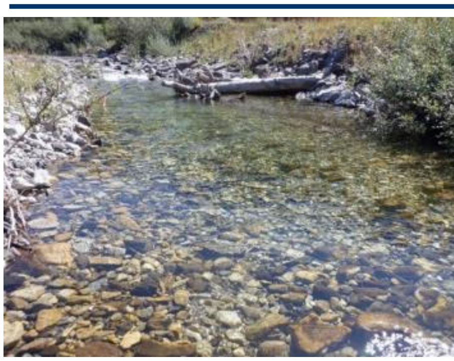
Subject Matter Expert Report: STREAMFLOW and INFERRED HABITAT AVAILABILITY

Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population



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EXECUTIVE SUMMARY

Reduced recruitment in the Harmer Creek population of Westslope Cutthroat Trout (WCT) was observed for the 2017, 2018, and 2019 spawning-year cohorts, and in the Grave Creek population of WCT in the 2018 spawn year. Teck Coal Ltd. (Teck Coal) initiated an "Evaluation of Cause" to assess factors potentially responsible for the reduced recruitment in the Harmer Creek WCT population. This report evaluates streamflow as a factor and concludes that changes in streamflow were not the sole cause, but may have contributed to reduced recruitment in the Harmer Creek population.

Background

Changes to water depth and velocity due to increased or reduced streamflow have the potential to alter availability of habitat for fish, which may in turn have implications for abundance and population size. Flow-related changes to fish habitat can result from natural factors (e.g., weather), land use changes, or water withdrawal for mining or other uses.

Streamflow data from sites within the Grave Creek watershed (Harmer Creek below the Dam (EV_HC1), and EVO Dry Creek below the Sedimentation Pond (EV_DC1)) as well as Water Survey of Canada reference sites at Elk River near Natal and Hosmer Creek above diversions) were examined to evaluate characteristics and anomalies in the hydrologic record during recent years to assess whether streamflow may have caused or contributed to reduced recruitment in Harmer Creek. These data were used to assess the causal effect pathway whereby changes in water levels in streams could have restricted the amount of suitable habitat for WCT, resulting in confinement of fish to a subset of habitats which could have a) increased competition (lowering carrying capacity), b) increased exposure to predation, stranding and other factors, or c) reduced habitat suitability through changes to freshet; each of these effect can result in an increase in mortality of one or more life stages.

Spatial and temporal trends in streamflow

Flow characteristics and anomalies during the period of reduced recruitment (2016-2019) were examined. Two prominent anomalies in the streamflow records are summarized below.

- The spring freshet of 2016 occurred earlier than average at all gauges analyzed. This early freshet resulted in early recession of flow and very low flows in June and July of that year. Streamflow was the lowest on record during parts of June at EV_DC1 and Elk River near Natal and was lower than the 25th percentile at all gauges during much of June and July 2016.
- The lowest average annual streamflow of the past decade occurred at EV_DC1, EV_HC1, and reference streams Hosmer Creek and Elk River near Natal in the 2018-2019 water year. The winter of 2018-2019 was also particularly low at gauges within the Grave Creek watershed and at the small Hosmer Creek reference stream, according to mean monthly flow records and visual analysis of annual hydrographs. Streamflow was low within the larger Elk River during that winter, but was not as low, relative to other years on record, as in the smaller watersheds.

Ecologically relevant streamflow trends and anomalies

Ecologically relevant statistics, based on Richter *et al.*'s (1996) widely used "*Indicators of Hydrological Alteration*" (IHA), were used to describe trends and anomalies in hydrology and to flag potential effects to fish populations in Harmer Creek.

Analysis of mean daily streamflow during WCT life stage periods revealed that flow during the Harmer Creek 2016 spawning period (June 12 – July 11) was the lowest on record at EV_DC1 and in Elk River near Natal. At EV_HC1 and Hosmer, 2016 was the third lowest year on record during the spawning period. Streamflow during the 2016 early incubation period (June 12 – August 12) and the rearing period (May 28 – October 10) was also the lowest on record at EV_DC1. At EV_HC1, Hosmer Creek, and Elk River near Natal streamflow during these periods were lower than the median (3^{rd}, $3^{rd}/4^{th}$, and 4^{th} lowest, respectively) in 2016, but not record breaking.

Average streamflow during the overwintering period of 2018/2019 was the lowest on record at EV_DC1. Streamflow during the 2018/2019 overwintering period was also very low at Hosmer, EV_HC1, and Elk near Natal during that year (2^{nd}, 4^{th}, and 5^{th} lowest, respectively).

Factors potentially influencing streamflow

Mining activities in the headwaters of Dry Creek have the potential to influence hydrology by: 1) removing vegetation and overburden and compacting soils, and 2) accumulation of minespoil and valley fill. These mining practices can have opposing hydrological effects, and local, complex interactions may be important in determining the total effect.

Factors that can affect streamflow include infrastructure, industrial and construction activities, consumptive water use, and climate; these factors were summarized for the Grave Creek watershed. There are no consumptive water licences in the current watershed boundaries of the Grave Creek watershed, and information provided by Teck indicates that mining and spoiling activities, logging, and other industrial and construction activities within the Grave and Harmer watersheds were not notably different during recent years than historically (Harmer Creek Evaluation of Cause Team 2021). Infrastructure (presence of a dam and sedimentation pond) and weather were two factors found to potentially impact streamflow in the Grave and Harmer watersheds.

EV_DC1 is located at the outlet of a sedimentation pond and EV_HC1 is below the Harmer Dam, which may have affected some streamflow patterns. For example, low streamflow seen during the winter of 2018-2019 may have been ameliorated (or exacerbated) by the dam/sedimentation pond, though the extent of amelioration (or exacerbation) of low flows is unknown.

Data from nearby climate monitoring stations were examined to investigate potential causes of the low winter streamflow of 2018-2019 seen at EV_HC1, EV_DC1, and Hosmer Creek and the early freshet and low June-July flow of 2016 seen at all gauges. Air temperature and precipitation records are summarized below.

- Air temperature during April 2016 reached record high levels, which may have resulted in early snowmelt and an early freshet that left little snowmelt left to contribute to flows during June/early July when WCT spawning occurs and during the subsequent rearing period.
- Air temperatures during February and March 2019 were below the 25th percentile, which likely resulted in ice formation in the creeks.
- Precipitation from late summer to early fall 2018 and during the 2018-2019 winter was below the 25th percentile, and during March 2019 reached record low levels. Precipitation may have contributed to low winter streamflow during 2018/2019 in small watersheds such as Dry Creek, Harmer Creek, and Hosmer Creek. The precipitation record indicates anomalously low precipitation in late summer and early fall may have been a cause of low streamflow during that winter, and low winter precipitation likely contributed to a smaller snowpack.

Cause/contribution of reduced recruitment

Conditions for sole cause of reduced recruitment were not met. EV_DC1 at Dry Creek, within the Harmer Creek watershed, reported some record low streamflow in 2016 and 2018-2019, but the data record here was short and therefore difficult to compare to historical conditions. For all WCT life stages in Harmer Creek, the EV_HC1 gauge on Harmer Creek reported no record low streamflow averages in recent years compared to older data. Although low streamflow was observed within the Harmer watershed, this trend was similar to other regional monitoring locations where reduced recruitment did not occur.

Conditions for contribution to the reduced recruitment were met for the 2016 and 2018 spawning-year cohorts. Large reductions in streamflow during the summer of 2016 in the Harmer Creek population area may have influenced availability of fish habitat for the 2016 spawning-year cohort. Likewise, reductions in streamflow during the winter of 2018-2019 may have influenced availability of fish habitat for the 2018 spawning-year cohort, the cohort with recruitment failure.

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ACRONYMS AND ABBREVIATIONS

ECCC Environment and Climate Change Canada

EoC Evaluation of Cause

EVO Elkview Operations

IFS Instream Flow Study

IHA Indicators of Hydrological Alteration

MAD Mean Annual Discharge

SME Subject Matter Expert

WCT Westslope Cutthroat Trout

WSC Water Survey of Canada

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·kxamis ʼqapi 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.

[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.

[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.

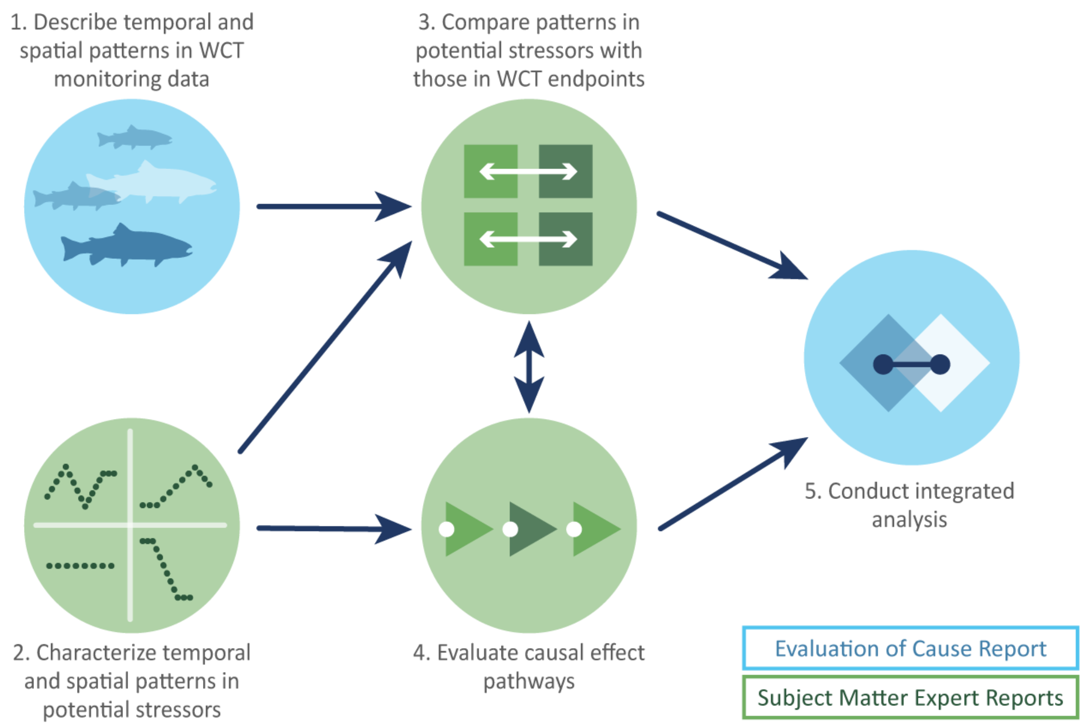
2. The Evaluation of Cause report. The SME reports provided the foundation for the Evaluation of Cause report, which was prepared by a subset of the Team and included input from SMEs.

