAVE CONTRIBUTED TO THE RECRUITMENT FAILURES?

In this appendix, we consider the potential for the following to have contributed toward the observed Reduced Recruitment in the Harmer Creek population: Fish mortality associated with capture and handling during scientific monitoring and salvage operations and targeted removal of WCT through recreational angling (licensed and poaching).

The evaluation of site-specific monitoring data described in this appendix indicates that the observed Reduced Recruitment is likely due to extremely low survival of juvenile fish (i.e., age-0 or age-1) and not due to changes in the adult population (e.g., abundance, fecundity, spawning). The potential for capture and handling and/or angling to have impacted either juvenile or adult fish, generally and during the period of interest, is discussed below.

Capture and Handling

Scientific Studies

For capture and handling during scientific monitoring studies to have contributed to the Reduced Recruitment, they would need to have resulted in the mortality of a substantial proportion of the age-0 individuals throughout the Harmer Creek population area in the falls of 2017, 2018 and 2019. Electrofishing during annual monitoring occurred in approximately 6% of the Harmer Creek population area. Assuming that the WCT population was distributed relatively evenly throughout the population area, this means that during scientific monitoring approximately 6% of the WCT could have been subjected to electrofishing. Per capita, the electrofishing capture, handling and delayed mortality was estimated by Cope (2020) to be 7%. This rate is higher than that reported in other studies. Mortality rates can be influenced by factors such as electrofishing methods and size of water body (large versus small) (Chiaramonte et al. 2020; McMichael et al.. 1998) and may be lower (e.g., 1-5% McMichael et al., 1998). Therefore, at this rate, capture handling during scientific studies could have resulted in the mortality of approximately 0.4% of the population (i.e., 6% for the area sampled multiplied by a 7% mortality rate). This level of mortality constitutes a negligible contribution to the Reduced Recruitment.

Further evidence that scientific monitoring could not have contributed meaningfully to the Reduced Recruitment is the fact that the extent of electrofishing in the Grave Creek population area was slightly higher, at 6–7% of the available habitat, but the Grave Creek population area showed no apparent reduction in recruitment, except in 2018.

Salvage

The immediate and latent effects associated with handling and relocation mean that a salvage operation with 100 % efficiency has the potential to cause the same per capita mortality rates as those associated with scientific studies (see above) and an additional estimated 10% mortality associated with the relocation of salvaged fish (Cope, 2020; Korman & Branton, 2021).

The only salvage in the Harmer Creek population area during the period of interest was conducted in Dry Creek in the fall of 2017. The salvage was conducted after the 2017 monitoring which documented age-1 fish from the 2016 spawning cohort throughout the Harmer Creek mainstem. The potential for the relocation to have contributed to the Reduced Recruitment or Recruitment Failure is considered negligible for the following reasons: (1) most of the adults in Dry Creek are likely to have spawned in Harmer Creek due to calcite concretion irrespective of the relocation, and (2) even if the all fish remained in Harmer Creek the 11% (24%– 5%) increase in the abundance of adults in the mainstem is no more than the annual change in the abundance of adults per year (see Chapter 4, Figure 4-12).

Angling

Anglers (licensed and unlicensed anglers) target adult WCT. However, angling activity was extremely limited historically in Harmer Creek and Grave Creek, due in part to the small size of the fish and low densities (near 0; Pers. Comm. Matt Neufeld, FLNRO). Angling was prohibited in Harmer Creek and Grave Creek beginning in 2020.

