# Subject Matter Expert Report: CALCITE. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population

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## EXECUTIVE SUMMARY

Abundance of age-1 Westslope Cutthroat Trout (WCT) was lower in 2018, 2019, and 2020 (spawning cohorts 2017, 2018, and 2019) in the Harmer Creek WCT population in comparison to previous years and the adjacent Grave Creek population. Teck Coal Ltd. (Teck Coal) initiated an "Evaluation of Cause" to assess potential stressors responsible for the Reduced Recruitment in the Harmer Creek population. This report evaluates calcite as one potential stressor.

Calcite ($CaCO_3$) is found in sedimentary rocks of the Rocky Mountains and precipitates naturally in non-mine-influenced streams in the Kootenay Rockies region. Calcite formation can be exacerbated by mining activity and can negatively affect fish habitat.

Calcite data from the Regional Calcite Monitoring Program (e.g., Robinson *et al.* 2013; McCabe and Robinson 2020) and the Calcite Biological Program (Hocking *et al.* 2020) were used to assess four causal effect pathways via which calcite could have caused or contributed to the Reduced Recruitment: 1) effects to spawning suitability, 2) effects to incubation conditions, 3) effects to overwintering habitat, and 4) effects to invertebrate prey habitat. Results were interpreted in consideration of conditions of explanatory factors that would have to be met for calcite to explain the Reduced Recruitment. Explanatory factors included: intensity, spatial extent, location, duration, and timing of changes in calcite. A calcite index (CI) >1 and calcite concretion (Cc) >0.5 were defined as the intensity thresholds for which biological effects would be expected to be explanatory based on previous biological effects assessments.

*Spatial and temporal trends in calcite*

Calcite was assessed in terms of CI and Cc at two different spatial scales: 1) at the stream level to assess trends in calcite across individual streams such as Grave Creek, Harmer Creek, and Dry Creek; and 2) at the population level to assess trends in calcite against WCT population estimates reported in Thorley *et al.* (2022).

Calcite levels (e.g., CI and Cc) from 2013 to 2019 were relatively low and stable in Grave Creek, Harmer Creek, and tributaries to Harmer Creek except Dry Creek. In Dry Creek, CI was elevated (ranging from 1.72 to 2.85) and increasing over time, with a peak of 2.85 in 2017 and 2018. For all other streams, calcite levels were statistically indistinguishable and were not increasing. Calcite exposure was higher for the Harmer Creek population compared to the Grave Creek population but was not increasing over time for either population.

Conditions of explanatory factors were not met for calcite to cause the Reduced Recruitment in the Harmer Creek population. For example, the condition for high calcite intensity was met only in Dry Creek (representing ~24% of the Harmer Creek population area). While calcite intensity was high and spawning suitability poor in Dry Creek, this stream was heavily concreted and had poor spawning suitability prior to and during the period of Reduced Recruitment. Conditions for timing and duration were somewhat met in that calcite intensity peaked in 2017 – 2018 in Dry Creek, but conditions for these factors were not met in any other stream. While the conditions for spatial extent and location of

calcite were also somewhat met in that calcite was present throughout the Grave and Harmer creeks study area, its distribution was patchy, and most of the habitat available for spawning by WCT had low levels of calcite concretion that are not at levels that would impair spawning.

*Effects to spawning suitability*

The effects of calcite on spawning suitability did not meet the conditions required to wholly explain the WCT Reduced Recruitment, but it is possible that calcite has both been a chronic stressor to the Harmer Creek WCT population and a minor contributor to the Reduced Recruitment. The effect of calcite on spawning suitability was assessed using the draft spawning suitability curve for mean redd counts developed in Hocking *et al.* (2020). Average annual spawning suitability was 80% in the Harmer Creek population area and 98% in the Grave Creek population area. This result was largely driven by low spawning suitability in Dry Creek, which represents ~24% of the habitat area for the Harmer Creek population. In contrast, spawning suitability with respect to calcite for the rest of the Harmer Creek population area and Grave Creek population area was high (>90% for all years, except Harmer Creek in 2014). A decline in spawning suitability was not observed for the Harmer Creek population area during 2017-2019, compared to previous years, although the spawning suitability in Dry Creek was the lowest during the period of Reduced Recruitment. Dry Creek supports a warmer growing season stream temperature regime than the remainder of the Harmer Creek population area (Hocking *et al.* 2022), and thus would likely support higher WCT recruitment than the Harmer Creek mainstem above the Sedimentation Pond if spawning was supported. High levels of calcite likely reduce the reproductive output of WCT that attempt to spawn in Dry Creek, a condition that may have peaked in Dry Creek during the period of Reduced Recruitment.

*Effects to Incubation Conditions*

Overall, effects of calcite to incubation conditions did not meet the conditions required to explain, wholly or in part, the WCT Reduced Recruitment. An effect of calcite on dissolved oxygen in the interstitial substrate has been observed in previous studies, although this effect was most pronounced at depths deeper than the average excavation depth for WCT redds (Wright *et al.* 2017; 2018). Declines in interstitial dissolved oxygen were also associated with CI scores higher than ~1.25 and relatively high percent fines; however high levels of fines were not present in most of the habitat throughout the Grave and Harmer creeks study area.

*Effects to Rearing - Overwintering Habitat*

The effect of calcite on overwintering habitat was unlikely to be a sole or contributing cause of the WCT Reduced Recruitment. Cope (2019) and Cope and Cope (2020) highlighted the importance of interstitial space as refuge for overwintering small fish and noted that winter mortality can affect fish through predation and ice effects, and Hocking *et al.* (2022) outlined the potential for winter habitat to be a limiting factor. Calcite therefore has the potential to reduce overwintering habitat suitability by reducing access to interstitial spaces for younger WCT age classes. It is possible that the high calcite conditions observed in Dry Creek could constitute a chronic stressor to the Harmer Creek population during the overwintering period. However, low flows during overwintering in Dry Creek (Cope and Cope 2020) likely preclude WCT from overwintering there in large numbers regardless of the calcite conditions, and thus high calcite concretion conditions in Dry Creek may not be biologically significant for this pathway.

### *Effects to Rearing - Invertebrate Prey Availability*

Overall, the effects of calcite on invertebrate prey availability did not meet the conditions required to explain, wholly or in part, the WCT Reduced Recruitment. Monitoring through the Regional Aquatic Effects Monitoring Program (RAEMP) from 2017 to 2019 found that invertebrate community endpoints did not differ from normal ranges for the three monitoring locations in Harmer Creek and Grave Creek (with one exception being percent EPT for some samples in Harmer Creek downstream of Harmer Pond, which is accessible by the Grave Creek population (Ings *et al.* 2020; Wiebe *et al.* 2022)). Although changes in several benthic invertebrate species corresponded with relative calcite exposure (e.g., a decrease in Ephemeroptera with calcite, an increase in Chironomidae with calcite, and an increase in Diptera with increasing calcite), total invertebrate abundance, which is a measure of total invertebrate production, has not been found to correlate with CI (Barrett *et al.* 2016). Furthermore, deviations from normal benthic community composition were only notable at CI values >1 (Barrett *et al.* 2016); such CI values occurred only in Dry Creek.

### *Conclusion*

Given the spatially restricted extent of calcite and the temporal consistency in calcite levels prior to and during the period of Reduced Recruitment in the Harmer Creek population area, we conclude that calcite is unlikely to have been the cause of the Reduced Recruitment. However, calcite exposure was significantly higher in the Harmer Creek population area than in the Grave Creek population area, and peaked in Dry Creek during the period of Reduced Recruitment, suggesting calcite may have contributed to the Reduced Recruitment via decreased spawning suitability. Calcite levels (i.e., CI and Cc) were relatively low and stable in the Grave and Harmer creeks study area from 2013 to 2019, except in Dry Creek where concretion was high and spawning suitability was low. High historical levels of calcite in Dry Creek have likely reduced spawning by WCT for some time, including WCT fry development in the warm growing season temperature regime in Dry Creek that can benefit recruitment (Hocking *et al.* 2022). Overall, high levels of calcite in Dry Creek represents a chronic stressor to the Harmer Creek WCT population that may reduce the reproductive output of fish attracted to Dry Creek to spawn and thus may have been a minor contributor to the observed reduced recruitment for the 2017 and 2018 spawning cohorts.

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# ACRONYMNS AND ABBREVIATIONS

| | |
|---|---|
| ANCOVA | Analysis of Covariance |
| $AIC_c$ | Akaike Information Criterion |
| BC | British Columbia |
| BRE | Baldy Ridge Expansion [Project] |
| CABIN | Canadian Aquatic Biomonitoring Network |
| $CaCO_3$ | Calcite |
| CI | Calcite Index |
| Cc | Calcite Concretion |
| Cp | Calcite Presence |
| cm | Centimeter |
| COSEWIC | Committee and the Status of Endangered Wildlife in Canada |
| EAC | Environmental Assessment Certificate |
| EoC | Evaluation of Cause |
| EPT | Ephemeroptera, Plecoptera, and Trichoptera |
| EVO | Elkview Operations |
| FRO | Fording River Operations |
| km | Kilometer |
| LPT | Lowest Practical Taxonomic |
| rkm | River Kilometer |
| SARA | Species at Risk Act |
| SME | Subject Matter Expert |
| UFR | Upper Fording River |
| WCT | Westslope Cutthroat Trout |

# READER'S NOTE

## 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 and Grave Creeks are upstream of a waterfall on Grave Creek, and they are home to isolated, genetically pure Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*). 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[1], the disturbance from logging, roads and other development is limited. The mine property belonging to Teck Coal Limited’s Elkview Operations includes an area in the southwest of the Harmer Creek subwatershed. These operations influence Harmer Creek through its tributary Dry Creek, and they influence Grave Creek below its confluence with Harmer Creek (Harmer Creek Evaluation of Cause, 2023)[2]. Westslope Cutthroat Trout populations in both Harmer and Grave Creeks are part of Teck Coal’s monitoring program.

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[1] Including Grave and Harmer Creeks and their tributaries.

[2] 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.

# The Evaluation of Cause Process

## The Process Was Initiated

Teck Coal undertakes aquatic monitoring programs in the Elk Valley, including fish population monitoring. Using data collected as part of Teck Coal's monitoring program, Cope & Cope (2020) reported low abundance of juvenile WCT in 2019, which appeared to be due to recruitment failure in Harmer Creek. 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 annual monitoring programs in the Harmer and Grave Creek population areas[3] from 2017 to 2021 (Thorley et al. 2022; Chapter 4, Evaluation of Cause), and several patterns related to recruitment[4] were identified:

- *Reduced Recruitment*[5] occurred during the 2017, 2018 and 2019 spawn years[6] in the Harmer Creek population and 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*[7].
- Recruitment was *Above Replacement*[8] for the 2020 spawn year in both the Harmer and Grave Creek populations.

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

[4] Recruitment refers to the addition of new individuals to a population through reproduction.

[5] For the purposes of the Evaluation of Cause, Reduced Recruitment is defined as a probability of > 50% that annual recruitment is <100% of that required for population replacement (See Chapter 4, Evaluation of Cause, Harmer Creek Evaluation of Cause Team 2023).

[6] The spawn year is the year a fish egg was deposited, and fry emerged.

[7] 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, Evaluation of Cause, Harmer Creek Evaluation of Cause Team 2023).

[8] For the purposes of the Evaluation of Cause, Above Replacement is defined as a probability of > 50% that annual recruitment is >100% of that required for population replacement (See Chapter 4, Evaluation of Cause, Harmer Creek Evaluation of Cause Team 2023).

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

## How the Evaluation of Cause Was Approached

When the Evaluation of Cause was initiated, an *Evaluation of Cause Team* (the Team) was established. It was composed of *Subject Matter Experts* (SMEs) who evaluated stressors with the potential to impact the WCT population. Further details about the Team are provided in the Evaluation of Cause report (Harmer Creek Evaluation of Cause Team, 2023).

During the Evaluation of Cause process, the Team had regularly scheduled meetings with representatives of the KNC and various agencies (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 key parameters of the WCT population, 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. Subject Matter Experts then revised their work to address feedback and, subsequently, participants reviewed and commented on the reports. Finally, results of the analysis of the population monitoring data and potential stressor assessments were integrated to determine the relative contribution of each potential stressor to the Reduced Recruitment in the Harmer Creek population.

## The Overarching Question the Team Investigated

The Team investigated the overarching question identified for 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 Reduced Recruitment?**

The Team developed a systematic and objective approach to investigate the potential stressors that could have contributed to the Reduced Recruitment in the Harmer Creek population. This approach is illustrated in the figure that follows the list of deliverables, below. The approach included evaluating patterns and trends, over time, in data from fish monitoring and potential stressors within the Harmer Creek population area and comparing them with patterns and trends in the nearby Grave Creek population area, which was used as a reference. The SMEs used currently available data to investigate causal effect pathways for the stressors and to determine if the stressors were present at a magnitude and for a duration sufficient to have adversely impacted the WCT. The results of this investigation are provided in two types of deliverables:

1. Individual Subject Matter Expert reports (such as the one that follows this Note). Potential stressors were evaluated by SMEs and their co-authors using the available data. These evaluations were documented in a series of reports that describe spatial and temporal patterns associated with the potential stressors, and they focus on the period of Reduced Recruitment, including the Recruitment Failure of the 2018 spawn year where appropriate. The reports describe if and to what extent potential stressors may explain the Reduced Recruitment.

   *The full list of Subject Matter Expert reports follows at the end of this Reader's Note.*

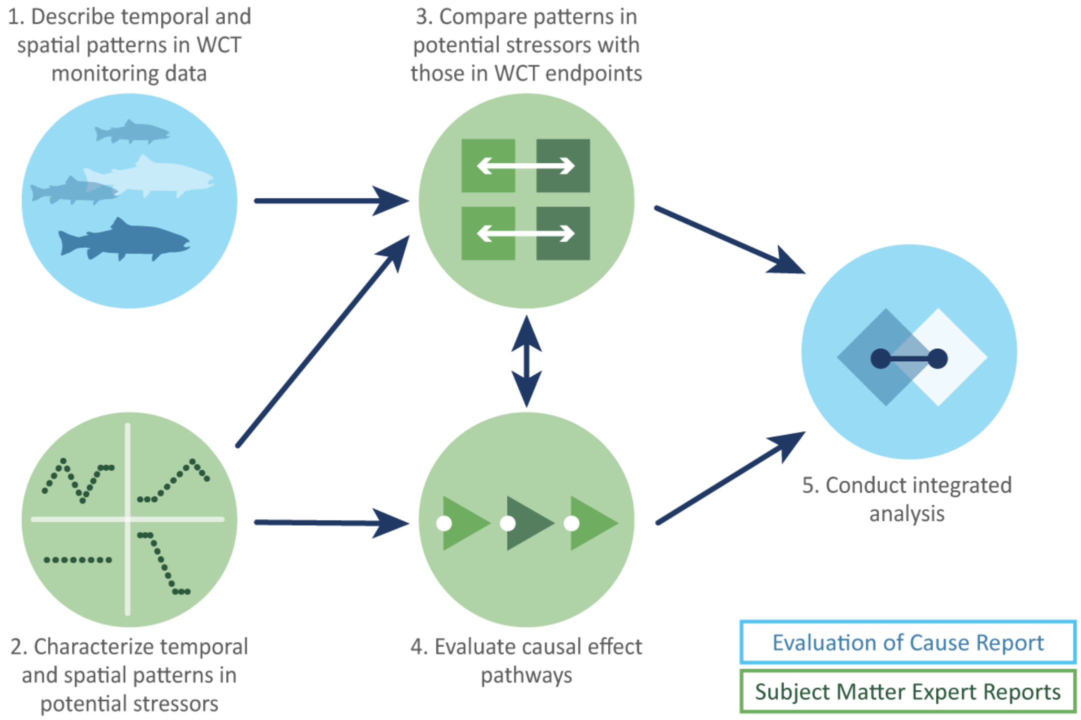
2. The Evaluation of Cause report. The SME reports provided the foundation for the Evaluation of Cause report, which was prepared by a subset of the Team and included input from SMEs.