   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 & Cope (2020) reported low abundance of juvenile 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 where appropriate.

[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. They 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 impact 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 provide support as Subject Matter Expert (SME) for an evaluation of streamflow (and inferred habitat availability) as a stressor. This document is one of a series of SME reports that support the overall 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

The amount of habitat available for a fish population influences the productivity and carrying capacity for that population. Although many factors influence fish abundance, the quantity and quality of habitat is considered an important driver of population resilience.

[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.

Changes to water depth and velocity, resulting from increased or reduced streamflow, have the potential to alter availability of suitable habitat for fish (Shirvell 1994), which may in turn have implications for abundance and population size. For instance, numerous studies (e.g., Fausch 1984, Fausch and White 1986, Hughes and Dill 1990) have hypothesized that juvenile salmonids select optimal stream positions with abundant drift food supply. When streamflow changes, spatial patterns of water velocity shift, and as a consequence, the locations of maximum net energy gain for fish also change (Bravender and Shirvell 1989), which results in fish redistributing themselves to new optimal positions. If habitat with suitable hydraulic characteristics becomes limited in area and distribution, fish may become crowded into the limited available habitat. This crowding of fish into smaller areas may directly reduce abundance through increased competition for limited resources among conspecifics (i.e., increasing use beyond the carrying capacity of the habitat). Further, if habitat with suitable hydraulic characteristics is limited to a specific segment of stream, then fish concentrated within this segment could make a large proportion of the population vulnerable to other stressors (e.g., localized environmental changes or impacts such as spills, predation, stranding, and icing).

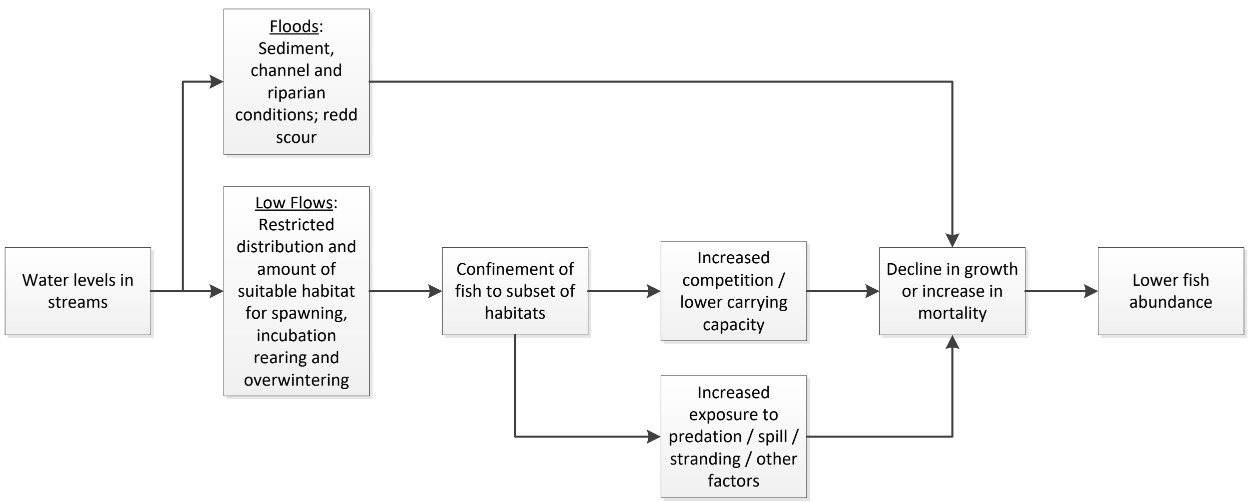
Figure 1 provides a causal effect pathway conceptual model for the cause-effect linkages between streamflow and fish abundance. It describes how extreme low or high flows can affect habitat availability (and suitability), and ultimately affect fish abundance and distribution.

This report uses streamflow as a proxy for habitat availability for fish and examines historical flow data to identify anomalies and trends that may be related to the Reduced Recruitment in the Harmer Creek WCT population. Broadly, evidence of anomalous low flows during the non-freshet period was used to infer habitat limitations during an activity period[16]; evidence of moderate to high flows during the non-freshet period were not expected to exacerbate habitat limitations and were therefore not flagged as potentially related to the Reduced Recruitment. In addition, evidence of anomalous high flows during freshet were used to infer direct effects to fish (e.g., scour of redds or displacement of free-swimming individuals) or rapid changes to stream morphology. High magnitude flows during freshet also have positive ecological effects and are referred to as channel-maintenance or flushing flows. These high flows maintain gravel quality, sediment dynamics, connectivity with off-channel habitat and riparian communities, and healthy vegetation dynamics in riparian communities. Finally, evidence of multi-year anomalously low flows during the freshet period was used to infer possible instream habitat limitations due to lack of flushing flows to remove fines from the stream or poor riparian condition. Thus, for the freshet period we sought to identify anomalously high and multi-year anomalously low flows, and for the non-freshet period, we sought to identify anomalously low flows. Timing of high and low flows was also examined, though the ecological mechanisms associated with timing are less clear than magnitude and duration. Therefore, information about timing is presented for completeness rather than to illustrate linkage to effects on fish or habitat.

[16] An activity period is defined by the fish periodicity table (see Table 1). For the Grave watershed, the activity periods are defined for: spawning, incubation, rearing, and overwintering.

Flow-related changes to fish habitat can result from natural factors (e.g., weather), land use changes, or water withdrawal for mining or other uses. Given the potential effect that stream hydrology can have on habitat availability and suitability for fish, streamflow has the potential to have caused or contributed to the WCT Reduced Recruitment. An assessment was therefore conducted to determine, first, if there were anomalies or deviations from historic trends in streamflow that could directly or indirectly affect fish survival, and second, to determine if any such deviations would be of sufficient magnitude and duration to explain the observed WCT Reduced Recruitment. It should be noted that this assessment did not attempt to evaluate the amount of streamflow that would be sufficient to sustain the WCT population or prescribe a flow regime that would be sufficient to sustain this population.

Figure 1. Causal effect pathway diagram showing the linkages between streamflow and fish.



1.1.2. Author Qualifications

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

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

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

Nicole Wright, Ph.D., PWS, P.Geo.

Nicole Wright, the primary technical lead for this project, is a registered Professional Geoscientist with a Ph.D. in hydrology. Nicole has 17 years of experience designing, planning, and executing hydrological studies and monitoring programs with a focus on aquatic ecology and water resources. She has led studies identifying local and regional challenges presented by climate change and evaluating implications for instream flow needs and water resource management, and she has conducted various surface energy and water balance studies.

Nicole has designed, implemented, and reported on several studies for Teck Coal Ltd since 2015. These studies include an assessment of hyporheic flows and calcite effects in relation to fish incubation on the Upper Fording River (UFR) and its tributaries, an evaluation of surface and subsurface hydrology in the seasonally drying reach of the UFR, an instream flow assessment to evaluate potential effects of water diversion from Goddard Marsh in the Elk River Valley, and several regional flow analyses to support Teck water licence applications. Recently, Nicole led the climate and flow characterization of the UFR watershed to support the UFR EoC of recent WCT population decline. She has also provided an environmental assessment review of the potential effects to climate and hydrology from the Quintette Teck mining project.

Nicole presents study results and contributes her technical expertise at regulatory and stakeholder meetings for various projects, including more than a dozen presentations to BC ENV in support of client impact assessment projects. Nicole has authored peer-reviewed publications in scientific journals and in-conference proceedings, environmental assessments, EAC amendments, and scoping, baseline, and monitoring reports. Her technical reviews encompass a wide range of hydrological issues, including the regulatory framework for surface and groundwater management in British Columbia; potential impacts to instream, wetland, and riparian condition and functions from proposed hydroelectric, pipeline, and mine projects; and hydrological guidance for wetland and river restoration.

1.2. Objectives

The objectives of this report were to evaluate streamflow in the Grave Creek watershed and to assess potential effects to WCT abundance from changes in streamflow (and inferred habitat availability). Prolonged changes in streamflow or anomalous streamflow events that occur during one or more key life stage activity periods can directly or indirectly affect the health and survival of WCT. Thus, changes to streamflow could have led to the Reduced Recruitment if a large proportion of the population was affected.

The specific question addressed was:

1. Did streamflow cause or contribute to the observed WCT Reduced Recruitment in Harmer Creek?

1.3. Approach

All available streamflow data from sites in Grave Creek, Harmer Creek, and Elkview Operations (EVO) Dry Creek were provided by Teck Coal. Streamflow data from locations outside of the Grave Creek watershed were obtained from Water Survey of Canada (WSC) and date back to October 1950. Streamflow was analyzed by standard temporal periods (months, years) to determine spatial and temporal trends in the available data, and by comparing streamflow during biological periods, as determined by periodicity of WCT in the Grave Creek watershed (i.e., overwintering, spawning, early incubation, late incubation, and rearing; Table 1). The periodicity of WCT in the Grave Creek watershed is described in Chapter 3 of the EoC report (Harmer Creek Evaluation of Cause Team 2022). Methods are further described in Sections 2.1 and 2.2.