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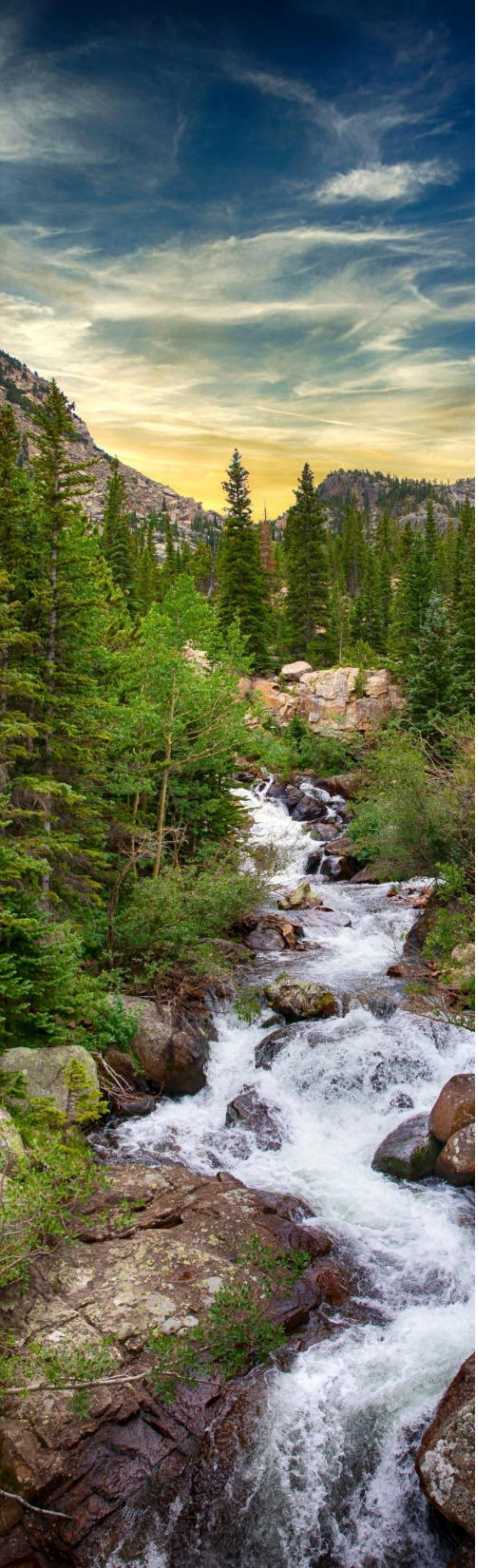
Appendix C: A Conceptual Evaluation of Ice Formation in Harmer Creek.



MacHydro

Technical Memorandum: A Conceptual Evaluation of Ice Formation in Harmer Creek

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Technical Memorandum: A Conceptual Evaluation of Ice Formation in Harmer Creek

September 26, 2022

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2 Introduction

2.1 Rationale

This technical memorandum evaluates the potential mechanisms that influence ice formation in Harmer Creek, with a focus on understanding the potential for temporal variation in the extent of in-stream ice. Observations and datasets related to the spatial and temporal extent of ice cover were not available; therefore, a theoretical approach is applied to provide insight into factors that are important to consider. We applied a physically based stream energy budget model to assist in this theoretical understanding with the goal of evaluating variation in the Harmer Creek energy budget from 2017 to 2019.

2.2 Overview of ice formation and ice cover estimates

Ice formation and growth are driven by interactions between channel hydraulics and hydrometeorological conditions (Buffin-Belanger *et al*. 2013). Bed slope, bed particle size, and morphology ultimately affect channel hydraulics, controlling turbulence and affecting ice formation. These factors are highly variable within and among small mountain streams and therefore result in high variability in freezing processes spatially and temporally. Step-pool and riffle-pool sequences are typical of smaller mountain streams (Montgomery and Buffington, 1997) and play a role in the presence of ice formation. Turcotte and Morse (2011) found that ice formation typically occurs on step crests in steep streams where abrupt changes in hydraulic conditions are present. Riffle-pool morphologies can exhibit border ice in pools whereas frazil and anchor ice form in more turbulent riffle morphologies (Stickler and Alfredsen, 2009). It is also important to consider transitions in slope along a reach, where breaks in slope can result in ice formation and ice jam formation. In Harmer Creek, the slope transition into the on-stream settling pond likely results in ice accumulation upstream of the Harmer Creek Sedimentation Pond.

In addition to channel variations, streamflow (volume and velocity of water in the stream channel) and atmospheric conditions (air temperature) dictate the potential for ice. Although the overall volume of water is a first order driver, the source of that water is also important given that the proportion of groundwater contribution to streamflow can influence the amount of heat stored in surface water and ultimately ice formation (Webb *et al*., 2008). This combination of factors results in a high degree of complexity in determining how ice may or may not be present in mountain streams.