   The Evaluation of Cause report:

   a. Provides readers with context for the SME reports and describes Harmer and Grave Creeks, the Grave Creek watershed, the history of development in the area and the natural history of WCT in these creeks

b. Presents fish monitoring data, which characterize the Harmer Creek and Grave Creek populations over time

c. Uses an integrated approach to assess the role of each potential stressor in contributing to Reduced Recruitment in the Harmer Creek population area.



**Conceptual approach to the Evaluation of Cause for the Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout population.**

## Participation, Engagement & Transparency

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

- Ktunaxa Nation Council
- BC Ministry of Forests,
- BC Ministry of Land, Water and Resource Stewardship

- BC Ministry Environment & Climate Change Strategy
- Ministry of Energy, Mines and Low Carbon Innovation
- Environmental Assessment Office

## Citations for Evaluation of Cause Team Reports

| 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. |

| Focus | Citation |
|---|---|
| Food availability | Wiebe, A., Orr, P., & Ings, J. (2022). *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. (2022). 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. |

| Focus | Citation |
|---|---|
| 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. |

# 1. INTRODUCTION

Teck Coal undertakes aquatic monitoring programs in the Elk Valley, including fish population monitoring. Using data collected from 2017 to 2019 in Harmer and Grave Creeks, Cope and Cope (2020) reported low abundance of age-1 Westslope Cutthroat Trout (WCT; *Oncorhynchus clarkii lewisi*), which indicated apparent recruitment failure in Harmer Creek. 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 annual monitoring programs in the Harmer and Grave Creek population areas[9] from 2017 to 2021 (Thorley *et al.* 2022; Chapter 4, Evaluation of Cause), and several patterns related to recruitment[10] were identified:

- *Reduced Recruitment*[11] occurred during the 2017, 2018 and 2019 spawn years[12] in the Harmer Creek population and 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*[13].
- Recruitment was *Above Replacement*[14] for the 2020 spawn year in both the Harmer and Grave Creek populations.

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

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[9] "Grave Creek population area" includes Grave Creek upstream of the waterfall and Harmer Creek below Harmer Sedimentation Pond. "Harmer Creek population area" includes Harmer Creek and its tributaries (including Dry Creek) from Harmer Sedimentation Pond and upstream.

[10] Recruitment refers to the addition of new individuals to a population through reproduction. For the EoC, recruitment is defined as the estimated number of age-1 fish in the fall (i.e., late-September/early October) following the first full overwintering period.

[11] 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, Evaluation of Cause, Harmer Creek Evaluation of Cause Team, 2022).

[12] The spawn year is the year a fish egg was deposited, and fry emerged.

[13] 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 Evaluation of Cause, Harmer Creek Evaluation of Cause Team, 2022).

[14] 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 Evaluation of Cause, Harmer Creek Evaluation of Cause Team, 2022)

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?** To investigate this question, the Team evaluated trends in WCT population parameters, including size, condition, and recruitment, and in the potential stressors[15] that could impact these parameters. The Team evaluated the trends in WCT population parameters based on monitoring data collected from 2017 to 2021 (reported in Thorley *et al.* 2022 and Chapter 4, Harmer Creek Evaluation of Cause Team 2022). The Grave Creek population area was used as a reference area for this evaluation.

The approach for analyzing potential stressors for the Evaluation of Cause was to: (1) characterize trends in each stressor for the Harmer and Grave Creek populations, (2) compare the trends between the two population areas, (3) identify any changes in Harmer Creek during the period of Reduced Recruitment, including the 2018 Recruitment Failure of the 2018 spawn year where appropriate, and (4) evaluate how each stressor trended relative to the fish population parameters. The Team then identified mechanisms by which the potential stressors could influence WCT and determined if the stressors were present at a sufficient magnitude and duration to have an adverse effect on WCT during the period of Reduced Recruitment. Together, these analyses were used in the Evaluation of Cause report to support conclusions about the relative contribution of each potential stressor to the Reduced Recruitment observed in the Harmer Creek population area.

Ecofish Research Ltd. (Ecofish) was asked to act as a Subject Matter Expert (SME) for an evaluation of calcite as one potential stressor. Exposure to calcite can have adverse effects on fish and fish habitat. This report investigates calcite conditions in Grave and Harmer creeks and their tributaries. This document is one of a series of SME reports that supports the integrated Harmer Creek Westslope Cutthroat Trout Evaluation of Cause (Harmer Creek Evaluation of Cause Team 2022). For additional information, see the preceding Reader's Note.

## 1.1. Background

### 1.1.1. Report-Specific Background

Calcite is a solid calcium carbonate deposit that can occur on the substrates of freshwater streams when dissolved calcium carbonate precipitates out of solution. Although naturally occurring, the magnitude and extent of calcite formation can increase downstream of mine spoils (Teck 2018). Calcite accumulation in streams can lead to consolidated substrates by cementing rocks together (referred to

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[15] 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 and (1) selenium data because the selenium report was not complete and substantive new datasets were available and (2) water temperature data for 2021 in the temperature report because a new sampling location was added in upper Grave Creek that contributed to our understanding of the Grave Creek population area.

as "concretion"). Calcite accumulation has the potential to negatively affect aquatic habitat through changes to stream sediment characteristics (Barrett *et al*. 2016; Hocking *et al*. 2020).

Calcite concretion can adversely affect fish via reduced suitability of spawning, incubation, and overwintering habitat, or via effects to benthic invertebrates that are important prey for adult and juvenile fish (Robinson 2010; Barrett *et al*. 2016; Wright *et al*. 2018; Hocking *et al*. 2020; Wiebe *et al*. 2022). The causal effect pathways examined in this report[16] are depicted in Figure 1 and include:

- **Spawning Habitat**—Calcite can reduce spawning habitat suitability by concreting substrate particles and making them immovable for redd construction, which can limit spawning success and recruitment.
- **Incubation Habitat**—Calcite can reduce hyporheic flow and dissolved oxygen in streambed substrates during egg incubation, which can decrease incubation success and recruitment.
- **Overwintering Habitat**—Calcite can reduce overwintering habitat suitability (especially for juveniles) by concreting substrate particles and making interstitial spaces inaccessible, which can increase overwintering mortality.
- **Invertebrate Habitat**—Calcite can reduce benthic invertebrate habitat suitability, which can decrease invertebrate production and prey availability for fish, potentially causing lower growth rates or body condition and lower survival or reproduction.

The ecological mechanisms of each causal effect pathway are described in Section 1.1.1.1 to Section 1.1.1.4 below.

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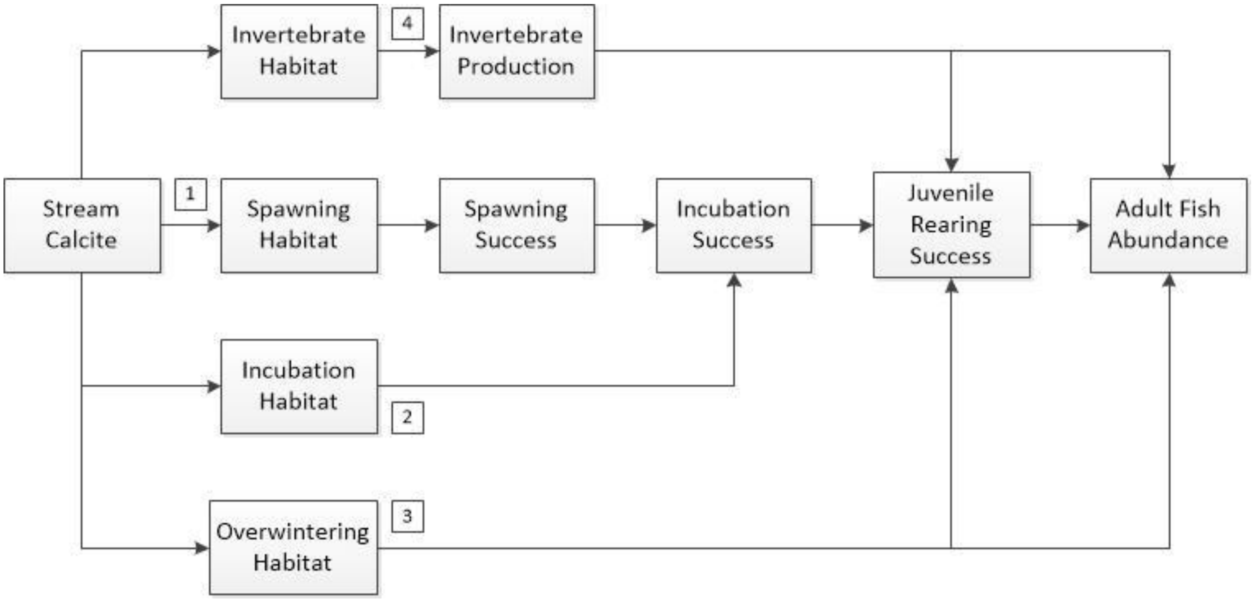
[16] Note: A fifth pathway related to biogenic calcite precipitation and dissolution was evaluated for the upper Fording River EoC, but is not evaluated here because this toxicity pathway is expected to act on incubation success and/or invertebrate production, both of which are already addressed. For additional details on the biogenic calcite causal pathway please see Hocking *et al.* (2021).

**Figure 1.** **Causal effect pathways diagram depicting the linkages between calcite and WCT recruitment. The numbered boxes refer to the individual pathways evaluated in this report.**



#### 1.1.1.1. Spawning Suitability

Calcite accumulations on the streambed can cause concretion of the substrate, which can reduce spawning suitability by affecting the ability of WCT to move the substrate and build redds, thereby reducing recruitment or forcing fish to move to more suitable habitat to spawn. Studies supporting Teck's Calcite Biological Program (Hocking *et al.* 2020) have developed a draft WCT spawning suitability curve with calcite concretion negatively related to the presence and count of redds per mesohabitat unit in a stream. Overall, spawning habitat suitability has been found to decrease rapidly with increasing levels of calcite concretion (Hocking *et al.* 2020). The current spawning suitability curves are based on calcite, habitat, and redd data from 2018 and 2019 and will be revised using additional data from 2020 and 2021 (Hocking *et al. In Preparation*).

#### 1.1.1.2. Incubation Condition

Calcite accumulations on the streambed can interfere with exchange of surface water and hyporheic water, which may lead to a reduction in water flow and dissolved oxygen in the interstitial spaces of gravel used for spawning and egg incubation. Wright *et al.* (2017, 2018) conducted field studies of Calcite Index (CI), hyporheic dissolved oxygen and flow, and environmental covariates (i.e., fish habitat variables, hyporheic water quality, substrate composition, and surface hydrology). Results from these studies are used in this report to assess this causal effect pathway.

#### 1.1.1.3. Overwintering Habitat

Generally, WCT migrate for overwintering to pools or interstitial areas, which protect them from harsh winter conditions (Cope *et al.* 2016) and high energy use (Cunjak 1996). Specifically, Cope and Cope (2020) noted that deep pool habitats suitable for overwintering are scarce in the Grave Creek watershed and suggested that all age classes appear to use coarse substrates as overwintering habitat. Small salmonids are known to seek cover in interstitial spaces in the stream substrate (McMahon and Hartman 1989; Lindstrom and Hubert 2004) but use by older age classes is likely determined in part by availability of suitable habitats and body size of the fish.

Calcite concretion is hypothesized to influence suitability of overwintering habitat for WCT by restricting access to interstitial spaces used by small-bodied individuals, particularly juveniles, during overwintering. If juvenile fish are unable to find suitable overwintering habitat due to high calcite concretion, then recruitment may be affected. This pathway is somewhat speculative since direct studies of overwintering success in relation to calcite levels have not been completed. Nevertheless, the pathway is deemed reasonable given knowledge of WCT habitat requirements and behaviours and observations from studies related to the other pathways evaluated here.

#### 1.1.1.4. Invertebrate Prey Habitat

Calcite can influence invertebrate habitat availability and quality, which in turn can reduce invertebrate production and food availability for WCT. Barrett *et al.* (2016) investigated the relationship between calcite and benthic invertebrate community characteristics in the Elk Valley and found an influence of calcite on some invertebrate species (e.g., % Ephemeroptera) at CI greater than ~1.0. Decreases in food availability can lead to reduced growth and survival of fry and parr, leading to Reduced Recruitment. Note that changes to food availability and WCT body condition are addressed in a separate SME report (Wiebe *et al.* 2022).

### 1.1.2. Author Qualifications

Since 2016, Ecofish has been involved in studies in the Elk River watershed to quantify the relationships between calcite and fish spawning and incubation success through the Calcite Biological Program (Wright *et al.* 2017; 2018; Hocking *et al.* 2019; 2020).

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

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

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

**Morgan Hocking, Ph.D., R.P.Bio.**

Morgan is Senior Environmental Scientist with Ecofish with over 20 years of experience conducting salmonid conservation and watershed resource management projects in British Columbia. For much of his career, he has studied how spawning Pacific salmon affect terrestrial biodiversity, and how this information can be used in ecosystem-based management. He uses a combination of field studies, experiments, watershed spatial data, quantitative modelling, and novel tools in ecology such as stable isotopes and environmental DNA to assess watershed status and the relationships between watershed developments and biodiversity and has published 25 peer-reviewed articles on his work. Morgan has extensive experience in designing and implementing large-scale monitoring programs and has over 15 years of experience working with First Nations, primarily related to fisheries management in the Great Bear Rainforest.

With Ecofish, Morgan works on technical project management, community engagement, experimental design, data analysis, reporting, and senior technical review on a diversity of projects such as the Cumulative Effects Monitoring Program in the Skeena watershed (Environmental Stewardship Initiative), the Fish and Wildlife Compensation Program (FWCP) Action Plan Update (FWCP Coastal and FWCP Peace), the Site C Tributary Mitigation Program (BC Hydro), and the Ecofish environmental DNA program. Morgan is the technical lead of the Calcite Biological Effects Program with Teck, the Teck Kilmarnock eDNA study, and the Teck Growing Season Degree Days Regional Model. Morgan also holds a position as an Adjunct Professor in the School of Environmental Studies at the University of Victoria.

## 1.2. Objective

The objective of this report was to evaluate calcite conditions in the Grave and Harmer Creek study areas using data collected from 2013 to 2019 to assess potential effects related to Reduced Recruitment in the Harmer Creek population (Map 1). Potential impacts were evaluated for four effect pathways mediated through changes to substrate conditions: spawning, incubation, overwintering, and invertebrate prey. Exposure to calcite could lead to Reduced Recruitment if a large proportion of the population was affected through one or more of these pathways.

The specific question evaluated was:

1. Did exposure to calcite cause or contribute to the WCT Reduced Recruitment in Harmer Creek in the 2017, 2018, and 2019 spawn years?