The available data were analyzed for long-term trends or anomalous events in recent years that may have caused or contributed to the Reduced Recruitment. Anomalous events were defined as events occurring in recent years (primarily 2017-2019 but data back to 2014 were reviewed as well) in which the mean streamflow computed over different durations was in the lower or upper end of the historical range observed at a given site over a sufficient duration during a key activity period. This approach relied on inter-site comparisons to detect anomalous streamflow conditions within the Grave Creek watershed. In cases of increasing streamflow trends, anomalous streamflow results, or extreme streamflow events, the streamflow results were compared to explanatory factors (Section 2.4) that could cause Reduced Recruitment of WCT in the Grave Creek watershed, including the intensity, duration, timing, location, and spatial extent of streamflow in comparison with the life history periods of WCT.

To discern the potential causes for observed anomalies and trends in streamflow during recent years, information on activities within the Grave Creek watershed (e.g., sedimentation ponds, construction, logging or road building, infrastructure changes) was requested from Teck, and climate data were reviewed. Precipitation amounts and types (e.g., rain or snow), as well as the timing of precipitation events directly influence streamflow by changing water inputs, which, in turn, affect stream habitat for fish. Similarly, air and water temperature affect streamflow (e.g., warm temperatures and freeze-up conditions can both cause reductions in flow). Climate and water temperature data were compiled and described in the Grave and Harmer Ice, Air and Water Temperature EoC report (Hocking et al 2022) and are summarized herein where relevant.

Similar to streamflow, trends and anomalies in the climate data were analyzed by standard temporal periods (months, years) and separately for each WCT activity period (Table 1) for direct comparison with the streamflow observations.

Table 1. Periodicity of Westslope Cutthroat Trout in the Grave Creek watershed (Harmer Creek Evaluation of Cause Team 2022).

Life History Activity	Jan				Feb				Mar				Apr				May				Jun				Jul				Aug				Sep				Oct				Nov				Dec			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Spawning																																																
Incubation (egg and alevin)[1]																																																
Rearing (>5ºC)[2]																																																
Over-wintering																																																

[1] Computed for two periods: 1) assuming early spawning (June 12 – August 15); and 2) assuming late spawning (July 11 – October 31).

2. METHODS

2.1. Streamflow Summary Statistics

Streamflow data were analyzed by standard temporal periods (months, years) to determine spatial and temporal trends in the available data. Annual statistics were computed from October of one year to October of the next (i.e., the water year from October 1 through September 30) to avoid interruptions by the calendar year end and so that the overwintering WCT period would occur in the same year.

Streamflow data have been collected by Teck at seven hydrometric stations in the Grave Creek watershed (Map 1; Table 2); however, continuous flow data were available for only one of these stations, EV_DC1 on Dry Creek, a tributary to Harmer Creek. The most extensive record of streamflow in Harmer Creek itself was at EV_HC1, which is located at the outlet of the dam, downstream of the reach of Harmer Creek that experienced Reduced Recruitment. The gauges upstream of the dam, where Reduced Recruitment occurred, were EV_HC1A, EV_HC4, EV_HC6 and EV_DC1. Of these, only EV_DC1 had a long-term record that spanned the 2016-2019 period (Table 1). Stage data were recorded at EV_DC1 and converted to flow using site-specific stage-flow relationships developed by Kerr Wood Leidel (KWL). Manual streamflow measurements were collected at EV_DC1 as well as the four stations on Harmer Creek and two on Grave Creek (Table 2). Data were collected and QA'd by KWL and provided to Ecofish by Teck as daily averages (for EV_DC1) or instantaneous measurements (for manually collected data). All data were then reviewed by Ecofish for gaps.

To provide historical context from a longer times series and to evaluate whether trends seen in the Grave and Harmer system were localized or regional, daily streamflow from the WSC Grave Creek at the Mouth station (08NK019), WSC Elk River near Natal station (08NK016), and WSC Hosmer Creek above Diversions (08NK026) were also reviewed (Map 1; Table 2). Data from several other WSC stations were examined to find a suitable nearby station to compare streamflow patterns to those seen in the Grave Creek watershed, but only the Elk River and Hosmer Creek stations were chosen as reference stations for comparison of 2016-2019 records. The Elk River station is located approximately 2 km upstream of the Elk River confluence with Grave Creek, and the Hosmer Creek station is approximately 30 km downstream of the Elk-Grave confluence (Map 1). While Elk River near Natal provides a nearby station with a long-term and current record, it is a much larger watershed than Grave Creek and Harmer Creek above the Dam. Hosmer Creek is further away but provides a recent and long-term record at a natural watershed that is similar in size to Dry Creek. Hosmer Creek is slightly lower in elevation than upper Harmer Creek; the Grave Creek watershed extends up to ~2450 masl (EV_DC1 is at ~1460 masl and EV_HC1 is at 1320 masl), whereas the Hosmer watershed extends up to ~2100 masl (Hosmer Creek above Diversions station is at 1110 masl).

Table 2. Location, period of record, and percent (%) complete for gauged flow data from monitoring stations in the Grave Creek watershed and nearby Elk River and Hosmer Creek.

Station Type	Station ID	Station Name	Drainage Area (km^2)	MAD[1,2] (m^3/s)	Lattitude	Longitude	Period of Record Start	Period of Record End	n[3]	% Complete[4] Min	% Complete[4] Max
Continuous	WSC 08NK016	WSC Elk River near Natal	1840	26.1	49°51'56" N	114°52'07" W	1-Oct-1950	31-Dec-2020	-	25	100
	WSC 08NK019	WSC Grave Creek at the Mouth	83.9	1.09	49°50'36" N	114°51'36" W	1-Jan-1970	12-Apr-1999	-	100	100
	EV_DC1	EVO Dry Creek at pond outlet	7.8	0.120	49°47'21" N	114°47'07" W	1-Jan-2014	31-Dec-2019	-	25	84
	WSC 08NK026	WSC Hosmer Creek above Diversions	6.4	0.120	49°35'03" N	114°57'14" W	31-Mar-1981	31-Dec-2020	-	71	100
Instantaneous	EV_GV1	Grave Creek near the mouth	79.2	-	49°50'35" N	114°51'47" W	7-Oct-2014	12-Sep-2016	25	67	78
	EV_HC1	Harmer Creek at Harmer Dam outlet	37.2	0.556	49°49'53" N	114°48'59" W	7-Jan-1992	1-Dec-2020	601	0	100
	EV_HC1A	Harmer Creak upstream of the dam	~37	-	49°49'46" N	114°48'47" W	20-Mar-2000	4-Dec-2001	28	50	83
	EV_GV3	Grave Creek upstream of Harmer Creek	24.1	-	49°49'56" N	114°49'19" W	3-Sep-2013	9-Dec-2015	24	42	100
	EV_HC4	Harmer Creek downstream of EVO Dry Creek	14	-	49°47'35" N	114°47'13" W	10-Jun-2019	10-Dec-2020	18	92	100
	EV_DC1	EVO Dry Creek at pond outlet	7.8	0.120	49°47'21" N	114°47'07" W	14-Jun-2005	10-Dec-2020	212	0	100
	EV_HC6	Harmer Creek upstream of EVO Dry Creek	5.9	-	49°47'01" N	114°47'03" W	3-Sep-2013	12-Sep-2016	41	67	100

[1] MAD calculated only at stations with more than three years of record.

[2] MAD was calculated using combined continuous and instantaneous measurements for EV_DC1.

[3] n is the number of measurements over the period of record. Computed only for instantaneous stations.

[4] % For instantaneous stations, % complete was calculated based on the total number of months within each year in which a measurement occurred, while for continous stations it was based on the total number of days within each year that flow data was available.

Data gaps that could affect the calculation of some statistics existed at all Teck stations. For example, instantaneous flow measurements at EV_HC1 were collected at approximately weekly intervals during the spring and summer, and monthly during fall and winter. For this station and others, gaps between measurements were filled using linear interpolation prior to calculating annual average flow, annual minimum flow, annual maximum flow, and year-round daily percentiles of flow. This ensured that calculation of annual average flow, for example, was not biased by more frequent measurements during the summer. Only gaps less than or equal to 45 days were filled. We chose to fill gaps of 45 days or less as this infilling allowed us to approximate daily percentiles year-round. At stations such as EV_HC1, where data gaps were frequently greater than 45 days in fall and winter months, the streamflow recession during this period could only be approximated. Annual metrics were not reported for years with gaps larger than 45 days.

2.2. Ecologically Relevant Metrics

Ecologically relevant statistics were used to describe trends and anomalies in hydrology and to flag potential effects to fish populations in Harmer Creek. Statistical summaries were based on Richter *et al.*'s (1996) widely used "*Indicators of Hydrological Alteration*" (IHA), which provides a set of metrics to characterize flow regimes. A modified subset of the IHA metrics was used, including timing, magnitude, and duration of mean, median, and extreme (minimum and maximum) flows (see Table 3). The IHA statistics were calculated using the R package by Law (2013). Statistical summaries were computed for each WCT life stage (i.e., overwintering, spawning, incubation, and rearing; see Table 1). Statistics for the incubation life stage were computed for two periods, one assuming early spawning (June 12 – August 15), and the other assuming late spawning (July 11 – October 31).

IHA statistics were calculated for the three current continuously monitored stations Elk River (08NK016), Hosmer Creek (08NK026), and Dry Creek (EV_DC1) using the activity period defined for the Grave Creek watershed. We also calculated the mean value for each WCT life stage period for Harmer Creek at Harmer Dam outlet (EV_HC1), which has a long-term record (28 years) of streamflow measurements collected approximately weekly during the summer and approximately monthly during the winter. Interannual variations in the IHA metrics were examined and compared to long-term data at the Elk River and Hosmer Creek to identify anomalies.

Table 3. Hydrologic metrics used to characterize anomalies in flow regime; a subset of metrics from Richter et al. (1996).