Modelling ice formation can be done using simple empirical or complex energy balance methods. Both methods require adequate observations of ice cover and type over space and time. As an example of a simple method, Bisaillon and Bergeron (2009) demonstrated that freezing-degree hours and water temperature could be used to predict anchor ice at reach scales. Timalsina *et al*. (2013) used a one-dimensional river ice model to simulate the presence/absence of frazil ice, verified with datasets that used continual photographic monitoring. Here, we do not have access to detailed ice cover or ice type data and although empirical and energy balance models could be developed based on general principles, results would be unverifiable. Therefore, the focus here is on describing the simulated stream energy budget and qualitative evaluation of the potential for ice cover variation over time.

3 Methods

We applied the physically based stream temperature model, Raven Thermal Wrapper, coupled with a process-based hydrological model to simulate stream temperature at major points of interest in Harmer Creek. The model has been under development through the Westslope Cutthroat Trout (*Oncorhynchus Clarkii Lewisi*) recovery work that is ongoing in the Elk Valley by Teck Coal.

The semi-distributed hydrological model used in this study is an adapted version of the HBV-EC model, emulated within the Raven Hydrological Modelling Framework version 3.5 (Craig et al., 2020). The Raven Thermal Wrapper is integrated into Raven and is unique in its ability to support a wide range of hydrological model configurations, in addition to very specific handling of the on-land and in-stream energy balance. The model simulates stream temperature, streamflow, and other hydro-climatic variables (i.e. snowmelt, evaporation, etc.) at an hourly timestep from 1980-2019. We used stream energy balance (Figure 1, Equation 1) outputs from the model for the reach upstream of Harmer Reach 2 (HRM-R2) in this evaluation to describe potential for ice cover variation between years.

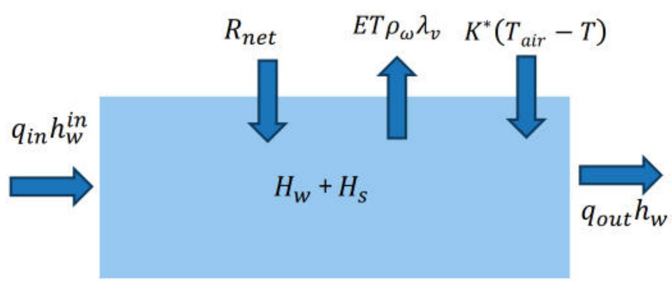

Figure 1. Stream channel energy balance conceptual model which the Thermal Wrapper model is based.

The in-stream energy balance is applied in each water storage compartment during each timestep, where q_{in} [m/d] is the flux of water entering the compartment; q_{out} [m/d] is the flux of water leaving the compartment; R_{net} [MJ/m^2 /d] is the net radiative heat flux applied to the boundary of the reach, k^* [MJ/m^2 /d/ °C] is a convection coefficient, T_{air} and T [°C] are the air temperature and compartment temperature, respectively, ET is the evapotranspiration loss rate [m/d], λ_v is the latent heat of evaporation, p_w is the density of water, and h_{in} and h_w [MJ/m^3] are the volumetric specific enthalpy of the water advecting into and out of the compartment.

Equation 1. Stream channel energy balance used in the equation

$$\frac{dH_w}{dt} = q_{in}h_w^{in} - q_{out}h_w + R_{net} + K^*(T_{air} - T) - ET\rho_\omega\lambda_v - \frac{dH_s}{dt}$$

Change in energy	Advection	Radiation	Convection	Evaporative Cooling	Soil Equilibrium

A progressive three stage calibration strategy was used for model calibration. First, energy balance terms were evaluated to ensure the model was accurately calculating each energy term. These terms included the radiative heat flux, sensible and latent heat fluxes, and groundwater heat flux. The energy balance was verified ensuring that each reach had the correct magnitude and seasonal trends within expected energy ranges. There were no energy balance measurements, so the terms were verified ensuring that the radiative heat flux was the dominant heat source with smaller contributions of latent and sensible heat.