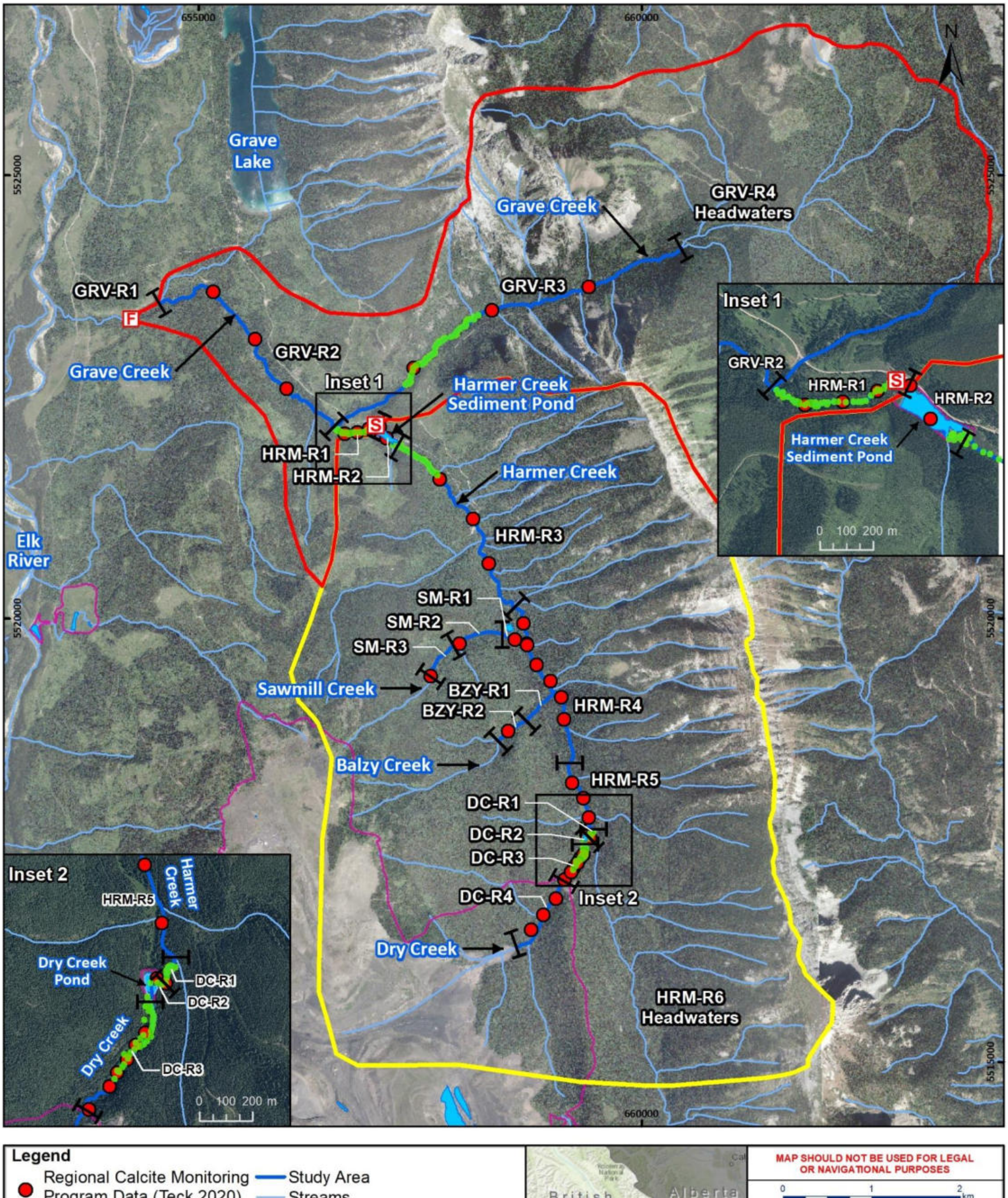
## 1.3. Approach

This report evaluates calcite on the streambed and its potential relationship to the Reduced Recruitment in the Harmer Creek population area. The evaluation includes separate analyses and conclusions that address the four causal effect pathways as described in Section 1.1.1. Details of data sources, data, and analytical approach are provided in Section 2.

The assessment was completed in three steps:

1) Identification, selection, and description of calcite pathways (i.e., development of an *a priori* rationale for how calcite might adversely affect WCT);
2) Determination of the spatial and temporal trends in calcite levels in fish-bearing habitat within the Grave and Harmer creek population areas, including comparisons among different stream reaches and WCT populations (i.e., determine calcite levels and whether they changed during the period of interest); and
3) Assessment of biological effects given the trends in calcite levels and whether the conditions were met for adverse biological effects.

# SME Report: Calcite. Overview Map



**Legend**

- ● Regional Calcite Monitoring Program Data (Teck 2020)
- ● Calcite Biological Program Data
- I Reach Break

**Barriers to Fish**

- S Spillway
- F Falls

- — Study Area
- — Streams
- 🟦 Water Management Polygons

**Permit Regions**

- ☐ EVO

**Population Area**

- 🟥 Grave Creek Population Area
- 🟨 Harmer Creek Population Area

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 1 2 km

Scale: 1:60,000

| NO. | DATE | REVISION | BY |
|---|---|---|---|
| 1 | 2022-03-18 | 1229_SME_StressorCalcite_4508_20211012 | EEC |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

Date Saved: 2022-03-18
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1229_EVWQP\MXD\Overview\1229_SME_StressorCalcite_4508_20211012.mxd

# 2. METHODS

## 2.1. Study Area

The study area is described in detail in Harmer Creek Evaluation of Cause Team (2021) and includes the Grave Creek and Harmer Creek population areas within the Grave Creek watershed (Map 1). The Grave Creek population area includes the Grave Creek mainstem and tributaries upstream of the impassable falls near the confluence with the Elk River; the population area excludes the Grave Lake sub-watershed but includes Harmer Creek reach 1, which is downstream of Harmer Sedimentation Pond and accessible to fish in Grave Creek. The Harmer Creek population area includes the Harmer Creek mainstem and tributaries upstream of Harmer Sedimentation Pond.

The Grave Creek and Harmer Creek population areas are broadly similar in watershed area, fish accessible stream length, habitat types and distribution, flow, and WCT use of the habitats (Cope and Cope 2020, Akaoka and Hatfield 2022, Hocking *et al.* 2022, Harmer Creek Evaluation of Cause Team 2022). There are some differences in physical attributes between the population areas; however, for the purposes of this report the population areas are considered sufficiently similar to allow comparisons of calcite levels and expected effects.

## 2.2. Calcite Data

### 2.2.1. Calcite Index, Calcite Presence, and Calcite Concretion

Calcite at a location is described using the calcite index (CI) and its components, calcite presence (amount of calcite present on stream sediments; Cp) and calcite concretion (the degree to which calcite is binding individual streambed particles; Cc). CI is the sum of Cp and Cc.

Calcite is measured using a modified Wolman pebble count (Wolman 1954). Beginning at the downstream end of a site, a field technician enters the stream and haphazardly selects an individual pebble and attempts to remove the rock. This is repeated for 100 observations per site (though sample size is reduced in some cases to 30 observations per site to increase efficiency and allow coverage of more mesohabitat units), with the following observations recorded for each particle:

a) Calcite concretion (Cc):

- Was the particle removed without calcite-induced resistance (score recorded = 0)?
- Was the particle removed with any noticeable amount of force to overcome calcite-induced resistance (score recorded = 1)?
- Was the particle non-movable or fully concreted by calcite (score recorded = 2)?

b) Calcite presence (versus absence; Cp):

- Did the individual particle have calcite deposition (No: score recorded = 0, Yes: score recorded = 1)?

Concretion score and calcite presence score are calculated and then summed to determine the composite CI value using to the following equations:

$$Cp = Calcite\ Presence\ Score\ = \frac{Sum\ of\ pebbles\ with\ calcite}{Number\ of\ pebbles\ counted}$$

$$Cc = Calcite\ Concretion\ Score = \frac{Sum\ of\ pebble\ concretion\ scores}{Number\ of\ pebbles\ counted}$$

$$CI = Calcite\ Index = Cp + Cc$$

Regional monitoring reports have assessed the relationship between the CI and its subcomponents (Cp and Cc), with the relationships of CI to Cp and Cc described in 2014 (Robinson and MacDonald 2014). Assessments show that CI scores below 1.00 are largely driven by Cp (Figure 2). Since the maximum Cp score is 1.00, any increase in CI beyond 1.00 must be primarily driven by increase in Cc (Figure 3). Concretion is indicative of a more advanced state of calcite deposition, occurring more substantially as CI reaches 1.00 and beyond. Cc, rather than CI or Cp, has the greatest influence on WCT spawning suitability (Hocking *et al.* 2020).

**Figure 2. Calcite index versus calcite presence scores.**

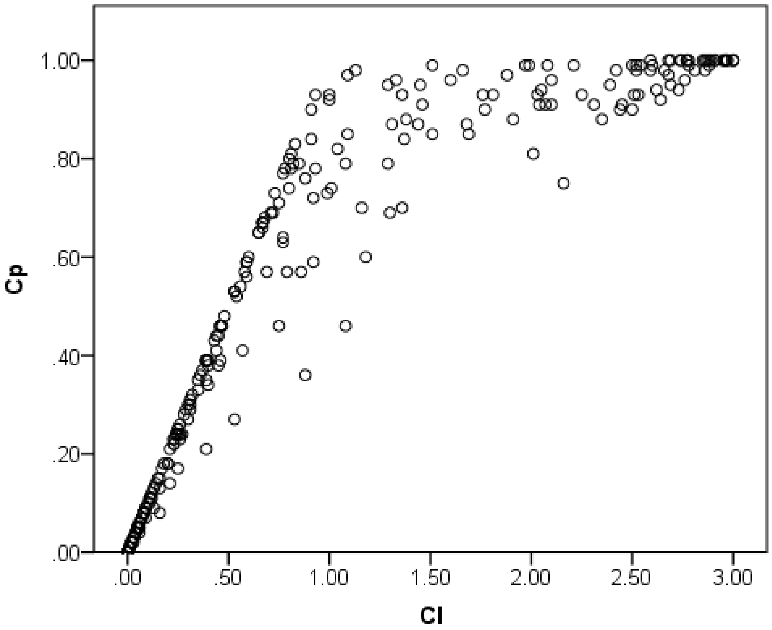


**Figure Note:** Data are from the 2018 Regional Calcite Monitoring Program (McCabe and Robinson 2020).

**Figure 3. Calcite index versus calcite concretion scores.**

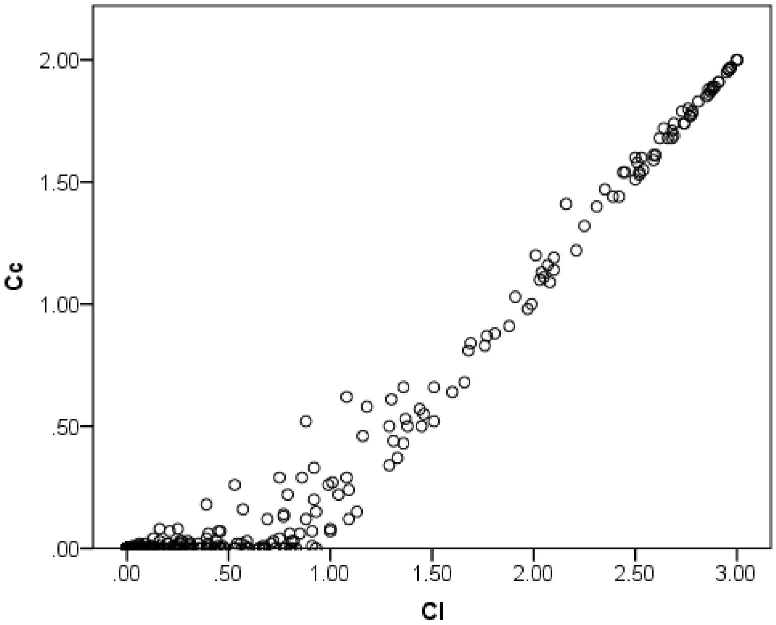


**Figure Note:** Data are from the 2018 Regional Calcite Monitoring Program (McCabe and Robinson 2020).

### 2.2.2. Regional Calcite Monitoring Program

Teck has been documenting the occurrence of calcite in streams downstream of its Elk Valley operations since 2008 (Berdusco 2009). The Regional Calcite Monitoring Program was implemented in 2013 (Robinson *et al.* 2013), with subsequent adjustments to methods and spatial coverage (Robinson *et al.* 2016; McCabe and Robinson 2020). Since 2013, sample locations have been visited annually in areas downstream of Fording River Operations (FRO), Greenhills Operations (GHO), Line Creek Operations (LCO), Elkview Operations (EVO), and Coal Mountain Operations[17] (CMO).

In 2016 and 2017, calcite sampling effort was reallocated from areas of low CI variability to areas of higher CI variability. With an improved understanding that within-reach variability was a function of the amount of calcite in a reach, the number of replicates (i.e., sites sampled) was set as a function of the degree of calcification in a particular stream reach (Table 1).

---

[17] Coal Mountain Operations is no longer operating and is in a Care and Maintenance status.

**Table 1. Number of sample sites per stream reach by CI bin for the Regional Calcite Monitoring Program.**

| CI Bin | N |
|---|---|
| 0.00 – 0.25 | 3 |
| 0.25 – 1.00 | 3 |
| 1.00 – 1.50 | 6 |
| 1.50 – 2.00 | 6 |
| 2.00 – 2.50 | 3 |
| 2.50 – 3.00 | 3 |

**Table Note:** This table was modified from Robinson and Atherton (2016).

During the Regional Calcite Monitoring Program, multiple reaches of Grave and Harmer creeks and tributaries have been surveyed. Overall, calcite data are available for 16 reaches (Table 2) and were used to assess the spatial distribution and temporal trends of calcite in the study area (Map 1). These reaches total ~18.3 km of river habitat within the study area. Reach 1 of Grave Creek was excluded from the analyses in this report since a natural waterfall precludes fish from ascending the falls; this reach is therefore not relevant to the EoC.

Not all stream reaches in the Grave Creek and Harmer Creek population areas were surveyed annually for calcite. Two reaches in Grave Creek, one in Harmer Creek, and one in Dry Creek were surveyed every year between 2013 and 2019 (Table 2). All other reaches were surveyed two to six times (at most once annually) over the seven-year time period (Table 2).

The number of replicate measurements in each reach also varied from year to year. For example, the sampling protocol for the Regional Calcite Monitoring Program calls for four replicate calcite measurements at different survey sites within each reach. The first measurement is taken at the downstream reach break (i.e., at the beginning of the reach, or at 0% of its length), with subsequent measurements taken at 25%, 50%, and 75% of the reach's total length. However, some deviations from this protocol occurred. For instance, in reach 2 of Dry Creek (e.g., DRYE2), only one replicate measurement was recorded in both 2013 and 2014, with similar cases for other reaches and years. Consequently, the resulting dataset is statistically "unbalanced", which influenced the selection of analytical methods (see Section 2.3 below). The final dataset derived from the Regional Calcite Monitoring Program contained 173 replicate calcite measurements representing 16 stream reaches in the Grave Creek watershed.

### 2.2.3. Calcite Biological Program

The Calcite Biological Program measured calcite, redds, and physical habitat in Grave, Harmer, and Dry creeks starting in 2019. This program was designed to assess relationships between calcite and spawning suitability. The program's survey area overlaps spatially with seven of the 16 reaches relevant to this report (Table 2). However, the sampling protocol used to collect the calcite data differed. For example, calcite was measured at the mesohabitat scale (e.g., channel units of pool, riffle, run, etc.), which is a smaller spatial scale than that used by the Regional Calcite Monitoring Program (Hocking *et al.* 2020; Robinson and MacDonald 2014). Consequently, Calcite Biological Program data were amalgamated by averaging replicates from mesohabitats to the stream reach level prior to the data being combined with the Regional Calcite Monitoring Program dataset.

**Table 2. Summary of calcite data used to characterize the Grave and Harmer creeks study area.**

| Stream | Stream Reach | WCT Population | Length (m) | Replicates[1] | Data Sources[2] | Sample Years[3] |
|---|---|---|---|---|---|---|
| Grave Creek | GRV-R2 | Grave Creek | 3045 | 12 | Regional | 2013, 2014, 2015, 2018 |
| | GRV-R3 | | 4749 | 19 | Regional, Biological | 2013, 2014, 2015, 2016, 2017, 2018, 2019* |
| Harmer Creek | HRM-R1 | Harmer Creek | 582 | 22 | Regional, Biological | 2013, 2014, 2015, 2016, 2017, 2018, 2019* |
| | HRM-R2 | | 347 | 5 | Regional, Biological | 2013, 2014, 2019* |
| | HRM-R3 | | 2642 | 22 | Regional, Biological | 2013, 2014, 2015, 2016, 2017, 2018, 2019* |
| | HRM-R4 | | 2133 | 15 | Regional | 2013, 2014, 2015, 2016, 2017, 2018 |
| | HRM-R5 | | 846 | 12 | Regional | 2013, 2014, 2015, 2018 |
| EVO Dry Creek | DC-R1 | | 107 | 6 | Regional, Biological | 2013, 2014, 2015, 2018, 2019* |
| | DC-R2 | | 136 | 3 | Regional, Biological | 2013, 2014, 2019* |
| | DC-R3 | | 522 | 24 | Regional, Biological | 2013, 2014, 2015, 2016, 2017, 2018, 2019* |
| | DC-R4 | | 986 | 7 | Regional | 2013, 2014, 2015, 2018, 2019* |
| Sawmill Creek | SM-R1 | | 296 | 10 | Regional | 2013, 2014, 2015, 2016, 2017, 2018 |
| | SM-R2 | | 612 | 6 | Regional | 2013, 2014, 2015, 2016, 2017, 2018 |
| | SM-R3 | | 461 | 6 | Regional | 2013, 2014, 2015, 2016, 2017, 2018 |
| Balzy Creek | BZY-R2 | | 397 | 6 | Regional | 2013, 2014, 2015, 2016, 2017, 2018 |

[1] Number of mesohabitats surveyed for the Calcite Biological Program are not included; only a single value (i.e. the average) was.