IHA Indicator	Indicator Metric from Richter *et al*. 1996	Modified Indicator Metric
Magnitude of Monthly Water Conditions	Mean value for each calendar month	Mean value for each WCT life stage period
Magnitude and Duration of Annual Extreme Water Conditions	Annual minimum 1, 3, 7, and 30-day flow means Annual maximum 1, 3, 7, and 30-day flow means	Minimum 1, 3, 7, and 30-day flow means for each WCT life stage period Maximum 1, 3, 7, and 30-day flow means for each WCT life stage period
Timing of Annual Extreme Water Conditions	Julian date of each annual 1-day minimum Julian date of each annual 1-day maximum	Julian date of 1-day minimum for each WCT life stage period Julian date of 1-day maximum for each WCT life stage period

2.3. Factors Potentially Influencing Streamflow Trends

Several factors can influence spatial and temporal characteristics of streamflow. This report considers watershed activities and climate factors. The influences of groundwater on streamflow or on fish habitat characteristics can also be important but are not addressed in this report. The evaluation of groundwater as a potential stressor to WCT in Harmer Creek was completed by SNC Lavalin (2022), which concluded that there was limited groundwater influence in the creeks.

2.3.1. Mining Activities and Other Watershed Factors

A literature review was conducted to describe the potential impacts of mining activities on streamflow. To ascertain whether changes in streamflow may have been influenced by anthropogenic activities, available information was obtained from Teck on the location, timing, and amount of mining and spoiling, water use, logging, and other industrial and construction activities within the Harmer and Grave watersheds (Chapter 2, Harmer Creek Evaluation of Cause Team 2022)

2.3.2. Climate Factors

Data from two nearby Environment and Climate Change Canada (ECCC) climate monitoring stations were examined to investigate whether and to what extent precipitation and air temperature contributed to anomalous streamflow events observed at hydrometric gauges within the Harmer and Grave watersheds and nearby reference watersheds.

Air temperature data from the ECCC Sparwood CS (1157631) station were used to fill gaps in the data series at ECCC Sparwood (1157630) station, and this data series is referred to herein as ECCC Sparwood – extended. To fill gaps, air temperature values at ECCC Sparwood were regressed against

Sparwood CS using a linear model ($R^2 = 0.993$). The resulting model parameters were then used to fill in the Sparwood data series. The original Sparwood data series covered 1980 to 2020 and was 95% complete; whereas the Sparwood CS covered 1992 to 2020 and was 97% complete. The gap-filled ECCC Sparwood extended dataset was 99.8% complete over a period of 41 years (1980-2020). This ECCC Sparwood extended time series of air temperature and precipitation was used to compare to streamflow observations. In addition, data from the Morrissey Ridge snow pillow station, operated by BC Hydro, were used to evaluate streamflow observations. This was the nearest station with comparable elevation to the upper reaches of the Grave Creek watershed and had 16 complete years of data from 2004-2020.

2.4. Evaluation of Explanatory Factors

Five explanatory factors were used to evaluate whether flow-related changes (and inferred reduction in habitat availability) resulted in stress to fish that caused or contributed to the observed spatial and temporal patterns in recruitment. For each of these factors, we defined a condition that had to be met in order to conclude that streamflow caused or contributed to the WCT Reduced Recruitment (Table 4). Response thresholds are unquantified between recruitment and streamflow in the Grave Creek watershed, so the explanatory factors were assessed qualitatively, based primarily on evaluation of how extreme a condition was relative to average conditions.

Table 4. Conditions that needed to be met to conclude cause or contribution to the WCT Reduced Recruitment.

Explanatory Factor	Condition
Intensity	A large change in minimum and/or maximum streamflow (and inferred effect on habitat) occurred during one or more WCT activity periods
Timing	A change in minimum and/or maximum streamflow occurred that is temporally consistent with the observed Reduced Recruitment
Duration	A prolonged change in minimum and/or maximum streamflow occurred within one or more WCT activity periods
Location	A change in minimum and/or maximum streamflow occurred in locations that are important for WCT in the Harmer Creek population area
Spatial Extent	A change in minimum and/or maximum streamflow occurred over much or most of the Harmer Creek population area

The explanatory factors were assessed as follows.

- Intensity was addressed by quantifying inter-annual differences in the magnitude of streamflow during each WCT activity period.
- Timing was assessed by determining the timing of extreme flows during each WCT activity period.
- Duration was evaluated by calculating the one-day, three-day, seven-day, and 30-day duration of extreme flows during WCT activity period.
- Location was addressed by analyzing two locations within the watershed (Dry Creek at the Dry Creek Sedimentation Pond outlet (EV_DC1), which is located just upstream of the confluence with Harmer Creek, and Harmer Creek below the dam outlet (EV_HC1)), and two regional locations (Elk River near Natal (08NK016) and Hosmer Creek above Diversions (08NK026)).
- Spatial extent was addressed by analyzing streamflow in Harmer Creek and Dry Creek and comparing those streamflow data with the data from WSC stations outside of the Grave Creek watershed, to determine whether trends and anomalous streamflows were localized and specific to the system or were more wide-spread.

Cause of Reduced Recruitment was indicated if anomalous streamflow occurred during key activity periods and was of high or very high magnitude in recent years relative to the prior period, and that occurred throughout much or most of Harmer Creek (i.e., was spatiotemporally coincident with a large portion of the area of Reduced Recruitment). Furthermore, if a change in streamflow (and inferred habitat) was the cause of Reduced Recruitment, the streamflow change was assumed to have occurred within one year of the observed lower recruitment. In other words, the mechanisms were assumed to act within 12 months of the initiation of the spawning-year cohort that exhibited the lower recruitment.

Contribution to Reduced Recruitment was indicated if anomalous streamflow occurred within a localized area, or had implied low to moderate-magnitude effects. Localized effects could have resulted in mortality and/or reduced reproductive investment but would occur at a spatial scale that was insufficient to explain all of the observed Reduced Recruitment; whereas, widespread moderate magnitude effects would not have directly caused mortality but could have reduced feeding or increased stress, which may have combined with effects from other stressors.

Streamflow results that did not meet the above criteria were said to have not caused or contributed to Reduced Recruitment, although there remained a possibility that changes in streamflow contributed in a minor way.

3. RESULTS

3.1. Spatial and Temporal Trends in Streamflow

Annual streamflow statistics during the past decade at two hydrometric gauges in the Grave Creek watershed (EV_HC1 (Harmer Creek below the dam) and EV_DC1 (Dry Creek at Sedimentation Pond outlet)) are summarized in Table 5 along with statistics for the WSC Elk River near Natal and Hosmer Creek stations. Data at other stations were insufficient to calculate reliable estimates of annual statistics during recent years (since 2010; see Table 1 for data record lengths).

Available daily streamflow data from 2010-2020 for all stations are displayed in Figure 2 to Figure 4.

Long-term mean monthly streamflow statistics are reported in Table **6** and mean monthly streamflow during recent years is expressed as a percentage of mean annual discharge (MAD) in Table 7. The streamflow records at the WSC Elk River near Natal and WSC Hosmer Creek gauges were used to provide historical and spatial context. Over the long-term record, mean monthly flow was greatest in June at Elk River near Natal, and in May at Grave Creek at the mouth, EV_HC1, EV_DC1, and Hosmer Creek (Table 6). Mean monthly flow was lowest during February at all stations except for Hosmer Creek, which was lowest in January (Table 6).

Streamflow data indicated that 2018-2019 was a low water year in this region, with persistent winter low flow relative to other years recorded at stations in the Grave Creek watershed and at the smaller reference streams. The low streamflows would have potentially affected fry from the 2018 spawning-year cohort. Effects to older life stages during the period are also possible, but such effects would not possibly influence recruitment until the spawning-year cohort of 2019 or later. Key supporting information includes the following:

- Over the last decade, the lowest average annual streamflow occurred in 2018-2019 at Elk River near Natal, Hosmer Creek, EV_HC1, and at EV_DC1 (Table 5). In general, average annual flows at all four stations were low (below median) during the 2017-2018 and 2018-2019 water years, relative to other years in the past decade (Table 5).
- The lowest annual maximum flow in the past decade occurred in 2018-2019 at EV_HC1, EV_DC1 and Hosmer; at Elk River near Natal, 2018-2019 annual maximum flow was the second lowest of the past decade (Table 5). At EV_DC1, maximum daily flow was below median for two consecutive years, 2018 and 2019, although there was no indication of prolonged (multi-year) lack of flushing flows at this location or at EV_HC1. (Table 5).
- The lowest mean monthly streamflow during the 2014-2020 period occurred during winter 2018-2019 (16% MAD in February 2019 at EV_HC1 and 15% MAD in December 2018 at EV_DC1; Table 7). Moreover, the mean monthly flow at EV_HC1 and EV_DC1 was above 20% MAD during all months on record except for February (for EV_HC1) and for December, January, and February (for EV_DC1) of 2018-2019 (Table 7). (September 2016 was also below 20% MAD at EV_DC1; however, this monthly average is based on a single measurement, and

it is unknown whether the low water recorded during that month was a persistent low flow event.)

- At Hosmer Creek, the lowest mean monthly flow also occurred in 2018-2019; mean monthly flow did not drop below 16% MAD for any other month during 2014-2020.
- In the Elk River, winter 2018-2019 streamflow was lower than average (18% MAD) thought not as low as in the winter 2017-2018 (Table 7).

Additional key annual streamflow characteristics include:

- From 2014-2020, mean monthly flow was greatest in April or May at both EV_HC1 and EV_DC1, with monthly flow as a percentage of mean annual discharge (%MAD; discharge meaning streamflow) exceeding 200% during the highest flow month in all years except for the 2019 (Table 7). At the Hosmer Creek and Elk River near Natal reference stations, 2019 freshet was lower than average but was not the lowest year in the 2014-2020 period.
- The highest maximum annual flow during the past decade occurred prior to the 2016-2019 period of Reduced Recruitment (during the 2013 flood), and the only maximum annual flow that was notably higher than average in this period occurred in 2018 at EV_HC1 (2nd highest in the decade); however, a high maximum flow was not observed at upstream EV_DC1 during that year~~, which indicates that extreme scouring flows were unlikely in the Harmer watershed~~.

Table 5. Annual streamflow statistics for hydrometric stations in the Grave Creek watershed and Elk River. Only stations with more than two years of data from 2010 to 2020 are included. Blue shades indicate years with higher than median streamflow, and red shades indicate years with lower than median streamflow; highest and lowest values are bolded.