Measured channel geometry was incorporated into the model from Harmer and Grave Creek Westslope Cutthroat Trout Habitat and Population Assessment: Interim Report 1. Report Prepared for Teck Coal Limited (Cope and Prince, 2018). Stream temperature varies with respect to channel width in the model. In cases where the modelled stream temperature was too cold, the width was increased to enhance the surface area receiving radiative inputs and decrease the depth, inversely the width was decreased if the modelled stream temperature was too warm.

Lastly, the subsurface components were calibrated to fit the model to the measured stream temperature (2017 – 2019). This included calibrating both the groundwater temperature and the rate of exchange with the surface water (hyporheic exchange). This groundwater temperature value was calibrated using the groundwater dominated site in Reach 5 (HRM-R5).

4 Results

4.1 Hydrological context and stream temperature simulations

Daily average stream temperature simulations from sites in Harmer Reach 1 (HRM-R1) and HRM-R2 compare well with observations over the study period (Figure 2). The site at HRM-R1 had a bias of -0.68 (r^2 is not relevant for this site given that the slope of the line is close to zero) and the site at HRM-R2 had a bias of -2.18 and r^2 of 0.86. These results suggest the model is representing hydrological and meteorological processes reasonably well. In particular, the model appears to be representing the relative proportion of groundwater to total streamflow other than in the spring at both sites where too much cold snowmelt water is entering the stream. Simulations suggest that there is a relatively high proportion of groundwater to total streamflow in HRM-R1 with 95% groundwater contribution over the year in 2018 and 2019. This contribution decreases longitudinally downstream to HRM-R2, where it is 89% during 2018 and 2019. The relative difference between these sites is small; however, it is important to understand how groundwater contribution changes spatially when assessing the likely extent of ice formation given that groundwater contribution to streamflow is an important buffering mechanism.

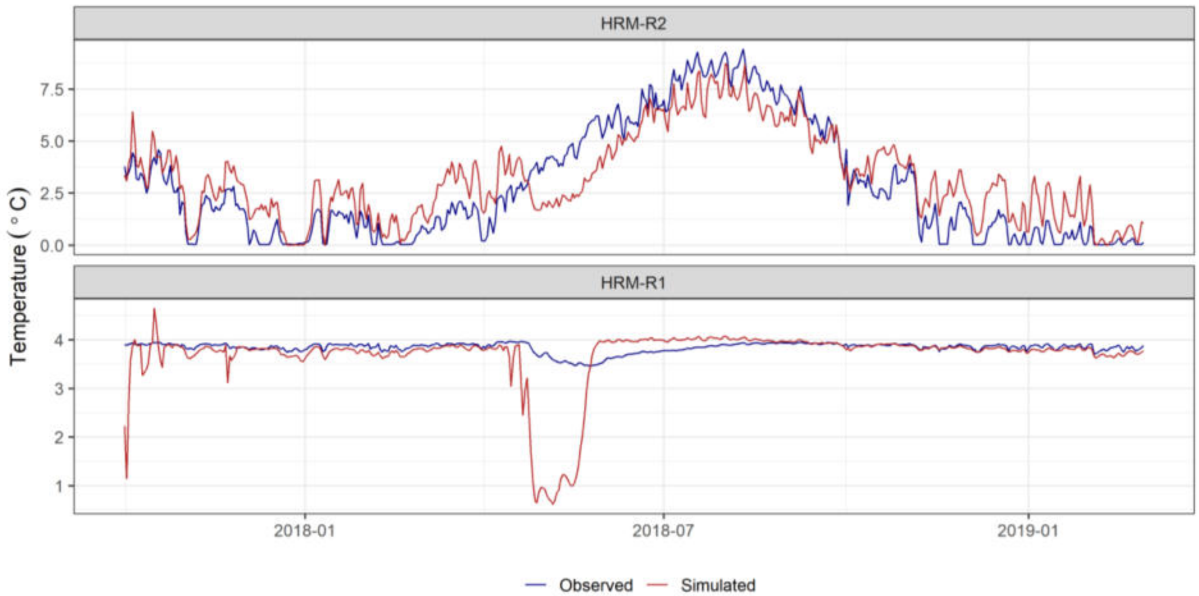

Figure 2 Observed (blue) and simulated (red) daily average stream temperature for stream temperature logger sites at HRM-R2 and HRM-R1.