[2] "Regional" refers to the Regional Calcite Monitoring Program; "Biological" refers to the Calcite Biological Program.

[3] Asterisk denotes years for which Calcite Biological Program data were included in the analyses

## 2.3. Calcite Trends

Calcite was assessed at two different spatial scales: 1) at the stream level to assess trends in calcite across different streams (Grave, Harmer, Sawmill, Balzy, and Dry creeks), and 2) at the population level to assess trends in calcite in the habitats available to either of the two isolated fish populations (i.e., the Grave Creek population and the Harmer Creek population).

Linear regression models were used to test three different calcite hypotheses:

- **Hypothesis 1**: Calcite differs by stream or population (i.e., Location).
    - Linear Equation 1: Calcite metric (CI or Cc) ~ Location.
- **Hypothesis 2**: Calcite differs by Location and over time (i.e., Time).
    - Linear Model 2: Calcite metric (CI or Cc) ~ Location + Time.

- **Hypothesis 3**: Calcite differs by Location, and over time, but this occurs in specific locations (i.e., Location*Time interaction).
    - Linear Model 3: Calcite metric (CI or Cc) ~ Location + Time + Location*Time.

The model term "Location" defined the spatial scale being tested by the model; it was a categorical variable referring to either stream or population. The model term "Time" defined the duration for the temporal trend being tested; it was a continuous variable represented by the integer of the survey year. The model interaction term "Time*Location" allowed the rate of change (i.e., the slope of the linear model) to vary between locations. For example, the explanatory factor associated with *timing* criterion would be met if increases in calcite were observed in the Harmer Creek population area but not in the Grave Creek population area.

To evaluate and compare models, pair-wise analyses of variance tests (ANOVA) and Akaike Information Criterion (AIC) scores were used. The pair-wise ANOVA tested for differences in the amount of variability in the data explained by the two models, whereas AIC scores allowed comparison of the goodness of fit of the models. When comparing models, it is best practice to choose the most parsimonious model (i.e., the one with fewest covariates) for a given AIC score. A more complex model is favoured only if it explains sufficiently more variability in that data to negate the "penalty" of including another covariate in the model. Models are said to be similar when the AIC differences are less than 4. With the best model identified, results were further evaluated using pairwise post-hoc t-tests to identify which comparisons (i.e., levels within a categorical value) were significantly different. Tukey's p-value adjustment for multiple comparisons was implemented to guard against Type I errors.

All modelling analyses were completed using the "base" and "emmeans" packages in the R Statistical Language (R Core Team 2021). Prior to modelling, calcite data were weighted by their corresponding reach length. This weighting scheme was applied to better account for unequal reach lengths, since reaches ranged in length from 107 m to 3045 m. Trends in calcite by stream and population were presented visually using line graphs of the weighted averages (±1 SE) for CI and Cc.

### 2.4. Biological Effects

To evaluate whether the Harmer Creek population was exposed to calcite conditions that could have caused or contributed to Reduced Recruitment, the four causal effect pathways (spawning suitability, incubation conditions, overwintering habitat, and invertebrate prey availability; see Section 1.1.1) were evaluated in terms of five explanatory factors: intensity, duration, spatial extent, location, and timing (Table 3). The following criteria were applied:

- **Calcite as a sole cause of the Reduced Recruitment**: Calcite levels need to have been high intensity, widespread, and of sufficient timing and duration within the period of interest.
- **Calcite as a contributor to the Reduced Recruitment**: Calcite levels need to have approached the intensity condition (Table 3), been evident in critical locations, and been of sufficient timing and duration within the period of interest.

**Table 3. Explanatory factors and conditions that needed to be met for calcite to have caused or contributed to the Reduced Recruitment in the Harmer Creek population.**

| Explanatory Factor | Condition |
|---|---|
| **Intensity** | Calcite levels were moderate to high (e.g., average annual CI >1 or $CI_c$ >0.5) |
| **Duration** | Elevated calcite levels persisted for two or more years |
| **Spatial Extent** | Calcite was widespread in Harmer Creek and tributaries |
| **Location** | Calcite was widespread in key habitats used by WCT |
| **Timing** | Elevated calcite levels were temporally coincident with the observed Reduced Recruitment |

### 2.4.1. Spawning Suitability

The draft spawning suitability curve developed by Hocking *et al.* (2020) for mean redd count was applied to the Cc data for the Grave and Harmer creeks study area to assess the *intensity* of calcite exposure (Figure 4). Cc data by stream reach and year were used as input data to the spawning suitability curve to compare estimated spawning suitability across streams, years, and between the Harmer Creek and Grave Creek populations. Calcite data were weighted by reach length for comparisons within streams and then by stream length for analyses of the Grave and Harmer Creek populations. Weighted averages and the 95% confidence intervals for spawning suitability were calculated over time, and expressed as a percentage decrease in suitability relative to a Cc value of zero. Tables and figures were assessed visually, focusing on the period of Reduced Recruitment. Absolute spawning suitability was not possible to calculate with available data due to the need to incorporate additional habitat and productivity variables. For example, spawning suitability may be limited by other factors such as suitable substrate and adult abundance.

This pathway was assessed using an *intensity* condition of Cc >0.5. This value represents an approximate level at which an adverse effect to spawning success was considered large enough to influence recruitment. The current draft curve predicts that mean redd count will decrease by 75% at a Cc score of 0.5, relative to average redd counts at a Cc score of 0. Of note, as described in Section 1.1.1.1, the Calcite Biological Program is ongoing and the spawning suitability curves for calcite will be updated as additional data are collected and analyzed. Analyses that include the 2020 and 2021 data (Hocking *et al.* 2021; Hocking *et al. In Preparation*) indicate that the spawning suitability relationship is similar but somewhat less steep than the curves developed in Hocking *et al.* (2020). The spawning suitability curve applied herein is thus likely to be conservative with respect to an estimate of effect of calcite to spawning WCT.

In addition to intensity, consideration of duration, spatial extent, location, and timing of calcite exposure was also required, per the descriptions provided in Table 3.

**Figure 4. Draft WCT spawning suitability response curves for calcite concretion.**

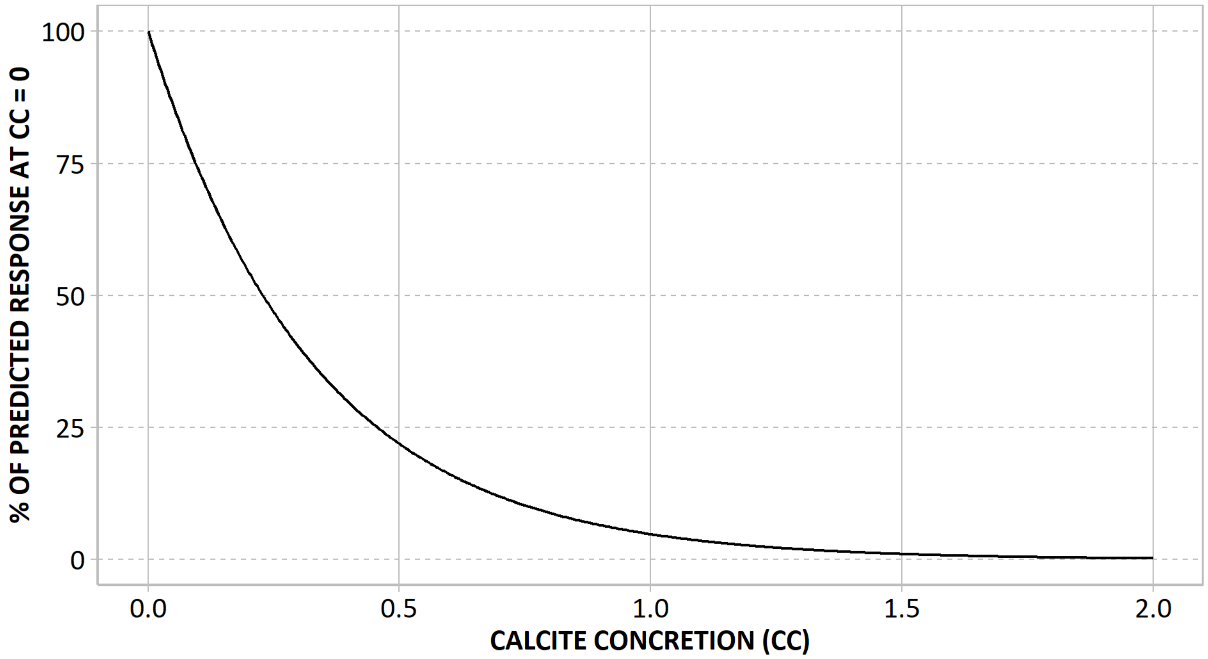


**Figure Note:** Spawning suitability curve created using data collected in 2018 and 2019 from 17 tributary streams of the Elk River, B.C. Suitability curves are model-averaged predictions of the effects of Cc on mean redd counts. Reproduced from Hocking *et al.* (2020).

### 2.4.2. Incubation Conditions

Potential effects to egg incubation conditions (leading to reduced juvenile recruitment) were assessed qualitatively relative to the five explanatory factors. Studies on the effects of calcite on hyporheic water flow and dissolved oxygen (Wright *et al.* 2017, 2018) were used to assess this causal effect pathway.

Wright *et al.* (2017, 2018) used two methods to measure hyporheic flow: a hydraulic head method using piezometers driven to 0 cm, 30 cm, and 50 cm depth within the substrate and a temperature method employing Tidbit temperature loggers installed in a vertical array at substrate depths of 10 cm to 40 cm. They used the data collected to model relationships between hyporheic conditions and CI, taking into consideration site characteristics and covariates (e.g., % fines), using linear mixed-effects models. Model outputs were then compared to BC Water Quality Guidelines for buried embryos/alevins and assessed in the context of WCT redd depths.

Wright *et al.* (2017, 2018) found that CI was an important predictor of dissolved oxygen in the substrate, but this effect occurred at depths in the substrate deeper than typical WCT redds. The model for dissolved oxygen predicted that at a maximum CI score of 3, the average instantaneous dissolved oxygen is ~7.5 mg/L at a depth of 30 cm and ~6 mg/L at a depth of 50 cm, both of which are at or above the instantaneous minimum BC Water Quality Guidelines for buried embryos/alevins.

The average redd depth for WCT is 10 to 30 cm (DeVries 1997, Magee and McMahon 1996); therefore, although dissolved oxygen concentrations observed in the studies were at times below the minimum guidelines for the protection of buried life stages, the most significant effects on incubation conditions were predicted to occur at sites with CI scores higher than ~1.25, relatively high percent fines, and at depths deeper than typical WCT redd depths. Results suggested that at depths less than 30 cm, increases in calcite may not be an important factor in determining incubation success.

This pathway was assessed using an *intensity* criterion of CI >1.0, since this was the level at which dissolved oxygen started to be influenced by CI (Wright *et al.* 2017, 2018). For the evaluation completed here, we selected a criterion of CI >1.0 as a precautionary value (i.e., precautionary relative to results in Wright *et al.* 2017, 2018) at which *may* have influenced recruitment. It should nevertheless be noted that effects to dissolved oxygen at typical redd depths were found to be minor, even in highly calcified habitats (Wright *et al.* 2017, 2018). In addition to intensity, consideration of duration, spatial extent, location, and timing of calcite exposure was also required, as per the descriptions provided in Table 3.

### 2.4.3. Overwintering Habitat

Potential effects to overwintering habitat (and influences on adult and juvenile mortality) were assessed qualitatively relative to the five explanatory factors. Previous studies on overwintering behaviour and movements of WCT and other salmonids (see McMahon and Hartman 1989; Cunjak 1996; Hiscock *et al.* 2002; Lindstrom and Hubert 2004; Huusko *et al.* 2007; Brown *et al.* 2011; Cope *et al.* 2016; Cope and Cope 2020) were reviewed to support assessment of this pathway.

Recent work by Cope and Cope (2020) and Akaoka and Hatfield (2022) showed that adult WCT in the watershed have small home ranges (on the order of ~1 km; although some fish moved farther, and others were limited by barriers) in the study area, and that summer and overwintering habitat are similar or the same. Because overwintering habitat can be limiting and substrate shelter provides important habitat, this causal effect pathway is based on the premise that Cc can affect the suitability and availability of (i.e., access to) interstitial areas that small fish (either juveniles or small-bodied adults) use for refuge during winter.

This pathway was assessed using an *intensity* condition of Cc >0.5. This value is somewhat arbitrary given the absence of an overwintering suitability curve, but it aligns with effect thresholds for other pathways. For the purposes of this analysis, the value represents an approximate level at which an adverse effect to overwintering success was considered large enough to have influenced recruitment. In addition to intensity, consideration of duration, spatial extent, location, and timing of calcite exposure was also required, as per the descriptions provided in Table 3.

### 2.4.4. Invertebrate Prey Availability

Supporting literature was used to assess potential effects to benthic invertebrate habitat (and influences on invertebrate production and prey availability to WCT) qualitatively relative to the five explanatory factors. Characterization of the effects of calcite on benthic invertebrates by Barrett *et al.* (2016) was the primary scientific reference used to assess this causal effect pathway. Benthic invertebrate monitoring data from 2017 to 2019 from the Regional Aquatic Effects Monitoring Program (RAEMP) was also reviewed to determine if invertebrate production and community endpoints differed from normal ranges at three monitoring stations in the Grave and Harmer creeks study area.

Barrett *et al.* (2016) surveyed 31 areas (24 mine-exposed and seven reference) in 2014 and 114 areas in 2015, with an additional 15 mine-exposed areas added (data provided by Teck) to expand the range of calcite conditions for which the study would be applicable. At each sampling area, benthic invertebrate communities were sampled using CABIN sampling protocols (Environment Canada 2012). Samples were sorted and identified to lowest practical taxonomic (LPT) level. Barrett *et al.* (2016) collected i*n situ* water quality measurements to provide additional context for use during interpretation of results (Figure 5).

The results from Barrett *et al.* (2016) suggest that seven selected benthic invertebrate community endpoints are correlated with relative calcite exposure. Key findings included a decrease in Ephemeroptera with CI > 1, an increase in Chironomidae with CI > 1, and an increase in Diptera with CI > 1. In contrast, total invertebrate abundance, which is a measure of total invertebrate production, was not correlated to CI ($p = 0.71$; Barrett *et al.* 2016).

Ephemeroptera are a preferred and common prey for drift-feeding salmonids like WCT (Minnow 2004, EVS 2005), but it is unclear if changes in invertebrate species composition would translate into effects on fish growth, recruitment, or abundance. WCT are known to feed on a variety of invertebrate prey, including terrestrial invertebrates and chironomids (McDonald and Strosher 1998; Romero *et al.* 2005; Fisheries and Oceans Canada 2016), so a shift in benthic species composition may not result in a change in fish growth or condition. Although these relationships cannot be solely ascribed to the effects of calcite due to potentially confounding effects of water quality or other parameters, the data indicate that benthic invertebrate community structure (and especially % Ephemeroptera) deviates from the normal range when CI is greater than 1.

This pathway was therefore assessed using an *intensity* condition of CI >1.0, based on results in Barrett *et al.* (2016) and Figure 5. In the evaluation provided here, this value represents an approximate level at which an adverse effect to benthic invertebrate suitability was considered large enough to have influenced recruitment. In addition to intensity, consideration of duration, spatial extent, location, and timing of calcite exposure was also required, as per the descriptions provided in Table 3.