Year	Streamflow (m^3/s)[1,2]											
	Elk River near Natal			EV_HC1			EV_DC1			Hosmer		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
2010-2011	27.7	3.20	155	-	-	-	-	-	-	0.142	0.014	0.92
2011-2012	**35.2**	3.26	214	**0.856**	**0.054**	**4.33**	-	-	-	0.142	0.020	0.93
2012-2013	35.1	**5.48**	**627**	0.671	0.075	3.78	-	-	-	**0.156**	**0.021**	**1.53**
2013-2014	31.2	3.79	214	0.675	**0.200**	3.62	-	-	**1.10**	0.130	0.019	0.90
2014-2015	20.8	5.38	108	-	-	-	-	-	-	0.100	0.013	0.94
2015-2016	20.8	5.20	**75.7**	0.460	0.196	1.89	-	-	0.67	0.100	0.015	0.73
2016-2017	26.5	3.54	162	0.616	0.180	3.38	**0.145**	**0.028**	0.75	0.128	**0.010**	0.79
2017-2018	23.2	**3.10**	164	0.548	0.110	3.88	0.087	0.026	0.53	0.092	0.016	0.87
2018-2019	**19.6**	3.67	100	**0.388**	0.066	**1.86**	**0.065**	**0.012**	**0.32**	**0.065**	0.012	**0.54**
2019-2020	25.2	4.48	211	0.474	0.131	2.58	0.101	0.016	0.39	0.115	0.016	0.90

1. Calculated from October 1 to September 30. Data prior to October 1, 2010 are not shown.

2. Average, minimum, and maximum were not calculated for years with > 45 day gaps between measurements, except in the case of maximum which was reported if it was clear that the peak freshet flow was captured.

Figure 2. **a) Streamflow (m^3/s) at the hydrometric gauges in the Grave Creek watershed from 2010 to 2019. Plot (b) shows streamflow on a log scale. Vertical reference lines indicate the start of the calendar year. Instantaneous flow was measured at all stations. In addition, continuous streamflow was recorded at station EV_DC1 and average daily streamflow for EV_DC1 is plotted below.**

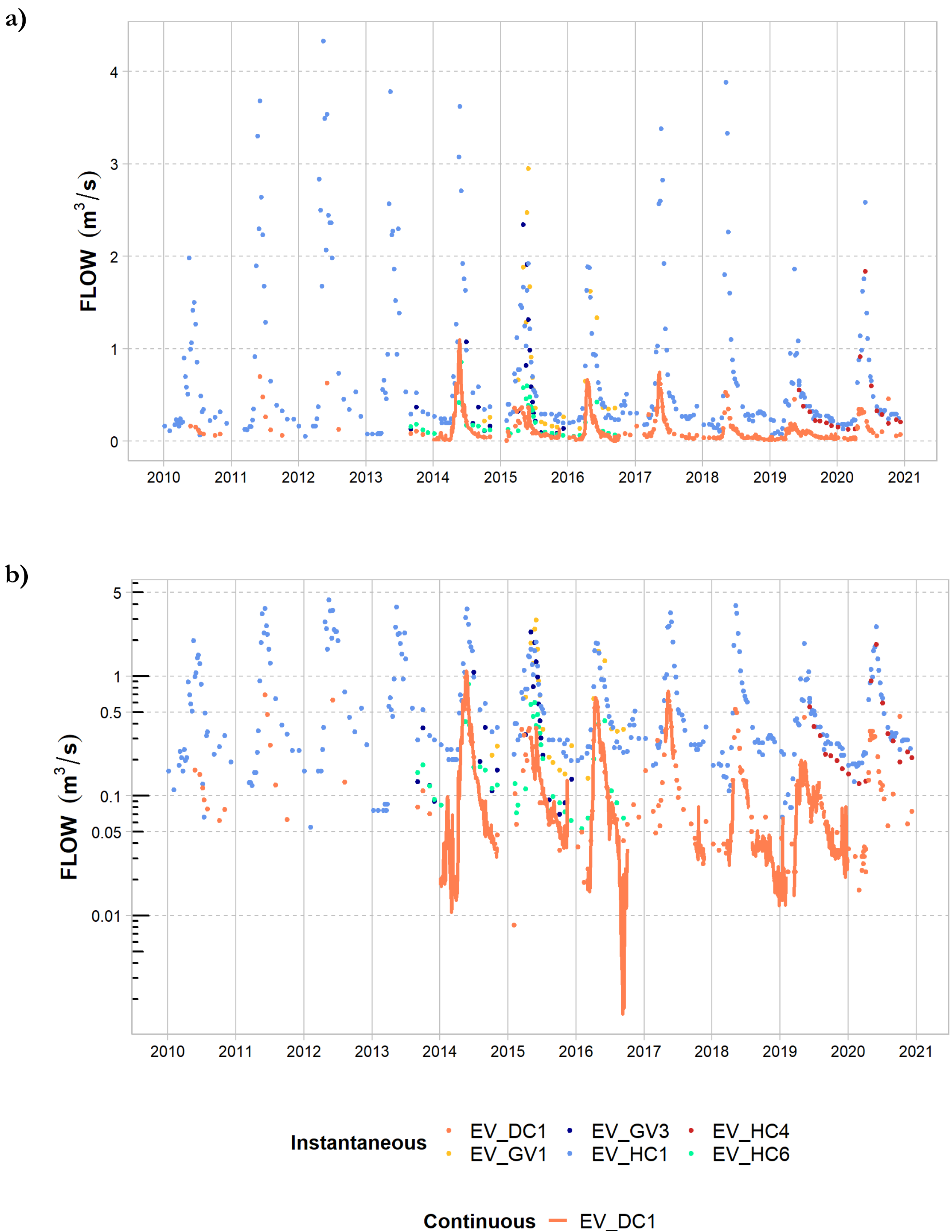
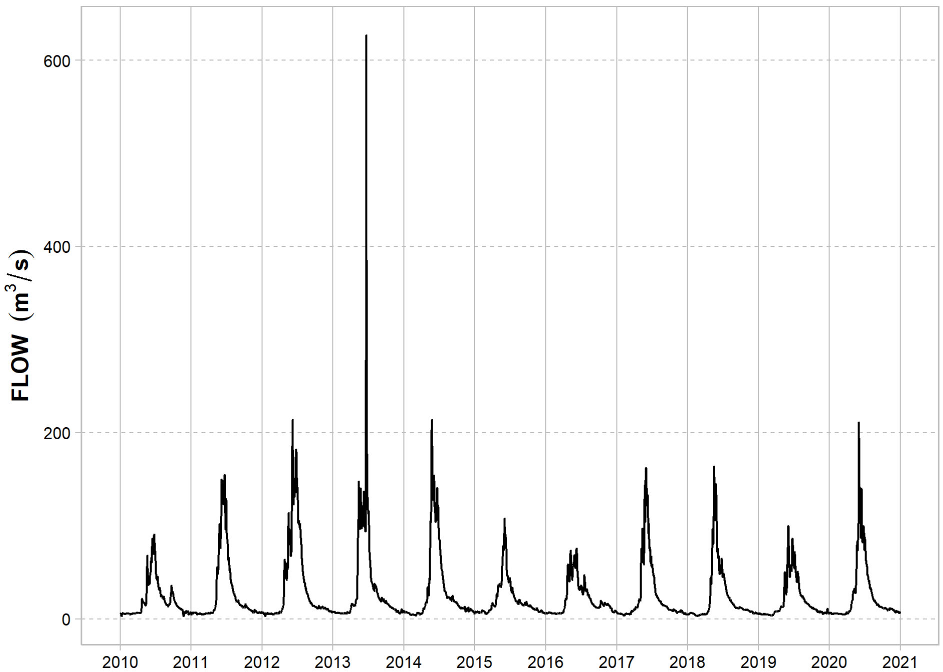


Figure 3. **a) Average daily streamflow (m^3/s) at the Elk River near Natal from 2010 to 2019. Plot (b) shows streamflow on a log scale. Vertical reference lines indicate the start of the calendar year.**

a)



b)