4.2 Relative energy budget contributions

The Harmer Creek energy budget was calculated for the years from 2017 to 2019, with results displayed for two winter periods defined as November 1 to March 31. The relative contributions to positive and negative fluxes for each of the energy balance terms are presented in Figure 3, demonstrating that radiation comprises most of the energy inputs to the system, while sensible heat represents most of the energy output. Friction is a relatively minor term, while groundwater heat input and output as well as latent heat output make up similar proportions of the total energy budget. The 2018-2019 winter was estimated to have slightly lower groundwater energy input overall and the sensible heat flux made up a slightly larger proportion of the total energy budget.

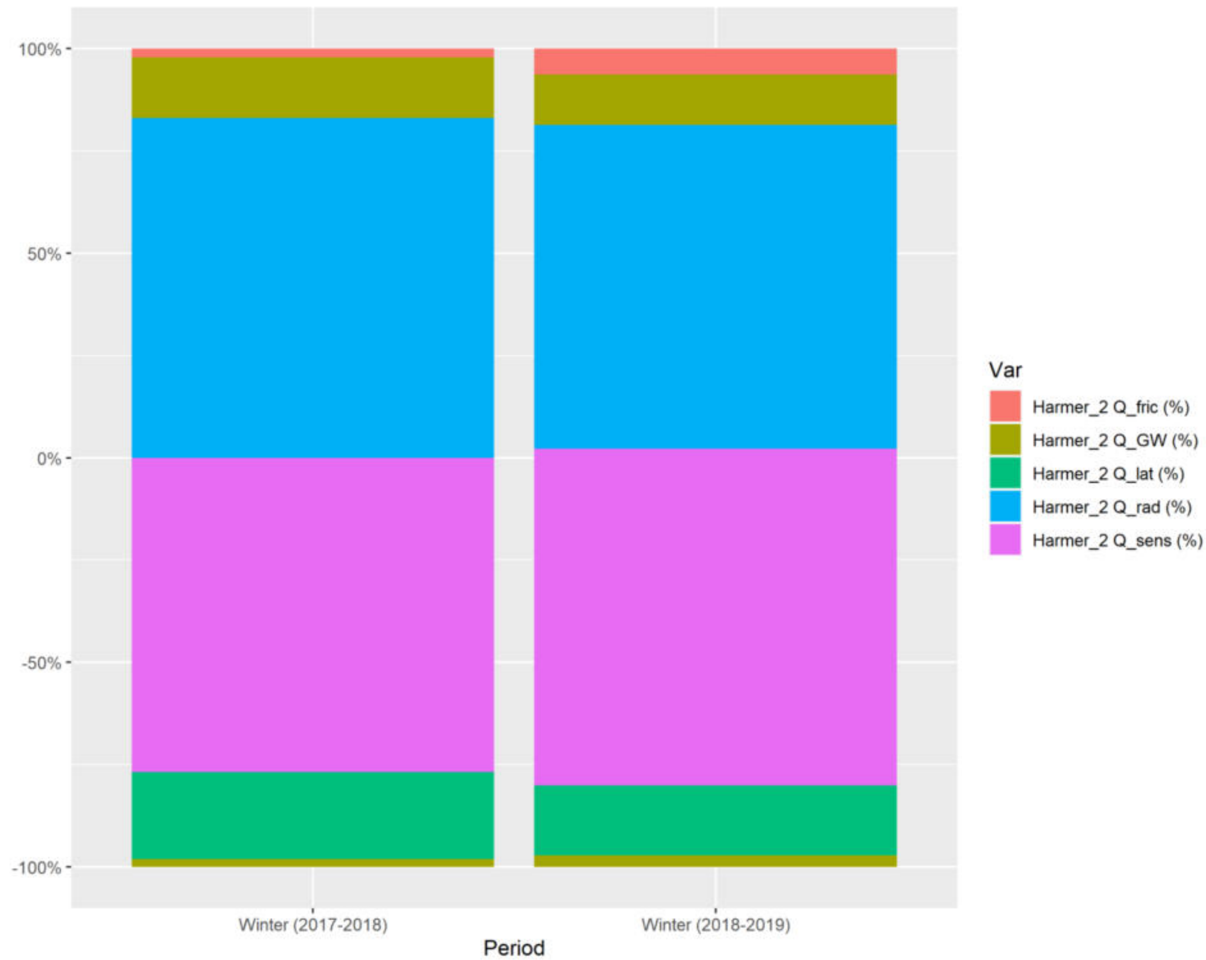

Figure 3 Relative contribution of each of the stream energy budget terms (Friction (Q_fric); Groundwater (Q_GW), latent heat (Q_lat), net radiation (Q_rad), and sensible heat (Q_sens) for the winter (2017-2018) and winter (2018-2019).