**Figure 5. Scatterplot of selected benthic invertebrate endpoints in relation to calcite index.**

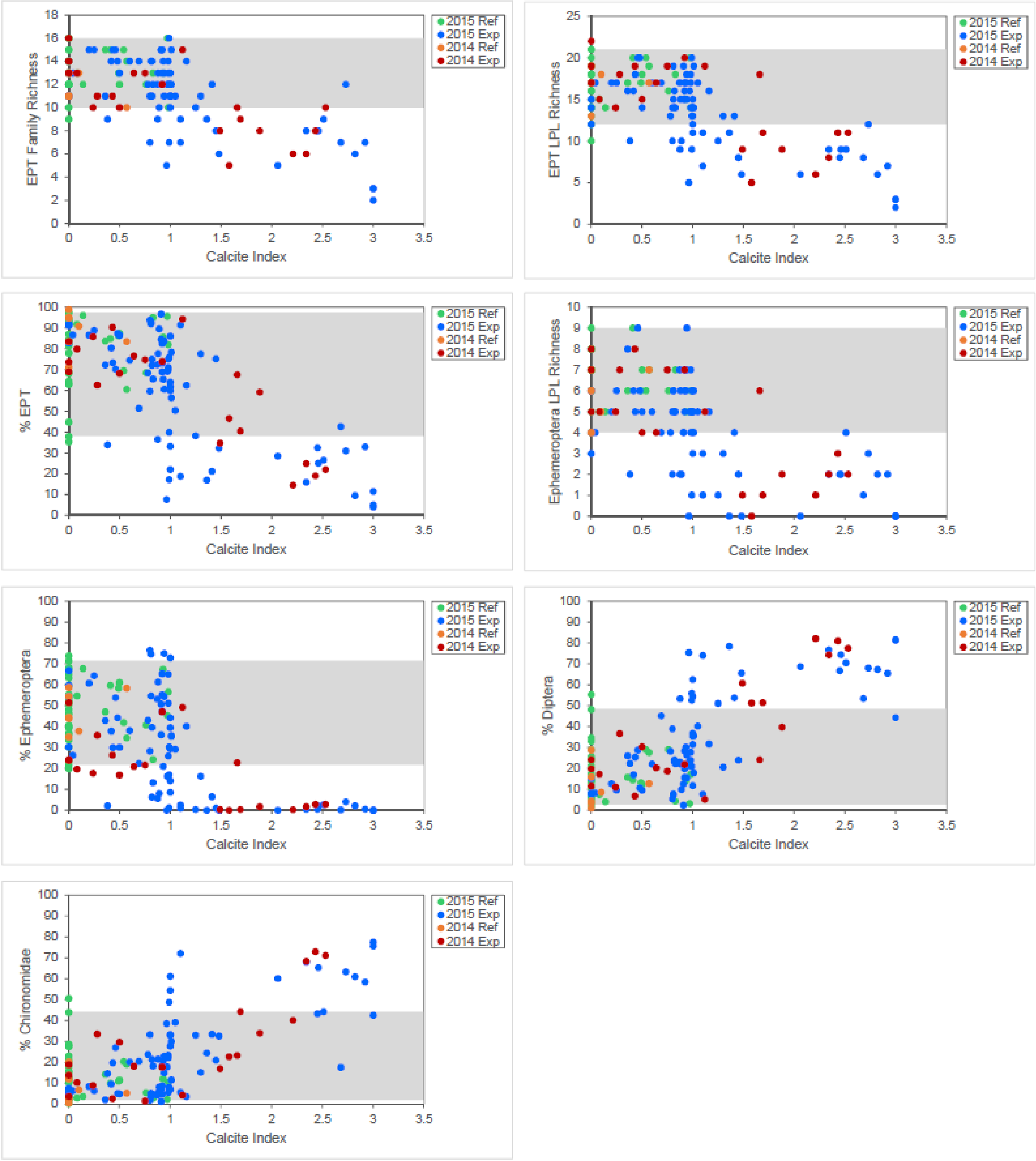


**Figure Note:** All reference and mine-exposed areas were sampled in Elk Valley in 2014 and 2015. Gray shade represents the normal range for each benthic endpoint, defined as the 2.5th and 97.5th percentiles for reference data collected in 2015. Figure reproduced from Barrett *et al.* (2016).

# 3. RESULTS

The results presented below include an assessment of temporal and spatial trends in calcite followed by an assessment of biological effects. First, we assess the temporal and spatial trends of calcite in fish-bearing habitat in the Grave and Harmer creeks study area (Section 3.1). This involves an assessment of trends in CI and Cc among different stream reaches and population areas, and whether changes in calcite accumulations have been observed over time in the period of interest. A set of three hypotheses were contrasted to test if calcite differs by location, over time, or over time but only in habitat supporting the Harmer and not Grave population. Second, we assess biological effects for the four causal effect pathways (Section 3.2) given the trends in calcite and whether the explanatory factors were met for adverse biological effects to cause or contribute to the recruitment failures.

## 3.1. Calcite Trends

Hypotheses one and three (Section 2.3; Table 4) were supported at the stream level, and hypothesis one was supported at the population level. At the stream level, calcite levels (e.g., CI and Cc) were high and increasing over time in Dry Creek but not in the other streams (Grave, Harmer, Balzy, and Sawmill creeks). Detailed stream-level results are provided in Section 3.1.1. At the population level, calcite exposure was higher for the Harmer Creek population than the Grave Creek population, but exposure was not changing over time for either population. The higher exposure for the Harmer Creek population was primarily due to high calcite levels in Dry Creek. Detailed population-level results are provided in Section 3.1.2.

**Table 4. Overview of hypothesis testing results for analyses completed at the spatial scale of individual streams (stream level) and between the Grave Creek and Harmer Creek populations (population level).**

<table>
<tr><th rowspan="2">Hypothesis</th><th colspan="2">Stream</th><th colspan="2">Population</th></tr>
<tr><th>CI</th><th>Cc</th><th>CI</th><th>Cc</th></tr>
<tr><td>1. Calcite level or exposure differs by stream or WCT population (i.e., "Location").</td><td colspan="2">Yes</td><td colspan="2">Yes</td></tr>
<tr><td>2. Calcite level or exposure differs by Location and over time (i.e., "Time").</td><td colspan="2">No</td><td colspan="2">No</td></tr>
<tr><td>3. Calcite level or exposure differs by Location, Time, but this occurs in specific locations (i.e., "Location*Time" interaction).</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
</table>

[1] "Yes" or "No" indicates which hypotheses were supported by the modelling results.

### 3.1.1. Stream Level

#### 3.1.1.1. Calcite Index

Hypothesis 1 was supported at the stream level as Dry Creek had higher CI than the other streams in the study area. The highest average annual CI values occurred in Dry Creek (ranging from 1.72 to 2.85), followed by Harmer Creek (ranging from 0.13 to 0.52) and Sawmill Creek (ranging from 0 to 0.30), with the lowest values occurring in Grave Creek (ranging from 0 to 0.09) and Balzy Creek (all values were zero) (Table 5; Figure 6).

The data did not support hypothesis 2; that is, analyses did not indicate that CI levels were changing notably over time for all streams as a group.

Hypothesis 3 was supported at the stream level. Specifically, the CI in Dry Creek was higher than in other streams and increasing over time, whereas in the remaining streams, CI was not statistically different among streams and was not changing over time. Model 3 (i.e., with the *Location*Time* interaction term) was better at explaining variance in CI than the other models (model 3 *versus* model 2: F = 5.21; df = 3; *p-value* = 0.003; AIC: 48.39 *versus* 58.11; and model 3 *versus* model 1: F = 4.07; df = 4; *p-value* = 0.005; AIC: 48.38 *versus* 56.71), indicating that the rate of change in CI varied across streams. Pairwise post-hoc t-tests of the significant *Location*Time* interaction term (F = 5.21; df = 3; *p-value* = 0.003; Figure 6) indicated that CI in Dry Creek was increasing at a significantly faster rate (average 0.15 [SE 0.04] CI units per year) than in any other stream in the study area (Dry *versus* Grave: t-ratio = 3.53, *p-value* = 0.004 ; Dry *versus* Harmer: t-ratio = 3.21, *p-value* = 0.011; Dry *versus* Sawmill: t-ratio = 3.31, *p-value* = 0.008). In contrast, differences in CI between the remaining streams were not significant (e.g., Grave *versus* Harmer: t-ratio = -0.35, *p-value* = 0.985; Grave *versus* Sawmill: t-ratio = 1.17, *p-value* = 0.647; Harmer *versus* Sawmill: t-ratio = 1.33, *p-value* = 0.546). Moreover, the estimated coefficients for *Time* at each Stream and resulting 95% confidence intervals for Grave, Harmer, and Sawmill creeks were centered on zero (e.g., Grave Creek estimate = -0.01 [-0.05; 0.03]; Harmer Creek estimate = 0.00 [-0.04; 0.05]; Sawmill Creek = -0.08 [-0.19; 0.04]).

Note that the average CI in Dry Creek decreased from 2.85 in 2018 to 2.14 in 2019, suggesting a potential non-linear trend through time. This nonlinearity may have resulted in an underestimated rate of change through *Time* in Dry Creek (Figure 6) during some portions of the time series.

Figure 6. Average annual calcite index values by stream in the Grave Creek watershed.

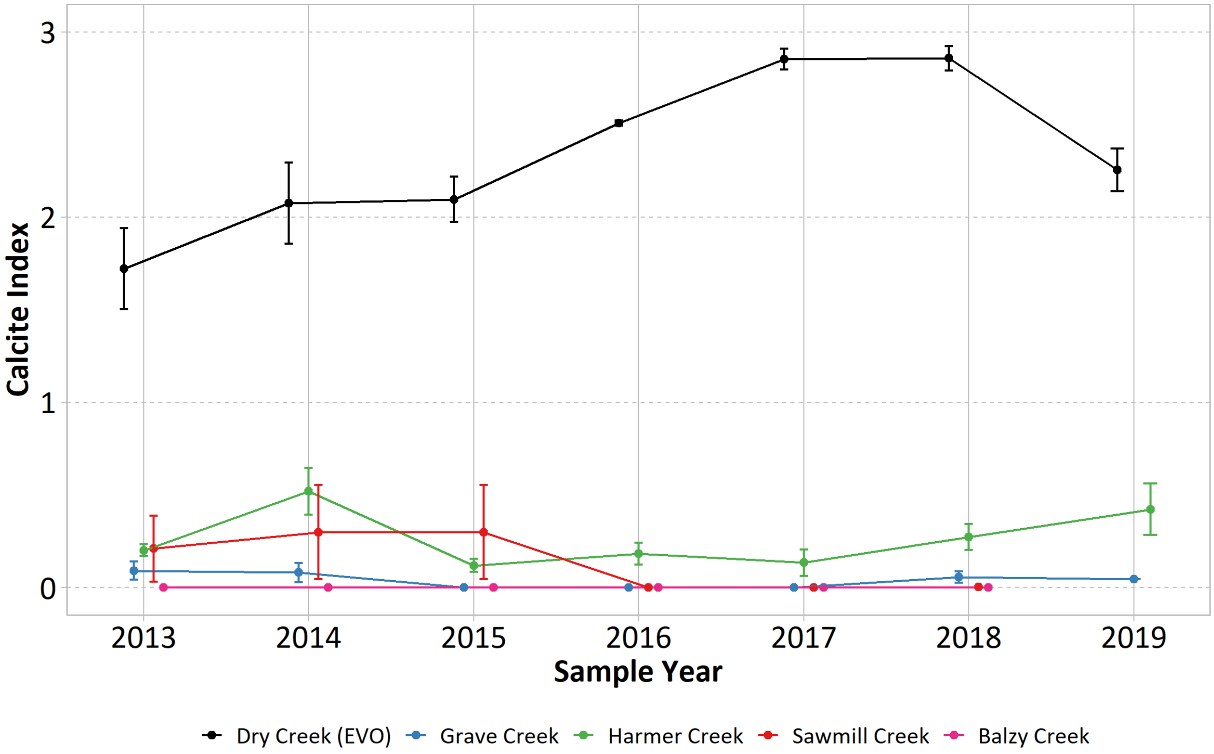


**Figure Note:** Average annual calcite values were weighted based on reach length. Error bars represent one standard error.

**Table 5. Average annual calcite index values by stream in the Grave Creek watershed.**

| Stream | Stream Reach | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|
| Grave Creek | GRV-R2 | 0.23 | 0.21 | 0.00 | N/A | N/A | 0.14 | N/A |
| | GRV-R3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 |
| | **Weighted Average** | 0.09 | 0.08 | 0.00 | 0.00 | 0.00 | 0.06 | 0.05 |
| Harmer Creek | HRM-R1[1] | 0.58 | 1.08 | 0.07 | 0.64 | 0.61 | 0.80 | 0.86 |
| | HRM-R2 | 0.17 | 0.10 | N/A | N/A | N/A | N/A | 0.67 |
| | HRM-R3 | 0.15 | 0.28 | 0.01 | 0.12 | 0.03 | 0.08 | 0.32 |
| | HRM-R4 | 0.17 | 0.70 | 0.19 | 0.05 | N/A | 0.35 | N/A |
| | HRM-R5 | 0.19 | 0.56 | 0.22 | N/A | N/A | 0.31 | N/A |
| | **Weighted Average** | 0.20 | 0.52 | 0.12 | 0.18 | 0.13 | 0.27 | 0.42 |
| Dry Creek | DC-R1 | 2.23 | 2.13 | 1.75 | N/A | N/A | 2.96 | 2.08 |
| | DC-R2 | 2.23 | 0.03 | N/A | N/A | N/A | N/A | 1.84 |
| | DC-R3 | 2.20 | 2.40 | 2.20 | 2.51 | 2.85 | 2.76 | 2.15 |
| | DC-R4 | 1.42 | 1.84 | 1.79 | N/A | N/A | 3.00 | 2.51 |
| | **Weighted Average** | 1.72 | 2.08 | 2.10 | 2.51 | 2.85 | 2.86 | 2.25 |
| Sawmill Creek | SM-R1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | N/A |
| | SM-R2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A |
| | SM-R3 | 0.76 | 1.08 | 1.08 | 0.00 | 0.00 | 0.00 | N/A |
| | **Weighted Average** | 0.21 | 0.30 | 0.30 | 0.00 | 0.00 | 0.00 | N/A |
| Balzy Creek | BZY-R2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A |
| | **Weighted Average** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A |

[1] The HRM-R1 stream reach is within the Grave Creek population area.

"N/A": No calcite index information was recorded.

#### 3.1.1.2. Calcite Concretion

Hypothesis 1 was supported at the stream level as Dry Creek had higher Cc than the other streams in the study area (Table 4). The highest average annual Cc values occurred in Dry Creek (ranging from 0.93 to 1.86), followed by low levels in Harmer Creek (ranging from 0 to 0.19), Sawmill Creek (ranging from 0 to 0.13), Grave Creek (ranging from 0 to 0.02), and Balzy Creek (all values were zero) (Table 6; Figure 7).

The evidence did not support hypothesis 2; that is, Cc levels were not changing notably over time for all streams as a group.

Hypothesis 3 was supported at the stream level; namely, Cc in Dry Creek was higher compared to other streams and increasing over time, whereas in the remaining streams, Cc was not statistically different among streams and was not changing over time. Model 3 (i.e., with the *Location*Time* interaction term) was better at explaining variance in Cc than the other models (model 3 *versus* model 2: F = 6.79; df = 3; *p-value* < 0.001; AIC: -34.84 *versus* -20.93; and model 3 *versus* model 1: F = 5.29; df = 4; *p-value* < 0.001; AIC: -34.84 *versus* -22.27), indicating the rate of change in Cc varied across streams. Pairwise post-hoc t-tests of the significant *Location*Time* interaction term (F = 6.80; df = 3; *p-value* < 0.001; Figure 6), indicated that Cc in Dry Creek was increasing at a significantly faster rate (average 0.10 [SE 0.02] Cc units per year) than in any other stream in the study area (Dry *versus* Grave: t-ratio = 4.08, *p-value* < 0.001; Dry *versus* Harmer: t-ratio = 4.28, *p-value* < 0.001; Dry *versus* Sawmill: t-ratio = 3.07, *p-value* = 0.016). In contrast, differences in Cc between the remaining streams were not significant (e.g., Grave *versus* Harmer: t-ratio = 0.46, *p-value* = 0.969; Grave *versus* Sawmill: t-ratio = 0.48, *p-value* = 0.963; Harmer *versus* Sawmill: t-ratio = 0.245, *p-value* = 0.995). Moreover, the estimated coefficients for *Time* at each stream and resulting 95% confidence intervals for Grave, Harmer, and Sawmill creeks were centered on zero (e.g., Grave Creek estimate = 0.00 [-0.02; 0.02]; Harmer Creek estimate = -0.01 [-0.04; 0.02]; Sawmill Creek = -0.02 [-0.08; 0.05]).