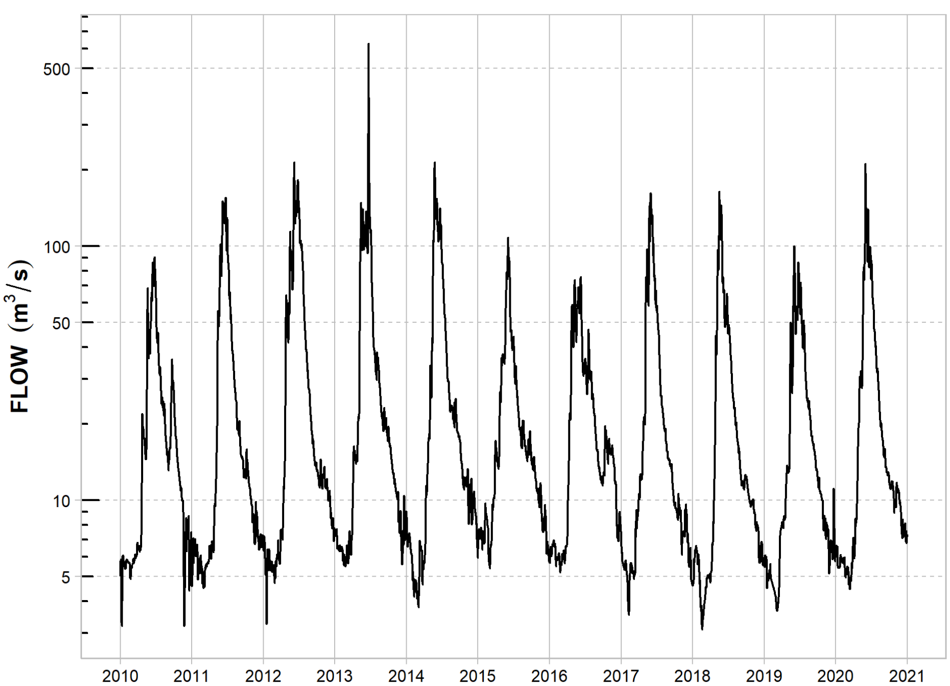
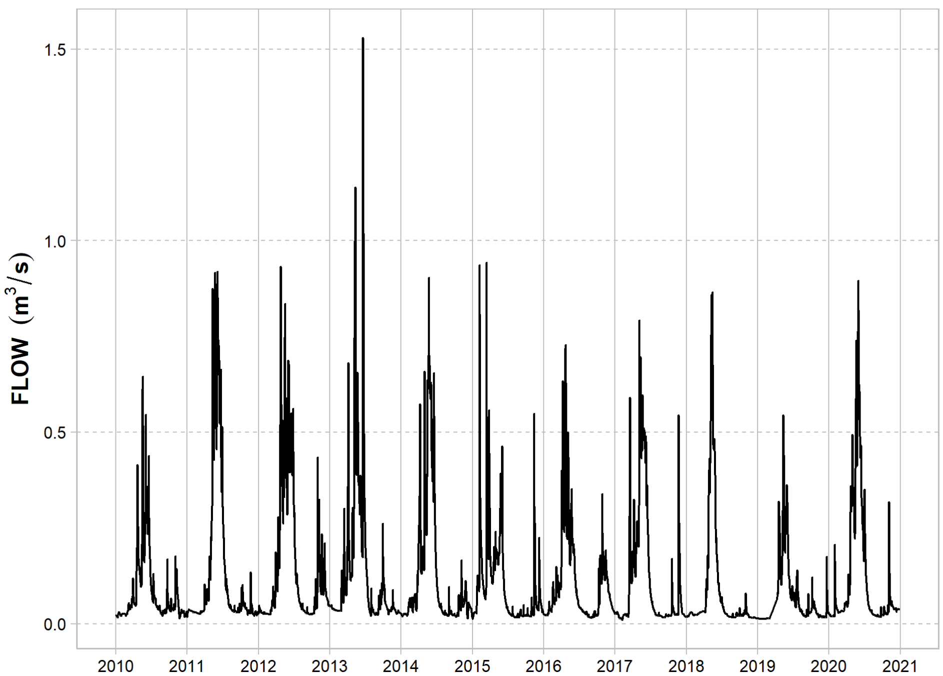


Figure 4. a) Average daily streamflow (m^3/s) at Hosmer Creek below Diversions from 2010 to 2019. Plot (b) shows streamflow on a log scale. Vertical reference lines indicate the start of the calendar year.

a)



b)

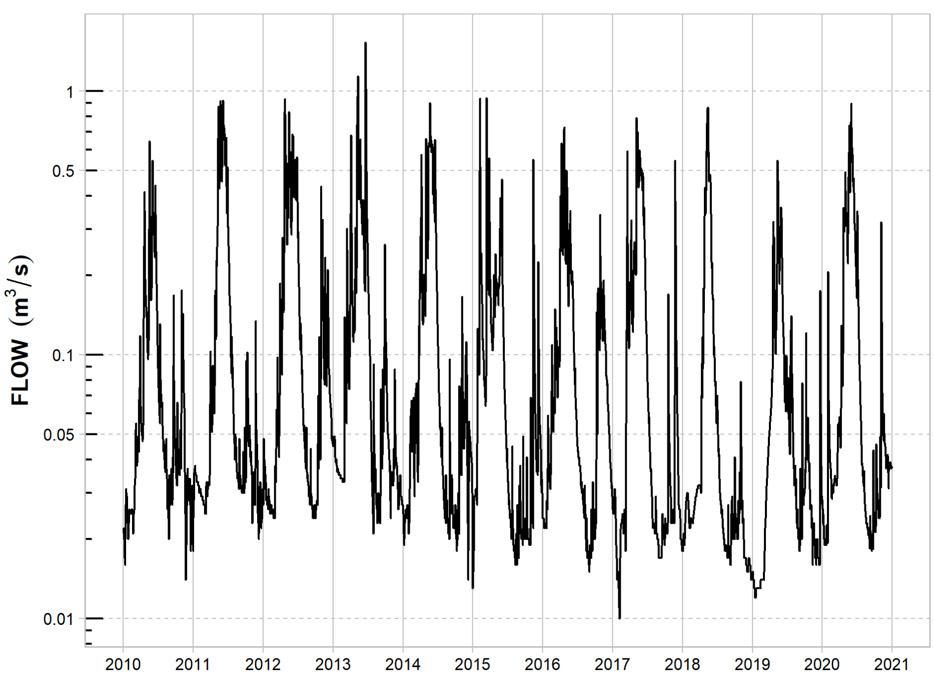


Table 6. Long-term mean monthly flow (i.e., mean of the mean monthly flow for each year on record) as well as minimum and maximum values of mean monthly flow.

Station[1]	Month	Monthly Flow (m^3/s) Mean	Minimum	Maximum	Mean Flow (%MAD)	Number of Years	Number of measurements[2]
Elk River near Natal	Jan	5.94	2.27	27.5	23%	69	
	Feb	5.51	2.49	26.3	21%	70	
	Mar	5.79	2.49	25.6	22%	69	
	Apr	12.2	3.95	85.6	47%	69	
	May	59.9	4.87	283	230%	69	
	Jun	98.0	30.6	627	376%	69	
	Jul	52.5	17.6	231	202%	69	
	Aug	25.2	10.8	85.2	97%	69	
	Sep	16.6	4.02	42.5	64%	69	
	Oct	13.0	6.64	40.9	50%	70	
	Nov	9.85	3.20	47.1	38%	70	
	Dec	7.13	2.49	20.5	27%	70	
Grave Creek at the Mouth	Jan	0.323	0.135	1.51	30%	30	
	Feb	0.321	0.137	0.783	30%	30	
	Mar	0.419	0.167	1.40	39%	30	
	Apr	1.16	0.240	7.88	107%	30	
	May	3.42	0.360	9.92	315%	29	
	Jun	3.29	0.354	17.8	303%	29	
	Jul	1.38	0.444	6.46	127%	29	
	Aug	0.824	0.319	9.91	76%	29	
	Sep	0.551	0.292	1.50	51%	29	
	Oct	0.488	0.263	0.929	45%	29	
	Nov	0.449	0.201	1.76	41%	29	
	Dec	0.365	0.139	0.949	34%	29	
EV_HC1	Jan	0.173	0.000	0.302	31%	17	21
	Feb	0.165	0.000	0.399	30%	19	29
	Mar	0.243	0.000	1.12	44%	22	85
	Apr	0.626	0.001	2.84	113%	22	87
	May	1.56	0.349	4.33	281%	23	85
	Jun	1.38	0.003	3.68	248%	22	98
	Jul	0.847	0.066	1.98	152%	24	38
	Aug	0.435	0.198	0.736	78%	23	32
	Sep	0.299	0.049	0.590	54%	24	30
	Oct	0.344	0.142	0.831	62%	24	36
	Nov	0.295	0.008	0.535	53%	25	37
	Dec	0.280	0.057	0.522	50%	23	24
EV_DC1	Jan	0.053	0.012	0.163	44%	6	5
	Feb	0.043	0.008	0.104	36%	7	9
	Mar	0.081	0.011	0.360	67%	7	24
	Apr	0.223	0.014	0.668	186%	7	27
	May	0.317	0.111	1.10	265%	9	32
	Jun	0.260	0.043	0.699	217%	12	40
	Jul	0.119	0.050	0.265	99%	10	20
	Aug	0.084	0.006	0.153	70%	12	13
	Sep	0.063	0.002	0.106	53%	10	10
	Oct	0.088	0.026	0.458	73%	11	15
	Nov	0.052	0.020	0.134	43%	10	11
	Dec	0.051	0.012	0.081	43%	5	6
Hosmer Creek	Jan	0.032	0.006	0.20	27%	39	
	Feb	0.041	0.005	0.936	34%	39	
	Mar	0.073	0.009	1.04	61%	41	
	Apr	0.20	0.020	1.30	169%	41	
	May	0.47	0.025	2.84	393%	41	
	Jun	0.32	0.032	5.4	268%	39	
	Jul	0.08	0.013	0.71	64%	40	
	Aug	0.031	0.013	0.17	26%	40	
	Sep	0.032	0.010	0.29	26%	40	
	Oct	0.048	0.015	1.290	40%	40	
	Nov	0.063	0.008	1.28	53%	40	
	Dec	0.038	0.009	0.559	31%	38	

1. Average, minimum, and maximum monthly flow was not reported for stations that had less than 3 years of data.
2. Number of measurements only reported for instantaneous (non-continuous) stations.