4.3 Monthly energy budget comparisons

Monthly simulated energy budget comparisons suggest that the 2018-2019 winter had higher radiation inputs and that radiation was the dominant input for all months (Figure 4). These higher radiation inputs would have been offset by sensible heat loss, particularly during February of 2019 when air temperature was anomalously low (Figure 5). The simulated groundwater energy contribution did not differ greatly between years (although slightly lower in the early winter of 2018-2019) and was a positive, relatively small contribution to the energy budget (Figure 6). Latent heat flux was slightly higher (more negative) in the 2018-2019 period relative to the 2017-2018 period (Figure 7), while friction was a small component in both years and slightly higher in 2018-2019 (Figure 8).

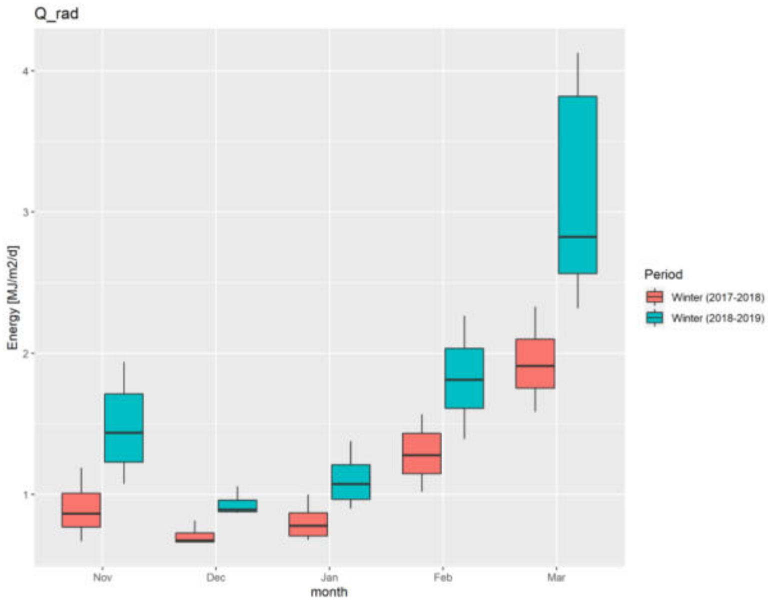

Figure 4 A comparison of net radiation (MJ/m²/day) between the 2017-2018 winter and the 2018-2019 winter.

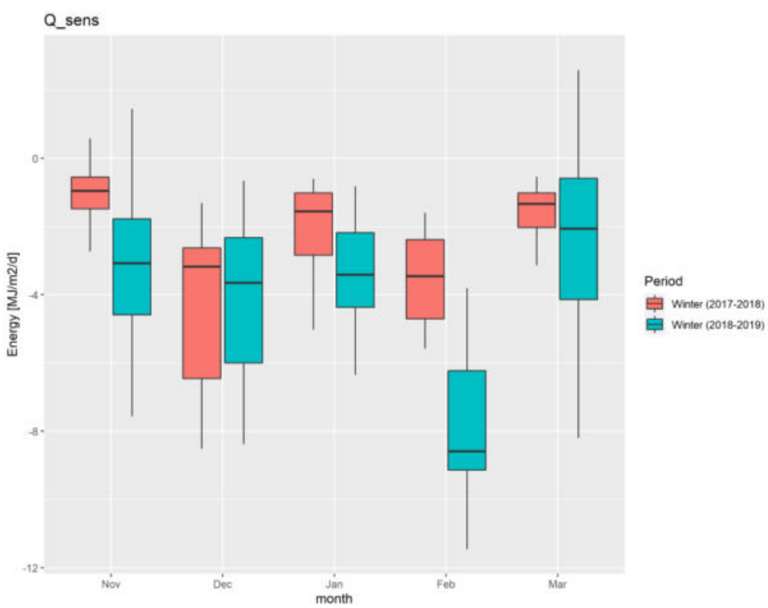

Figure 5 A comparison of sensible heat (MJ/m²/day) between the 2017-2018 winter and the 2018-2019 winter.