Note that the average Cc in Dry Creek decreased from 1.85 in 2018 to 1.14 in 2019, suggesting a potential non-linear trend through time (or sampling error). This nonlinearity may have resulted in an underestimated rate of change through *Time* in Dry Creek during some portions of the time series (Figure 6).

**Figure 7.** **Average annual calcite concretion values by stream in the Grave Creek watershed.**

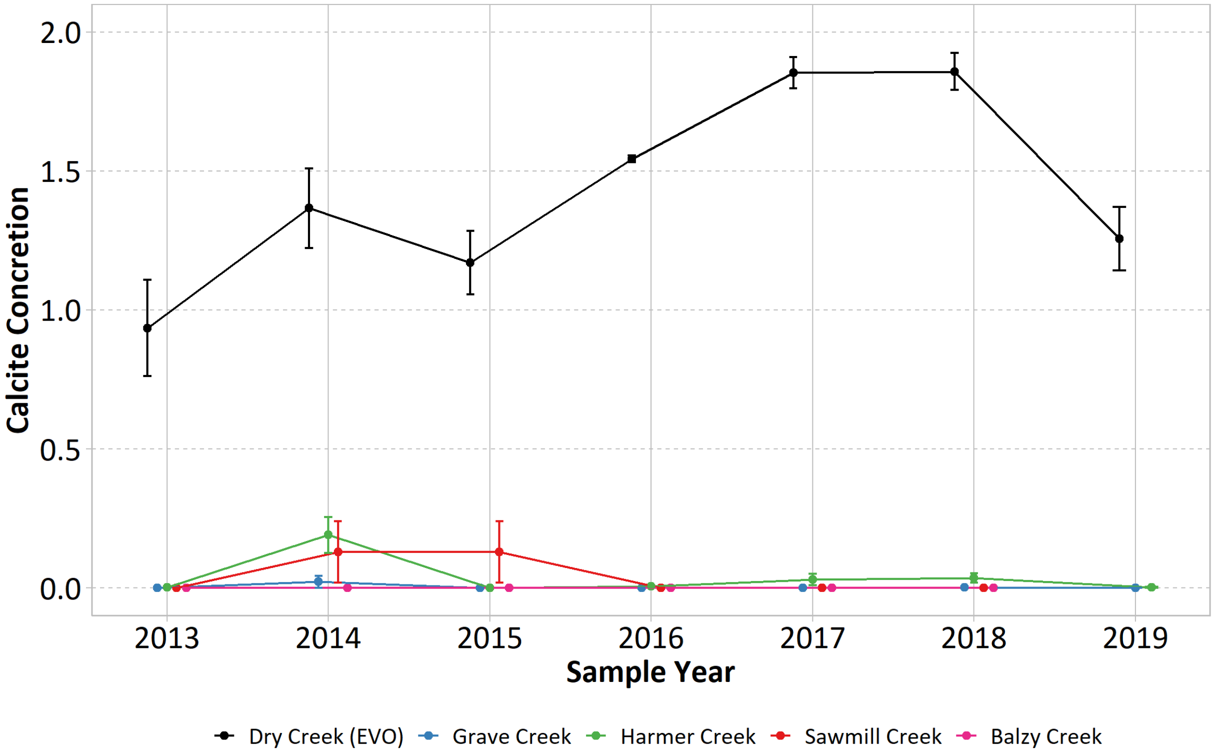


**Figure Note:** Average annual calcite values were weighted based on reach length. Error bars represent one standard error.

**Table 6.** Average annual calcite concretion values by stream in the Grave Creek watershed.

| Stream | Stream Reach | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|
| Grave Creek | GRV-R2 | 0.00 | 0.06 | 0.00 | N/A | N/A | 0.00 | N/A |
| | GRV-R3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Weighted Average** | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Harmer Creek | HRM-R1[1] | 0.00 | 0.29 | 0.00 | N/A | 0.16 | 0.08 | 0.00 |
| | HRM-R2 | 0.00 | 0.00 | N/A | N/A | N/A | N/A | 0.00 |
| | HRM-R3 | 0.00 | 0.12 | 0.00 | 0.01 | 0.00 | 0.02 | 0.00 |
| | HRM-R4 | 0.01 | 0.29 | 0.00 | 0.00 | N/A | 0.05 | N/A |
| | HRM-R5 | 0.00 | 0.16 | 0.00 | N/A | N/A | 0.01 | N/A |
| | **Weighted Average** | 0.00 | 0.19 | 0.00 | 0.01 | 0.03 | 0.04 | 0.00 |
| Dry Creek | DC-R1 | 1.38 | 1.16 | 0.81 | N/A | N/A | 1.96 | 1.09 |
| | DC-R2 | 1.38 | 0.00 | N/A | N/A | N/A | N/A | 0.84 |
| | DC-R3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | DC-R4 | 0.68 | 1.22 | 0.85 | N/A | N/A | 2.00 | 1.51 |
| | **Weighted Average** | 0.93 | 1.37 | 1.17 | 1.54 | 1.85 | 1.86 | 1.26 |
| Sawmill Creek | SM-R1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A |
| | SM-R2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A |
| | SM-R3 | 0.00 | 0.47 | 0.47 | 0.00 | 0.00 | 0.00 | N/A |
| | **Weighted Average** | 0.00 | 0.13 | 0.13 | 0.00 | 0.00 | 0.00 | N/A |
| Balzy Creek | BZY-R2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A |
| | **Weighted Average** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A |

[1] The HRM-R1 stream reach is within the Grave Creek population area.

"N/A": No calcite concretion information was recorded.

### 3.1.2. Population Level

#### 3.1.2.1. Calcite Index

Hypothesis 1 was supported at the WCT population level; namely, CI exposure for the Harmer Creek population was higher than for the Grave Creek population (Figure 8; Table 6). The average annual CI exposure experienced by the Harmer Creek population ranged from 0.37 to 0.73, whereas the Grave Creek population ranged from between 0.00 and 0.31 (Figure 8; Table 6). A caveat is that this is driven mainly by high CI in Dry Creek.

Hypotheses 2 and 3 were not supported; that is, it is unlikely that CI levels within either population area were changing notably over time. Analysis of Variance tests and AIC comparison showed that model 1 (i.e., that with the *Location* term only) was equally suitable to explain the variance in CI compared to models 2 and 3 (model 3 *versus* model 1: F = 0.38; df = 2; *p-value* = 0.684; AIC: 204.25 *versus* 201.04; model 1 *versus* model 2: F = 0.37; df = 1; *p-value* = 0.544; AIC: 201.04 *versus* 202.66). Model results indicated that the term *Location* was statistically significant (Grave Creek population CI = 0.09 [SE 0.10]; Harmer Creek population CI = 0.55 [SE 0.10]; F = 10.74; df = 1; *p-value* = 0.002), supporting the conclusion that CI exposure was greater for the Harmer Creek population than for the Grave Creek population.

**Figure 8. Average annual calcite index value by WCT population.**

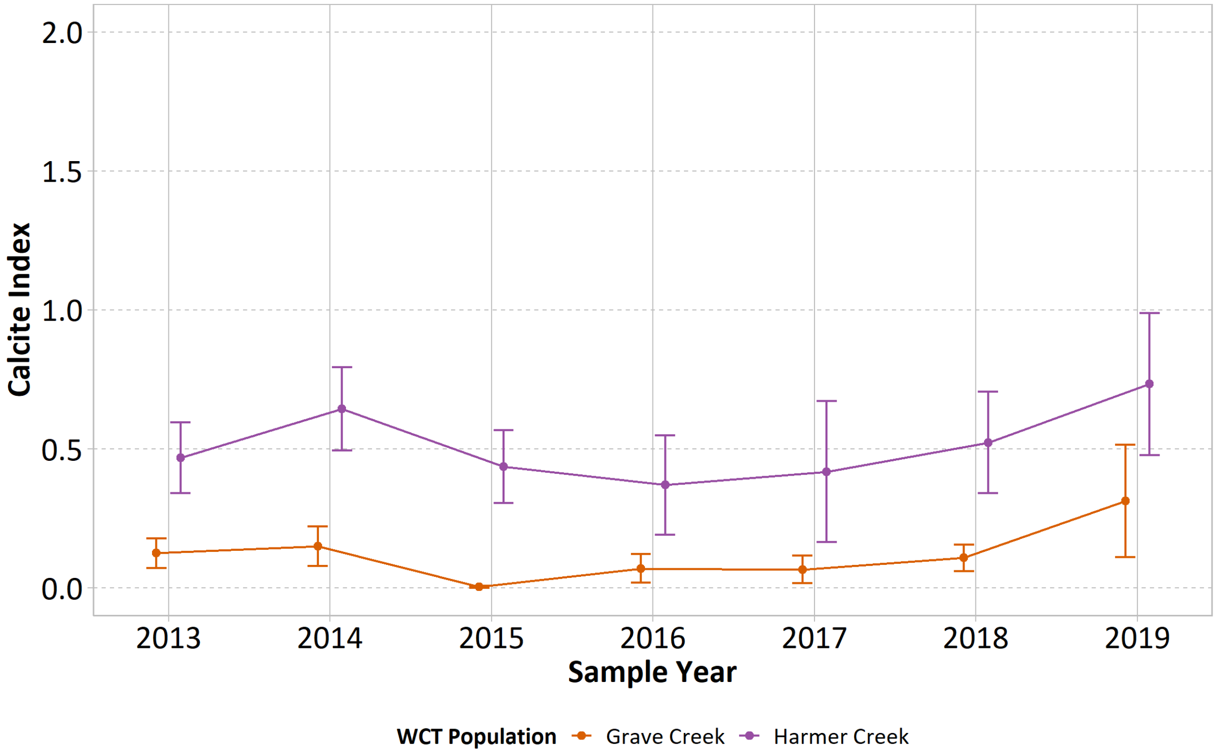


**Figure Note:** Average annual calcite index values were weighted based on reach length. Error bars represent one standard error.

Table 7. Average annual calcite index value by WCT population.

| WCT Population | Year | Weighted Average CI | Std. Dev |
|---|---|---|---|
| Grave Creek[1] | 2013 | 0.12 | 0.18 |
| | 2014 | 0.15 | 0.29 |
| | 2015 | 0.00 | 0.02 |
| | 2016 | 0.07 | 0.21 |
| | 2017 | 0.07 | 0.19 |
| | 2018 | 0.11 | 0.21 |
| | 2019 | 0.31 | 0.39 |
| Harmer Creek | 2013 | 0.47 | 0.67 |
| | 2014 | 0.64 | 0.69 |
| | 2015 | 0.44 | 0.74 |
| | 2016 | 0.37 | 0.78 |
| | 2017 | 0.42 | 0.98 |
| | 2018 | 0.52 | 0.89 |
| | 2019 | 0.73 | 0.84 |

[1] The HRM-R1 stream reach is within the Grave Creek population area.

#### 3.1.2.2. Calcite Concretion

Hypothesis 1 was supported at the WCT population level. Namely, Cc exposure for the Harmer Creek population was higher compared to that experienced by the Grave Creek population (Figure 9; Table 7). The average annual Cc exposure for the Harmer Creek population ranged from 0.18 to 0.32, whereas exposure for the Grave Creek population ranged from 0.00 to 0.04 (Figure 9; Table 7). A caveat is that this is driven mainly by high Cc in Dry Creek.

Hypotheses 2 and 3 were not supported; that is, it is unlikely that Cc levels within either population area were changing notably over time. Model 1 (i.e., that with the *Location* term only) was better at explaining variance in Cc compared to models 2 and 3 (model 3 *versus* model 1: F = 0.41; df = 2; *p-value* = 0.662; AIC: 127.88 *versus* 124.74; model 1 *versus* model 2: F = 0.37; df = 1; *p-value* = 0.543; AIC: 124.74 *versus* 126.35). Model 1 indicated that *Location* was statistically significant (Grave Creek population Cc = 0.01 [SE 0.06]; Harmer Creek population Cc = 0.27 [SE 0.06]; F = 8.81; df = 1; *p-value* = 0.004), supporting a conclusion that Cc exposure was greater for the Harmer Creek population compared to the Grave Creek population.

**Figure 9.** **Average annual calcite concretion value by WCT population.**

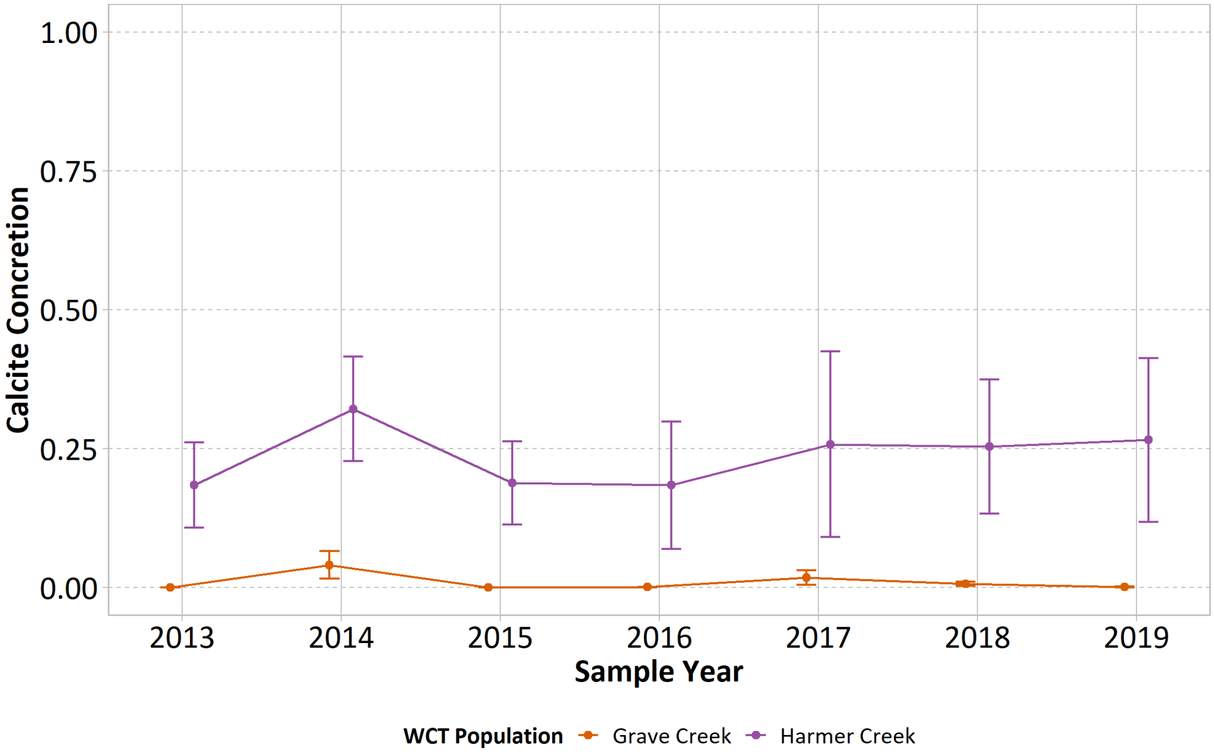


**Figure Note:** Average annual calcite concretion values were weighted based on reach length. Error bars represent one standard error.