Table 7. **Mean monthly streamflow during the last six years, expressed as flow (m^3/s) and percent mean annual discharge (% MAD).**

Station	Month	2019-2020			2018-2019			2017-2018			2016-2017			2015-2016			2014-2015		
		Mean Flow (m^3/s)	Mean Flow %MAD	n[1]	Mean Flow (m^3/s)	Mean Flow %MAD	n[1]	Mean Flow (m^3/s)	Mean Flow %MAD	n[1]	Mean Flow (m^3/s)	Mean Flow %MAD	n[1]	Mean Flow (m^3/s)	Mean Flow %MAD	n[1]	Mean Flow (m^3/s)	Mean Flow %MAD	n[1]
Elk River near Natal	Oct	10.6	41%	31	10.6	41%	31	9.32	36%	31	15.8	61%	31	13.03	50%	31	13.09	50%	31
	Nov	7.60	29%	30	8.71	33%	30	7.87	30%	30	15.1	58%	30	9.62	37%	30	10.81	41%	30
	Dec	6.86	26%	31	6.20	24%	31	6.13	24%	31	8.69	33%	31	7.39	28%	31	8.78	34%	31
	Jan	5.93	23%	31	5.35	21%	31	5.83	22%	31	5.70	22%	31	6.46	25%	31	7.33	28%	31
	Feb	5.55	21%	29	4.66	18%	28	4.06	16%	28	4.86	19%	28	5.81	22%	29	7.63	29%	28
	Mar	5.30	20%	31	5.24	20%	31	4.69	18%	31	6.93	27%	31	6.12	23%	31	9.03	35%	31
	Apr	10.9	42%	30	9.65	37%	30	12.1	46%	30	14.3	55%	30	28.55	110%	30	18.34	70%	30
	May	52.0	200%	31	29.1	112%	31	99.4	382%	31	79.6	305%	31	56.41	216%	31	47.25	181%	31
	Jun	109	419%	30	66.8	256%	30	60.7	233%	30	97.3	374%	30	47.10	181%	30	63.83	245%	30
	Jul	52.6	202%	31	49.3	189%	31	35.8	137%	31	37.8	145%	31	33.11	127%	31	29.21	112%	31
	Aug	22.5	86%	31	23.5	90%	31	18.2	70%	31	17.9	69%	31	22.29	86%	31	17.95	69%	31
	Sep	13.7	53%	30	15.3	59%	30	12.0	46%	30	12.5	48%	30	13.00	50%	30	15.93	61%	30
EV_HC1	Oct	0.27	49%	1	0.26	47%	4	0.26	46%	5	0.31	56%	3	0.26	47%	2	0.34	62%	1
	Nov	0.25	46%	4	0.31	56%	4	0.28	51%	1	0.44	80%	3	0.26	47%	3	0.37	67%	1
	Dec	0.23	42%	2	0.28	51%	1	0.38	68%	1	0.30	54%	1	0.20	35%	1	-	-	0
	Jan	0.18	33%	2	0.15	27%	4	0.18	32%	1	0.30	54%	1	0.20	35%	1	-	-	0
	Feb	0.17	30%	4	0.09	16%	2	0.20	36%	3	0.18	32%	1	0.21	37%	1	0.33	59%	4
	Mar	0.21	37%	4	0.22	39%	4	0.16	28%	3	0.25	45%	5	0.27	48%	5	0.70	126%	4
	Apr	0.58	104%	3	0.56	101%	5	0.56	100%	5	0.58	104%	4	1.55	279%	4	1.12	201%	4
	May	1.38	247%	4	1.09	196%	4	2.77	498%	4	2.48	446%	5	1.11	199%	5	1.39	250%	4
	Jun	1.33	239%	5	0.64	115%	7	0.85	153%	4	1.21	218%	4	0.62	111%	4	1.05	189%	5
	Jul	0.57	102%	2	0.45	81%	3	0.62	111%	2	0.49	89%	3	0.36	64%	4	0.51	92%	2
	Aug	0.33	59%	4	0.31	56%	3	0.32	58%	2	0.39	70%	2	0.27	48%	2	0.29	52%	1
	Sep	0.32	58%	3	0.29	52%	3	0.27	48%	3	0.27	48%	1	0.23	41%	1	0.29	52%	1

Monthly streamflow is listed only for those stations with at least one measurement per month from 2014 to 2020

[1] n is the number of measurements taken per month (continuous stations were counted as 1 measurement per day).

Table 7. Continued (2 of 2).

Station	Month	2019-2020			2018-2019			2017-2018			2016-2017			2015-2016			2014-2015		
		Mean Flow		n[1]	Mean Flow		n[1]	Mean Flow		n[1]	Mean Flow		n[1]	Mean Flow		n[1]	Mean Flow		n[1]
		(m^3/s)	%MAD		(m^3/s)	%MAD		(m^3/s)	%MAD		(m^3/s)	%MAD		(m^3/s)	%MAD		(m^3/s)	%MAD	
EV_DC1	Oct	0.035	29%	28	0.036	30%	34	0.039	32%	29	0.038	32%	4	0.04	37%	32	0.04	35%	28
	Nov	0.036	30%	25	0.032	27%	29	0.032	27%	22	0.084	70%	1	0.06	49%	19	0.04	35%	6
	Dec	0.036	30%	33	0.018	15%	31	0.061	51%	1	0.066	55%	1	-	-	0	-	-	0
	Jan	0.036	30%	1	0.022	18%	30	0.039	33%	1	0.163	136%	1	0.04	31%	1	-	-	0
	Feb	0.031	26%	1	0.020	17%	4	0.035	29%	1	0.074	62%	1	0.03	29%	2	0.06	47%	3
	Mar	0.029	24%	7	0.044	37%	18	0.038	32%	16	0.119	99%	4	0.04	30%	35	0.28	234%	3
	Apr	0.164	137%	6	0.134	112%	35	0.057	48%	28	0.267	223%	10	0.50	415%	34	0.28	236%	4
	May	0.317	264%	5	0.152	127%	35	0.315	263%	8	0.526	439%	35	0.27	224%	36	0.20	167%	29
	Jun	0.153	127%	4	0.088	74%	34	0.141	117%	18	0.220	183%	11	0.12	102%	34	0.18	153%	35
	Jul	0.108	90%	2	0.100	83%	32	0.104	87%	19	0.106	89%	2	0.07	59%	35	0.10	82%	33
	Aug	0.056	47%	1	0.080	67%	23	0.038	32%	31	0.077	64%	1	0.04	29%	32	0.07	57%	32
	Sep	0.103	86%	1	0.049	41%	30	0.040	33%	32	0.058	49%	1	0.01	10%	30	0.07	56%	31
Hosmer	Oct	0.043	36%	31	0.026	21%	31	0.036	30%	31	0.115	97%	31	0.02	19%	31	0.03	25%	31
	Nov	0.0210	18%	30	0.026	21%	30	0.088	74%	30	0.134	112%	30	0.09	75%	30	0.07	60%	30
	Dec	0.035	29%	31	0.015	13%	31	0.035	29%	31	0.049	41%	31	0.06	49%	31	0.04	34%	31
	Jan	0.0215	18%	31	0.013	11%	31	0.0241	20%	31	0.022	19%	31	0.03	23%	31	0.04	37%	31
	Feb	0.050	42%	29	0.014	11%	28	0.0235	20%	28	0.019	16%	28	0.05	44%	29	0.23	193%	28
	Mar	0.040	33%	31	0.031	26%	31	0.030	25%	31	0.112	94%	31	0.10	79%	31	0.23	189%	31
	Apr	0.162	136%	30	0.130	108%	30	0.138	116%	30	0.194	162%	30	0.39	328%	30	0.15	126%	30
	May	0.446	373%	31	0.259	216%	31	0.527	441%	31	0.496	415%	31	0.27	230%	31	0.22	181%	31
	Jun	0.403	337%	30	0.136	113%	30	0.121	101%	30	0.297	249%	30	0.11	92%	30	0.13	105%	30
	Jul	0.114	96%	31	0.075	63%	31	0.036	30%	31	0.045	38%	31	0.04	30%	31	0.03	23%	31
	Aug	0.026	22%	31	0.031	26%	31	0.019	16%	31	0.021	18%	31	0.02	18%	31	0.02	16%	31
	Sep	0.023	19%	30	0.027	23%	30	0.021	17%	30	0.019	16%	30	0.02	18%	30	0.02	20%	30

Monthly streamflow is listed only for those stations with at least one measurement per month from 2014 to 2020

1. n is the number of measurements taken per month (continuous stations were counted as 1 measurement per day).

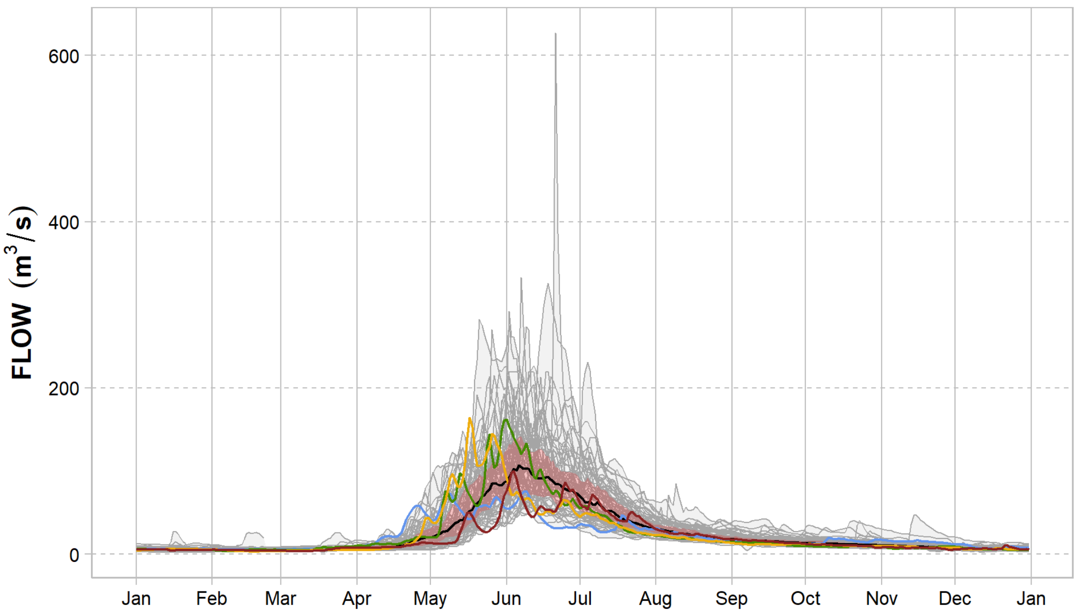
Mean daily streamflow time series for WSC Elk River near Natal, EV_HC1, EV_DC1, and WSC Hosmer Creek above Diversions are presented in Figure 5 to Figure 8. The historical range (minimum to maximum) and interquartile range (25^{th} to 75^{th} percentiles) and streamflow records from 2016-2019 are highlighted. Instantaneous flow records for EV_GV1, EV_GV3, EV_HC4, EV_HC1A, and EV_HC6 were insufficient to calculate historical range or percentiles. Figures in Appendix A illustrate the limited data records that are available for these stations.