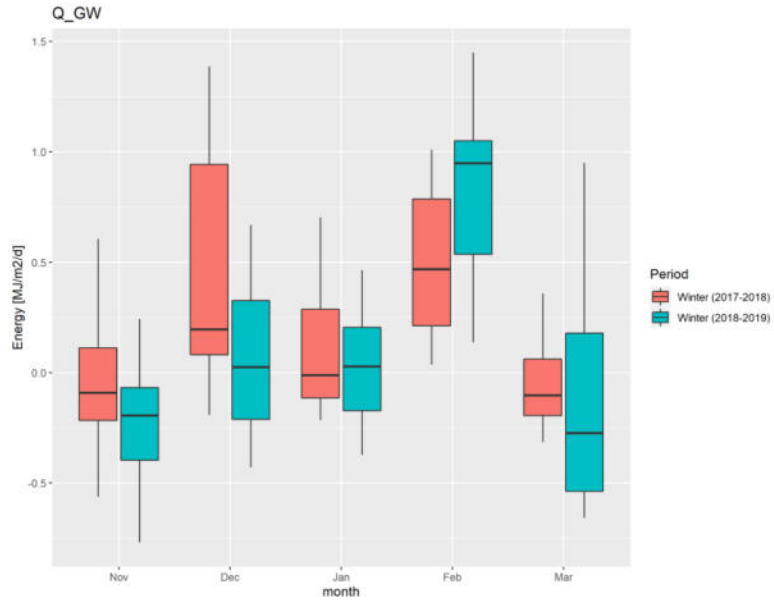

Figure 6 A comparison of heat from groundwater (MJ/m²/day) between the 2017-2018 winter and the 2018-2019 winter.

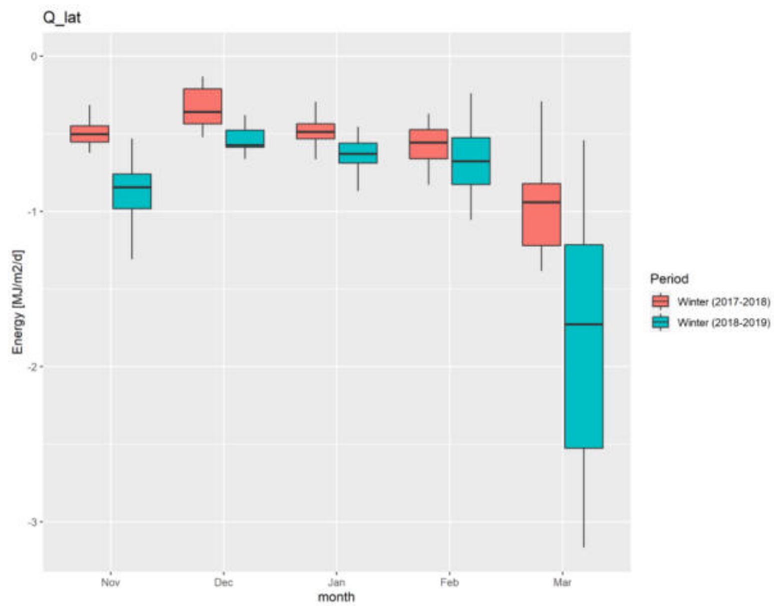

Figure 7 A comparison of latent heat (MJ/m²/day) between the 2017-2018 winter and the 2018-2019 winter.