**Table 8. Average annual calcite concretion value by WCT population.**

| WCT Population | Year | Weighted Average Cc | Std. Dev |
|---|---|---|---|
| Grave Creek[1] | 2013 | 0.00 | 0.00 |
| | 2014 | 0.04 | 0.10 |
| | 2015 | 0.00 | 0.00 |
| | 2016 | 0.00 | 0.00 |
| | 2017 | 0.02 | 0.05 |
| | 2018 | 0.01 | 0.02 |
| | 2019 | 0.00 | 0.00 |
| Harmer Creek | 2013 | 0.18 | 0.42 |
| | 2014 | 0.32 | 0.46 |
| | 2015 | 0.19 | 0.44 |
| | 2016 | 0.18 | 0.49 |
| | 2017 | 0.26 | 0.64 |
| | 2018 | 0.25 | 0.60 |
| | 2019 | 0.27 | 0.52 |

[1] The HRM-R1 stream reach is within the Grave Creek population area.

## 3.2. Biological Effects

To determine whether the Harmer Creek population was exposed to calcite conditions that could have caused or contributed to the Reduced Recruitment, the four causal pathways (spawning suitability, incubation conditions, overwintering habitat, and invertebrate prey availability; Section 1.1.1) were evaluated in terms of the five explanatory factors (intensity, duration, spatial extent, location, and timing; Table 3, Section 142.4).

### 3.2.1. Spawning Suitability

This section presents results of the spawning suitability analysis and describes the degree to which the conditions for explanatory factors were met. The predicted spawning suitability is presented as a percentage decrease in suitability relative to a Cc level of zero. Absolute spawning suitability was not estimated, as described in Section 2.4.1.

Spawning suitability results broadly mirrored the trends in Cc. A decline in spawning suitability was not observed for either population coincident with the period of Reduced Recruitment. Spawning suitability was considerably lower in Dry Creek than in the rest of the Harmer Creek population area or Grave Creek population area and decreasing over time (i.e., mirroring the trends in Cc in Dry Creek), but spawning suitability was consistently poor during the period of interest.

Supporting context for assessing effects of calcite on spawning is provided in Map 2, which shows the population areas with 2019 observed calcite levels and 2018-2019 redd observations. Redd observations in each of the population areas indicated widespread spawning in areas with high spawning habitat suitability and very little spawning in Dry Creek where spawning habitat suitability was low.

#### 3.2.1.1. Stream Level

Overall, spawning suitability was high for all streams except Dry Creek and for all years except one (2014) in Harmer Creek. A slight decline in suitability may have occurred in Harmer Creek from 2017 to 2018; however, suitability was near 100% in 2019. Changes in spawning suitability coincident with the Reduced Recruitment were not evident, suggesting that calcite was not the primary cause of Reduced Recruitment in Harmer Creek. In Dry Creek, spawning suitability was low throughout the period of interest and was lowest during the period of Reduced Recruitment (Table 9; Figure 10).

## Table 9. Predicted spawning suitability by stream.

| Stream | Year | Weighted Average Spawning Suitability | Std. Dev. |
|---|---|---|---|
| Grave Creek | 2013 | 1.00 | 0.00 |
| | 2014 | 0.95 | 0.14 |
| | 2015 | 1.00 | 0.00 |
| | 2016 | 1.00 | 0.00 |
| | 2017 | 1.00 | 0.00 |
| | 2018 | 1.00 | 0.01 |
| | 2019 | 1.00 | 0.00 |
| Harmer Creek[1] | 2013 | 0.99 | 0.02 |
| | 2014 | 0.65 | 0.29 |
| | 2015 | 1.00 | 0.00 |
| | 2016 | 0.98 | 0.03 |
| | 2017 | 0.93 | 0.15 |
| | 2018 | 0.91 | 0.12 |
| | 2019 | 0.99 | 0.01 |
| Dry Creek | 2013 | 0.12 | 0.13 |
| | 2014 | 0.06 | 0.21 |
| | 2015 | 0.04 | 0.03 |
| | 2016 | 0.01 | 0.00 |
| | 2017 | 0.00 | 0.00 |
| | 2018 | 0.00 | 0.00 |
| | 2019 | 0.03 | 0.02 |
| Sawmill Creek | 2013 | 1.00 | 0.00 |
| | 2014 | 0.79 | 0.34 |
| | 2015 | 0.79 | 0.34 |
| | 2016 | 1.00 | 0.00 |
| | 2017 | 1.00 | 0.00 |
| | 2018 | 1.00 | 0.00 |
| | 2019 | N/A | N/A |
| Balzy Creek | 2013 | 1.00 | 0.00 |
| | 2014 | 1.00 | 0.00 |
| | 2015 | 1.00 | 0.00 |
| | 2016 | 1.00 | 0.00 |
| | 2017 | 1.00 | 0.00 |
| | 2018 | 1.00 | 0.00 |
| | 2019 | N/A | N/A |

[1] The HRM-R1 stream reach is within the Grave Creek population

**Figure 10.** **Predicted spawning suitability by stream.**

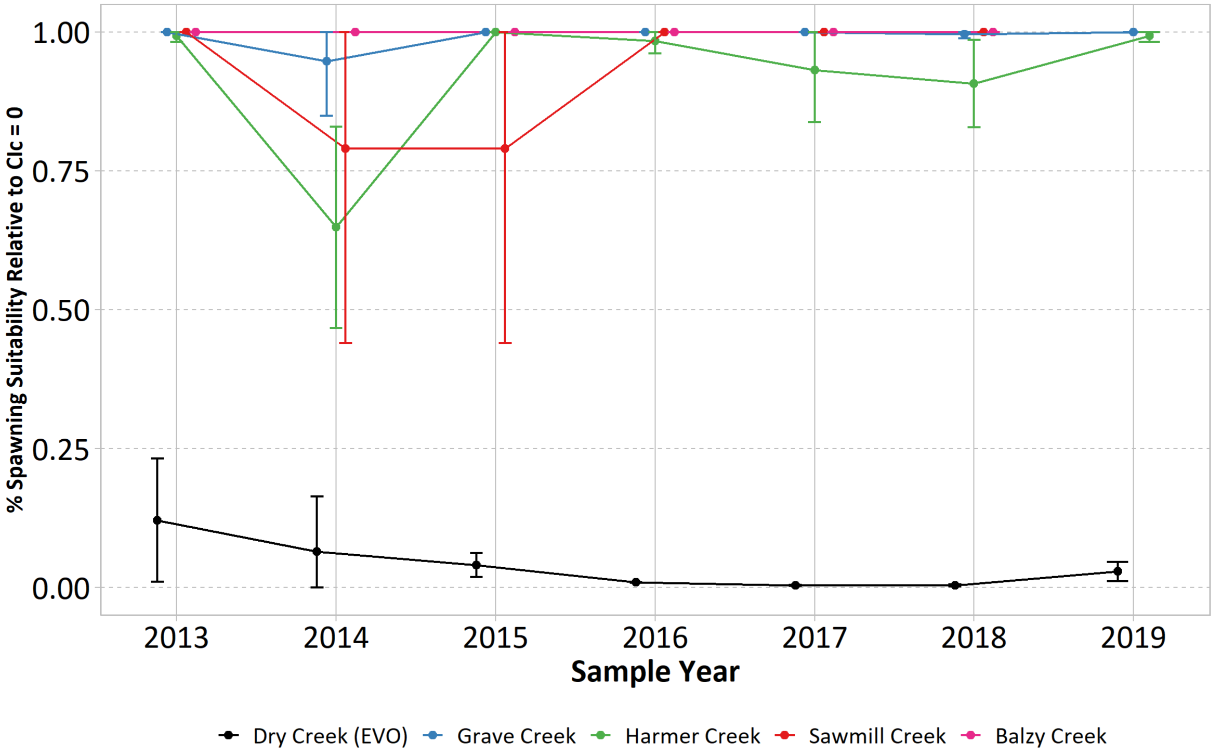


**Figure Note:** Spawning Suitability estimates are based on the suitability curve developed by Hocking *et al.* (2020) using stream reach level Cc records. The resulting suitability estimates were subsequently weighted based on reach length. Error bars represent 95% confidence interval.

#### 3.2.1.2. Population Level

Average spawning suitability across all years was lower for the Harmer Creek population than for the Grave Creek population. Average spawning suitability was 80% (ranging from 61% to 87%) for the Harmer Creek population and 98% (ranging from 91% to 100%) for the Grave Creek population (Table 9). The difference between average suitability for both populations was driven primarily by calcite conditions in Dry Creek; spawning suitability within the mainstem of Harmer Creek was close to 100% (Table 9). In general, average spawning suitability did not change markedly for either population across the time series; that is, there was no sudden decline in spawning suitability that was coincident with the period of reduced WCT recruitment (Figure 11).

**Table 10. Predicted spawning suitability by WCT population area for each year, averaged for each population and weighted by stream length (weighted average spawning suitability).**

| WCT Population | Year | Weighted Average Spawning Suitability | Std. Dev. |
|---|---|---|---|
| Grave Creek[1] | 2013 | 1.00 | 0.00 |
| | 2014 | 0.91 | 0.19 |
| | 2015 | 1.00 | 0.00 |
| | 2016 | 1.00 | 0.01 |
| | 2017 | 0.96 | 0.12 |
| | 2018 | 0.98 | 0.06 |
| | 2019 | 1.00 | 0.01 |
| Harmer Creek | 2013 | 0.82 | 0.35 |
| | 2014 | 0.61 | 0.35 |
| | 2015 | 0.84 | 0.35 |
| | 2016 | 0.87 | 0.31 |
| | 2017 | 0.86 | 0.34 |
| | 2018 | 0.81 | 0.32 |
| | 2019 | 0.79 | 0.39 |

[1] The HRM-R1 stream reach is within the Grave Creek population.

**Figure 11. Predicted spawning suitability by WCT population.**

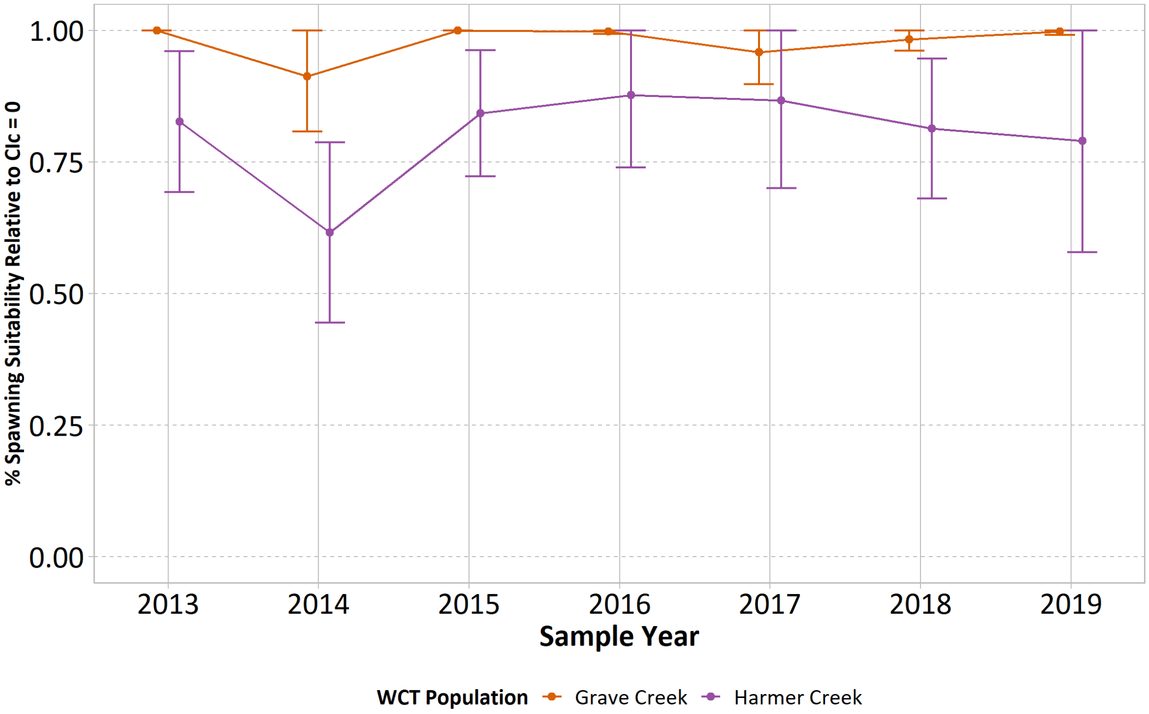


**Figure Note:** Spawning Suitability estimates are based on the suitability curve developed by Hocking *et al.* (2020) using stream reach level Cc records. The resulting suitability estimates were subsequently weighted based on reach length. Error bars represent 95% confidence interval.

The conditions for explanatory factors were not met for calcite to wholly explain the Reduced Recruitment in the Harmer Creek population. The condition for high calcite intensity was not met in any stream other than Dry Creek and was not met for either the Grave Creek or Harmer Creek populations. While conditions for the spatial extent and location of calcite were somewhat met in that calcite was present throughout the study area, its distribution was patchy and areas with low concretion were available for spawning in Harmer Creek mainstem and its tributaries (e.g., Balzy and Sawmill creeks; Table 5; Table 6). Similarly, while the conditions for timing and duration were somewhat met in that calcite intensity peaked in 2017 – 2018 in Dry Creek, these conditions were not met in any other part of the Harmer Creek population area, and high calcite levels and poor suitability occurred throughout the time series.

In Dry Creek, the condition for intensity was met throughout the time series since the lowest suitability was observed to be coincident with the period of Reduced Recruitment. Calcite intensity and resulting spawning suitability were poor in Dry Creek, which reduced the average spawning suitability within the Harmer Creek population area. A comparison of WCT redd count and Cc using data from the Grave Creek watershed suggested that little to no spawning occurred in Dry Creek during the monitoring period (Map 2), which is consistent with the suitability predictions based on Cc observations up to 1.86 (Table 6).

Although the full suite of conditions was not met and no sudden decline in spawning suitability was evident, the Harmer Creek population was exposed to higher calcite levels (e.g., CI and Cc) and had lower average annual spawning suitability compared to the Grave Creek population as a result of the low spawning suitability in Dry Creek. This highlights that calcite is likely to be a chronic stressor to the Harmer Creek WCT population, including prior to the period of Reduced Recruitment. However, because spawning suitability conditions were poorest in Dry Creek in the spawning cohorts of 2017 and 2018, it is possible that calcite was a minor contributing factor to the observed Reduced Recruitment.

### 3.2.2. Incubation Conditions

Changes to incubation conditions from calcite are unlikely to explain, either wholly or in part, the Reduced Recruitment in the Harmer Creek population. The intensity condition was somewhat met in that calcite levels were high in Dry Creek, but other conditions were not met for the same reasons noted in Section 3.2.1.

### 3.2.3. Overwintering Habitat

Changes to overwintering habitat from calcite are unlikely to explain, either wholly or in part, the Reduced Recruitment in the Harmer Creek population. The intensity condition was somewhat met in that calcite levels were high in Dry Creek, but other conditions were not met for the same reasons noted in Section 3.2.1.

### 3.2.4. Invertebrate Prey Availability

Changes to invertebrate prey availability from calcite are unlikely to explain, wholly or in part, the Reduced Recruitment in the Harmer Creek population. The intensity condition was met somewhat in that calcite levels were high in Dry Creek, but other conditions were not met for the reasons noted in Section 3.2.1. (Note that changes to food availability and body condition are addressed in a separate SME report (Wiebe *et al.* 2022)).

Effects of calcite to invertebrate community endpoints occur above CI > 1 (Barrett *et al.* 2016), although relationships between calcite and total invertebrate biomass have not been observed. Monitoring conducted under the RAEMP from 2017 to 2019 found that invertebrate community endpoints did not differ from the normal ranges for the three monitoring locations in Grave and Harmer creeks. The one exception was for %EPT for some samples at station HACKDS, which is within the Grave Creek population area in Harmer Creek downstream of Harmer Pond (Ings *et al.* 2020).

# 4. DISCUSSION

## 4.1. Calcite Trends

Calcite levels (CI and Cc) during the study period (2013-2019) were relatively low and stable in all streams except Dry Creek, where calcite levels were consistently high and increased over time. Calcite levels in all other streams did not differ significantly and did not increase during the study period. Calcite exposure was higher for the Harmer Creek population than the Grave Creek population, but this difference was primarily due to the high levels of calcite in Dry Creek. Calcite exposure did not increase over time for either population.