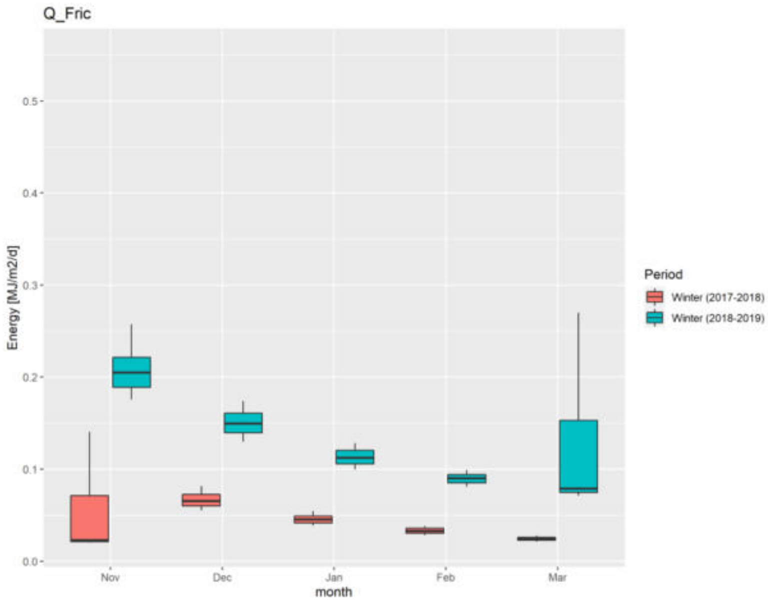

Figure 8 A comparison of net radiation (MJ/m²/day) between the 2017-2018 winter and the 2018-2019 winter.

Overall, these results suggest that the sensible heat flux in the 2018-2019 period could have driven higher amounts of frazil ice presence and anchor or border ice accumulation in the lower reaches of Harmer Creek upstream of the Harmer Creek Sedimentation Pond. The sequence of hydrometeorological conditions is particularly important to consider here. Very cold air temperatures and relatively low streamflow can result in the formation of frazil ice, which ultimately leads to the formation of anchor and border ice as it accumulates. Maintaining cold air temperatures can enhance this ice formation sequence, resulting in more accumulation over time. Although sub-surface water contributions can buffer atmospheric effects, it is likely that the buffering effect is outweighed by atmospheric conditions during extreme events like those observed in February of 2019.

5 Conclusions and Recommendations

5.1 Conclusions

A general description of ice formation processes was presented, demonstrating that streams like Harmer Creek have complex and highly variable conditions that lead to ice formation. It is likely that frazil and subsequent development of anchor ice or border (surface) ice are the dominant ice forms in Harmer Creek and that atmospheric conditions play a major role in this system given that it is a relatively small stream and has a low volume of water over the winter period. Modelling results suggest the uppermost reach of Harmer Creek (HRM-R1) is groundwater dominated and that influence continues below the confluence with Dry Creek, but diminishes downstream to the bottom of HRM-R3, just above the Harmer Creek Sedimentation pond where groundwater makes up a lower proportion of total streamflow. The buffering influence of groundwater does not likely differ between years in terms of flow contributions and temperature. However, it is important to consider that the influence of atmospheric conditions on stream temperature and ice formation increases as the proportion of groundwater to total streamflow decreases. Therefore, extreme atmospheric conditions like those observed in the winter of 2019 likely did result in the development of frazil and subsequent anchor and surface ice that could have extended farther upstream relative to more moderate years. Furthermore, the sensible heat flux was a dominant factor in the stream energy budget, suggesting colder water and higher likelihood of ice formation would have occurred in the latter part of the 2018-2019 winter. Quantifying the spatial and temporal extent of ice formation was not possible in this small study and with the available data.

5.2 Considerations for Further Study

Studies reviewed for this memo used ice cover monitoring to support their findings. It is recommended that repeat photography be used to monitor ice cover if ice is determined to be a key variable in defining the viability of the Westslope Cutthroat Trout population in Harmer Creek. In addition, long-term stream temperature records would be highly valuable in this system to support ongoing recovery efforts and additional modelling work to help support mitigation measures aimed at improving Westslope Cutthroat Trout habitat.

6 Closure and Limitations

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This technical memorandum was limited by input data and used modelling efforts from work carried out as part of the Westslope Cutthroat trout recovery program. Results are meant to be informative and provide context for ice formation; however, linkages between energy budgets and ice formation have not been made directly. Therefore, results should be taken with caution.

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