## 4.2. Biological Effects

### 4.2.1. Spawning Suitability

The spatial and temporal trends in calcite and spawning suitability did not meet the conditions to wholly explain the Reduced Recruitment (Section 3.2). Some factors were met in Dry Creek, where high levels of calcite have likely precluded significant WCT spawning activity for some time and lowest spawning suitability was observed in 2017 and 2018 spawning cohorts during the period of Reduced Recruitment. However, consistently low levels of calcite concretion in other areas of the Harmer Creek population area indicated that conditions for intensity, location, duration, timing, and spatial extent explanatory factors were not met for the Harmer Creek population as a whole and therefore calcite likely did not cause the Reduced Recruitment.

The low spawning habitat suitability in Dry Creek may be a chronic stressor on recruitment within the Harmer Creek population area and would have occurred during and prior to the period of Reduced Recruitment. An important determinant of WCT recruitment in high elevation streams is stream temperature during the growing season. Hocking *et al.* (2022) discuss the importance of stream temperature in observations of Reduced Recruitment in the Harmer Creek population, and note that Dry Creek has a warmer summer growing season temperature regime than the Harmer Creek mainstem. The warm temperature regime may attract WCT to rear in Dry Creek, but the high calcite concretion there may force fish to spawn in sub-optimal conditions or to seek more suitable spawning habitat elsewhere, thus reducing the reproductive output of those fish. Since calcite concretion inhibits WCT from spawning successfully in Dry Creek, there are also few fry that would rear in Dry Creek and benefit from the relatively warm temperature regime. This potential effect would have been most pronounced for the 2017 and 2018 spawning cohorts due to the peak in concretion observed in Dry Creek at that time, though we note that effects of calcite would have been present prior to 2017 and 2018 due to high levels of calcite through time. It is important to note that that mine development and calcite concretion may be part of the reason for higher temperatures in Dry Creek. Historical stream temperature conditions in Dry Creek are unknown. It is also possible that poor water quality conditions would influence recruitment in Dry Creek if spawning and incubation were to occur there (de Bruyn *et al.* 2022; Warner and Lancaster 2022).

#### 4.2.2. Incubation Conditions

Results from Wright *et al.* (2017, 2018) indicated that CI did not significantly affect hyporheic flow, but CI was an important predictor of dissolved oxygen in the substrate. The effect of calcite on dissolved oxygen was most pronounced at depths greater than the average excavation depth for WCT redds. Moreover, the most significant effects on incubation conditions were observed at sites with CI scores higher than ~1.25 with relatively high percent fines in the substrate. Calcite levels that could cause declines in interstitial dissolved oxygen (Wright *et al,* 2017, 2018) were not present in Grave or Harmer creeks (Table 5; Table 6). We therefore conclude that calcite conditions would not have been sufficiently detrimental to incubation conditions to have played a meaningful role in the Reduced Recruitment.

High levels of calcite in Dry Creek may have influenced incubation conditions if spawning were to have occurred there. However, spawning was likely precluded in much of Dry Creek due to high levels of calcite. Thus, conditions for location, duration, timing, intensity, and spatial extent were not met, indicating that changes in incubation success due to calcite did not cause or contribute to the Reduced Recruitment.

#### 4.2.3. Overwintering Habitat

The importance of interstitial space as refuge for overwintering small fish has been highlighted in several studies (Jakober 1995, Cunjak 1996, Jakober *et al.* 1998, Cope *et al.* 2016, Cope 2019, Cope and Cope 2020). While overwintering mortality can potentially affect fish of all ages (fry, parr, adults), small fish (fry and parr) are presumed to be more susceptible to exclusion from interstices, since large-bodied individuals tend to rely on deep habitats like pools. The small size of fish in the Grave Creek watershed and observations of overwintering in riffles (Cope and Cope 2020) suggest that overwintering within coarse substrate likely occurs in this system and therefore has the potential to be influenced by calcite concretion.

Calcite concretion was widespread in Dry Creek but not elsewhere. Consistently high levels of calcite and seasonal low flows (Cope and Cope 2020) may have precluded WCT from overwintering in Dry Creek in high numbers. Thus, although there may be some linkage between calcite levels and overwintering conditions in Dry Creek, conditions for timing and spatial extent were not met. Consequently, effects of calcite on overwintering habitat are unlikely to have caused or contributed to the Reduced Recruitment. However, we also note that the relationship between calcite and overwintering success is poorly understood, so influence on the Reduced Recruitment could only be assessed qualitatively.

#### 4.2.4. Invertebrate Prey Availability

Barrett *et al.* (2016) showed that benthic invertebrate community composition is related to calcite, and that proportions of EPT and Ephemeroptera decreased with increasing calcite, especially above a CI of ~1. However, CI was below 1 in Harmer and Grave creeks (Table 5; Table 6), and RAEMP monitoring of invertebrates did not indicate that invertebrate community endpoints were outside of the normal ranges expected (Ings *et al.* 2020; Wiebe *et al.* 2022). Consequently, the effect of calcite on invertebrate prey availability is unlikely to have caused or contributed to the Reduced Recruitment.

High levels of calcite did occur in Dry Creek, suggesting a possible influence of calcite on invertebrate prey within this portion of the Harmer Creek population area. Nevertheless, the potential effect would be restricted to ~24% of available habitat and would have been fairly consistent over a period that extends prior to the recruitment decline, as calcite levels were high and consistently elevated in Dry Creek.

Note that changes to food availability and body condition are addressed in a separate SME report (Wiebe *et al.* 2022).

### 4.3. Confidence and Uncertainty

Overall, we conclude that calcite is unlikely to have been the cause of the Reduced Recruitment in the Harmer Creek population. However, calcite is likely to be a long-term chronic stressor to the Harmer Creek population and may have been a minor contributor to the Reduced Recruitment. There are several uncertainties associated with this assessment.

The largest uncertainty relates to fish use of Dry Creek and the relative importance of Dry Creek to recruitment in the Harmer Creek population. Spatial and temporal calcite trends suggest that Dry Creek has been affected by calcite for a number of years, including prior to the period of Reduced Recruitment. Since the presence of these high calcite levels pre-dates the Reduced Recruitment, it seems a strong causal link between calcite in Dry Creek and the Reduced Recruitment could be established only if the effect relationship changed recently or the number of fish exposed to the effect changed recently. The highest levels of calcite concretion were observed during the 2017 and 2018 spawning years in Dry Creek, although it is unclear whether this change is meaningful enough to have contributed to the Reduced Recruitment. As calcite concretion increases the availability of small patches of suitable habitat decreases. For example, the few redds observed in Dry Creek in recent years have been observed in mesohabitat units with lower concretion than the average for the stream as a whole (Hocking *et al.* 2020). This suggests that despite low spawning suitability in Dry Creek during the entire available calcite time series, it is possible that fewer redds were produced in Dry Creek during the period of Reduced Recruitment than in the years prior. Overall, there is no evidence that the relative use of Dry Creek by WCT has changed in recent years in the Harmer Creek population area – a conclusion supported by telemetry data (Cope and Cope 2020; Akaoka and Hatfield 2022), and fish distribution and density data (Cope and Cope 2020; Thorley *et al.* 2021).

A second set of uncertainties relates to the effect relationships underlying the causal effect pathways investigated in this report. The draft spawning suitability curve is based on a diverse and growing dataset, but the curve has inherent statistical uncertainty, the confidence limits are broad, and ongoing data collection may improve the relationships it describes (Hocking *et al.* 2020). More recent analyses completed since the first draft of this report was written (Hocking *et al.* 2021; Hocking *et al. In Preparation*) suggest that the spawning suitability response relationship is similar but less steep than the curve indicated in Figure 4. This means that the peak in calcite concretion in 2017 and 2018 in Dry Creek may be more meaningful than the current suitability curves predict for Dry Creek, although the overall spawning suitability estimated across the full Harmer Creek population area may be higher. Moreover, predicting population effects from spawning suitability is challenging, particularly if spawning habitat is not the most limiting habitat. Nevertheless, the same curve (i.e., Figure 4) was used to assess all years and locations, and thus would have indicated consistent relative differences among locations and time periods. A notable decrease in spawning suitability, either spatially or temporally, within the evaluation would have been detected, so the accuracy of the curve may not be especially important for this evaluation. Furthermore, the draft spawning suitability curve would not have under-predicted the effects of calcite concretion on spawning suitability. The three other pathways are based on smaller datasets and thus also have inherent uncertainties.

A third set of uncertainties relates to differences or similarities in the physical features of the Harmer and Grave Creek population areas. The results presented here depend in part on an expectation of similar effect relationships in each of the population areas. We assumed that the broadly similar physical features of each population area will lead to similar responses to calcite, but it is possible that some types of habitat are more limiting in one of the population areas than the other, and thus that calcite has a different influence in each area. One example is the role of stream temperature, which may be limiting recruitment in the Harmer Creek population area more than the Grave Creek population area. The warmer temperature regime of Dry Creek may not be accessed by fry because spawning is inhibited there (and we assume fry cannot or do not travel long distances). The warm temperature regime may also attract WCT to rear in Dry Creek while not allowing completion of their life history within Dry Creek. That is, fish that rear in Dry Creek would need to spawn locally in sub-optimal conditions or seek suitable spawning habitat elsewhere, thus reducing the reproductive output of those fish. We note that although this effect is biologically plausible, there is currently no empirical evidence to test the hypothesis in this location.

The last set of uncertainties relates to the underlying data used to determine spatial and temporal trends in calcite. The methods for collection and analysis of calcite data are well-described and tested (McCabe and Robinson 2020). However, there are inevitable uncertainties related to data collection in the field, calcite measurements; therefore, data summaries have inherent error and small differences in calcite may not be real or may not be biologically meaningful.

## 5. CONCLUSION

This assessment evaluated the potential for calcite exposure to have caused or contributed to the WCT Reduced Recruitment in Harmer Creek. Calcite data from the Regional Calcite Monitoring Program (e.g., Robinson *et al.* 2013; McCabe and Robinson 2020) and the Calcite Biological Program (Hocking *et al.* 2020) along with redd data from Cope and Cope (2020) were used to assess causal effect pathways relating calcite to spawning, incubation, overwintering, and invertebrate prey availability.

Given the spatially restricted extent of calcite and the temporal consistency in calcite levels in the Harmer Creek population area, we conclude that calcite is unlikely to have been the cause of the Reduced Recruitment in the Harmer Creek population. However, calcite exposure was significantly higher in Dry Creek, leading to higher exposure overall within the Harmer Creek population area than in the Grave Creek population area. Furthermore, calcite peaked in Dry Creek during the period of Reduced Recruitment. Thus, we conclude that spatial and temporal patterns in calcite indicate a possible contribution of calcite to the Reduced Recruitment via the spawning suitability pathway. Calcite levels (i.e., CI and Cc) were relatively low and stable in the Grave and Harmer creeks study area from 2013 to 2019, except in Dry Creek where concretion was high and spawning suitability was low. High historical levels of calcite in Dry Creek have likely impacted spawning by WCT for some time, and precluded WCT fry development in the warm growing season temperature regime in Dry Creek that can benefit recruitment (see Hocking *et al.* 2022). Overall, high levels of calcite in Dry Creek represent a chronic stressor to the Harmer Creek WCT population that may reduce the reproductive output of fish attracted to Dry Creek by warm water temperatures, and thus may have been a minor contributor to the observed Reduced Recruitment in the 2017 and 2018 spawning cohorts.

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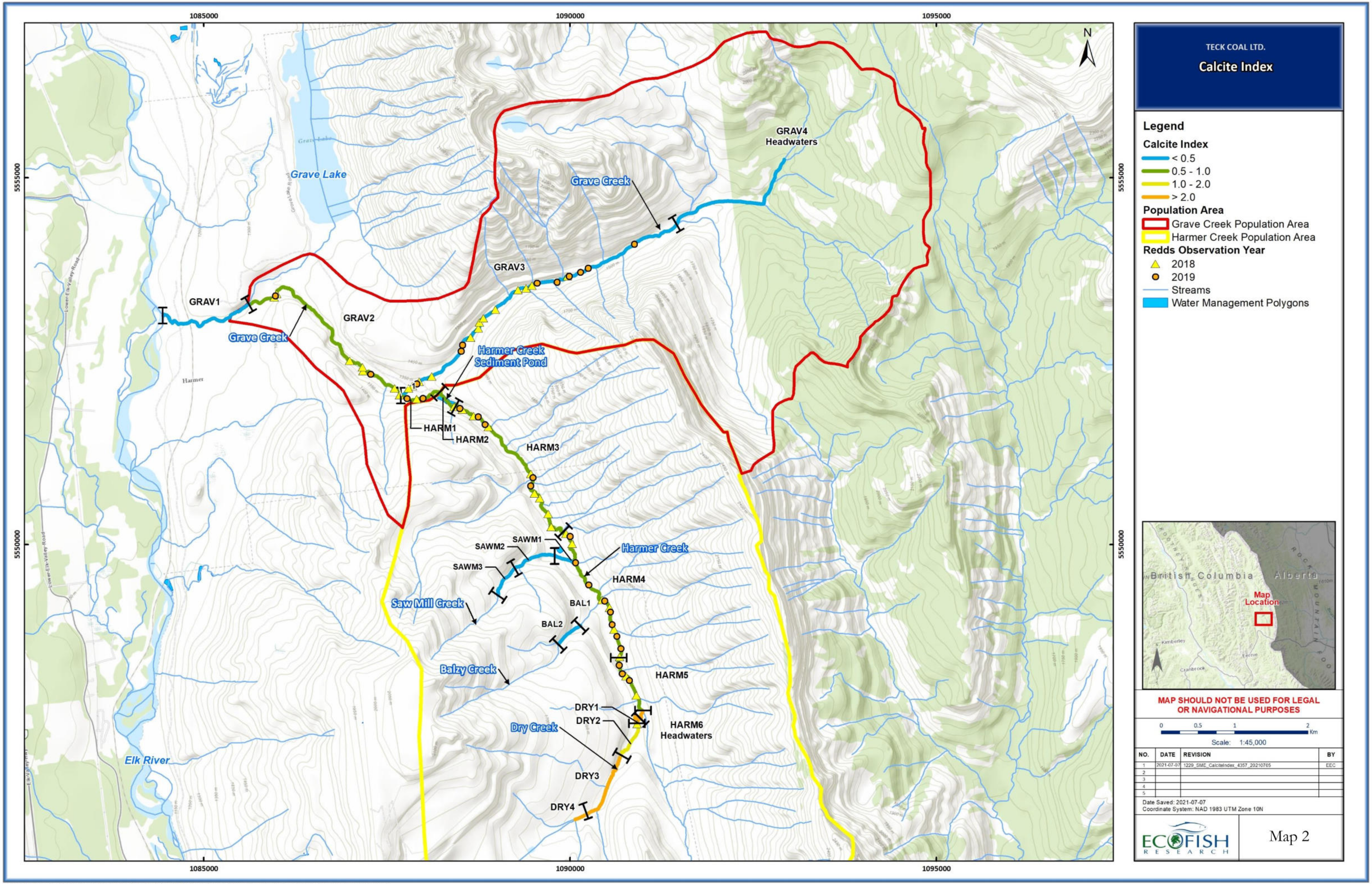
## PROJECT MAP

TECK COAL LTD.

## Calcite Index



**Legend**

**Calcite Index**

- < 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

**Population Area**

- ▭ Grave Creek Population Area
- ▭ Harmer Creek Population Area

**Redds Observation Year**

- △ 2018
- ● 2019
- Streams
- Water Management Polygons

**MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES**

Scale: 1:45,000

| NO. | DATE | REVISION | BY |
|---|---|---|---|
| 1 | 2021-07-07 | 1229_SME_CalciteIndex_4357_20210705 | EEC |
| 2 | | | |
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Date Saved: 2021-07-07
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 2

Path: M:\Projects-Active\1229_EVWQP\MXD\WaterQuality\1229_SME_CalciteIndex_4357_20210705.mxd