Two anomalies in the daily streamflow record during 2016-2019 were notable and widespread: 1) Freshet of 2016 was unusually early, resulting in early recession of streamflow and low flow during June and July during the 2016 spawn year, and 2) Flow during winter of 2018-2019 was extremely low and possibly affected the 2018 spawning-year cohort. Key hydrograph characteristics and anomalies provide support for these conclusions as follows:

- During 2016, freshet occurred earlier than usual at all gauges (in April at EV_DC1, EV_HC1, and Hosmer Creek and during April/May at Elk River near Natal; Figure 5 to Figure 8), resulting in an earlier than usual summer flow recession and very low flows at all gauges during June 2016 and early July 2016. Streamflow was the lowest on record during parts of June at EV_DC1 and Elk River near Natal and was lower than the 25^{th} percentile at all gauges during much of June and July 2016.
- Winter streamflow was the lowest on record at EV_DC1 from mid-November 2018 to the end of January 2019 (Figure 7). At EV_HC1, streamflow was also lower than usual (lower than the 25^{th} percentile) from January to the beginning of March 2019 (Figure 6). Low flow was also observed at Hosmer Creek during winter 2018-2019; streamflow was below the 25^{th} percentile from late 2018 to April 2019, with near record low flow from late December to early March (Figure 8). At the Elk River gauge, winter flow was below the 25^{th} percentile during February and early March 2019 (Figure 5).
- Freshet streamflow at EV_DC1 was the lowest on record from late April to mid-June 2019 (Figure 7). At the Elk River, EV_HC1, and Hosmer Creek, 2019 freshet was slightly lower than usual with multiple peaks (Figure 5, Figure 6, and Figure 8).
- Freshet peak flow at EV_DC1 was higher than the 75^{th} percentile during 2016 and 2017. At EV_HC1, Hosmer, and Elk River, 2017 freshet flow was also slightly higher than the 75^{th} percentile, and 2016 freshet was early but not particularly high.
- Streamflow at EV_DC1 in August and September 2016 was extremely low (Figure 7). These low water levels were determined to have been influenced by calcite deposition, which likely resulted in inaccurate low flow measurements (KWL 2017). Thus, it is likely that this anomaly was the result of instrumentation error rather than actual low streamflow.

Figure 5. (a) Daily streamflow (m³/s) at WSC Station 08NK019 (Elk River near Natal) from 1950 to 2020. Plot (b) shows streamflow on a log scale.

a)



b)

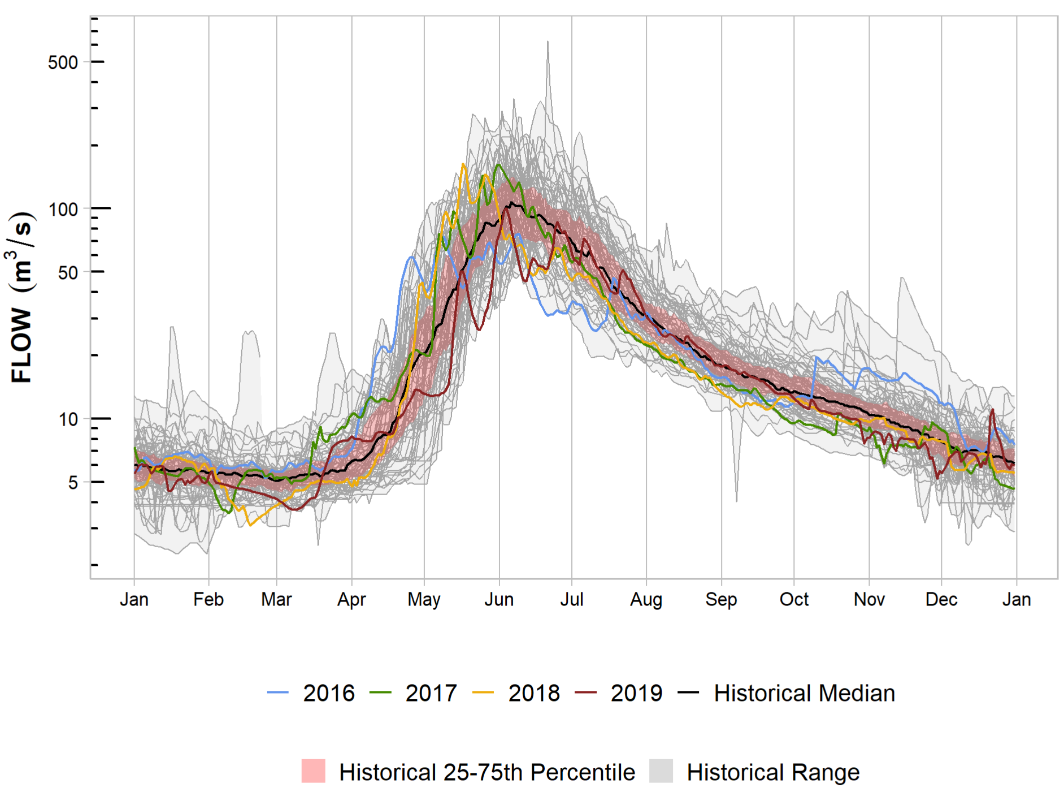
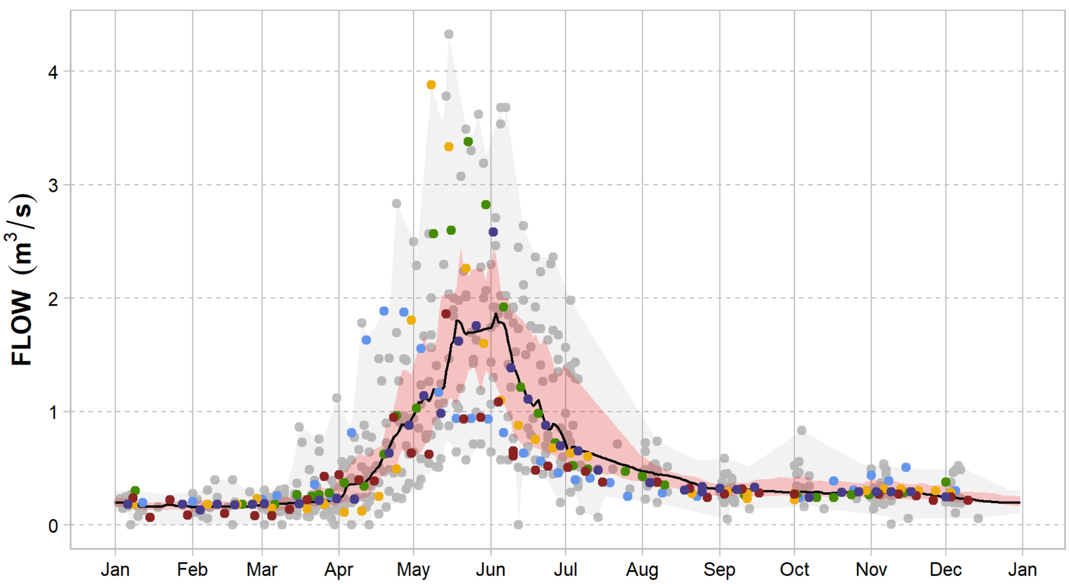


Figure 6. **(a) Daily streamflow (m^3/s) at EV_HC1 (Harmer Creek at Harmer dam outlet) from 1992 to 2020. Plot (b) shows streamflow on a log scale.**

a)



b)

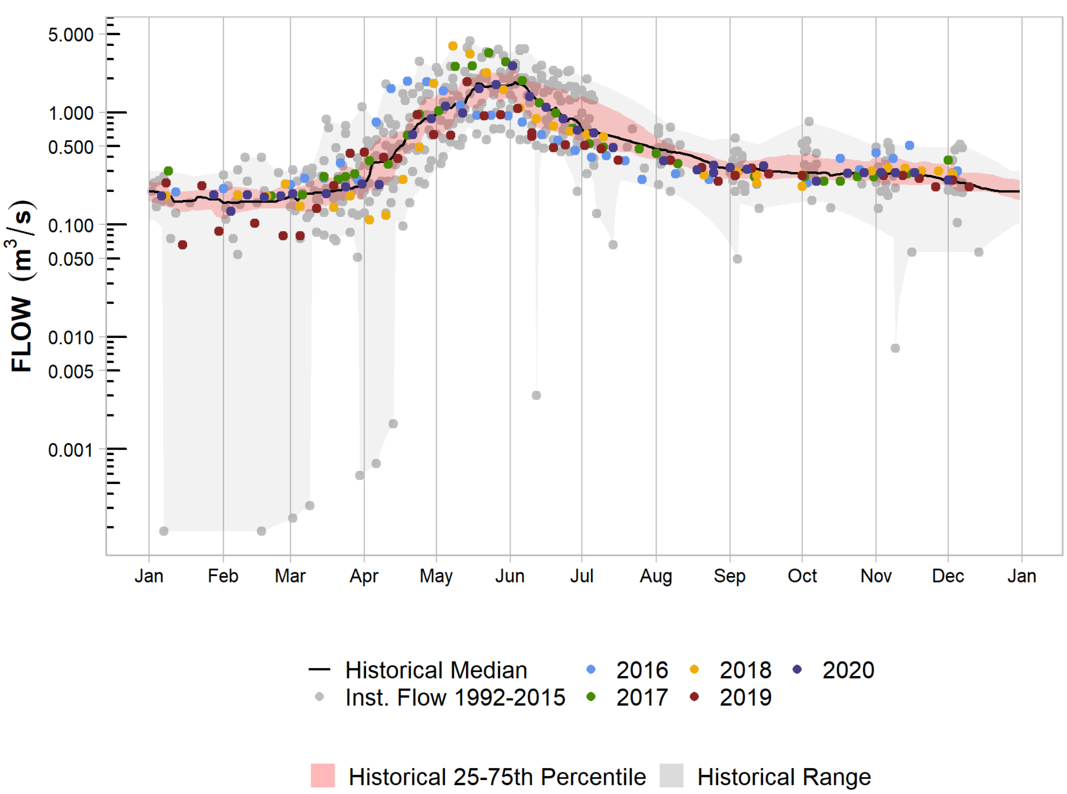
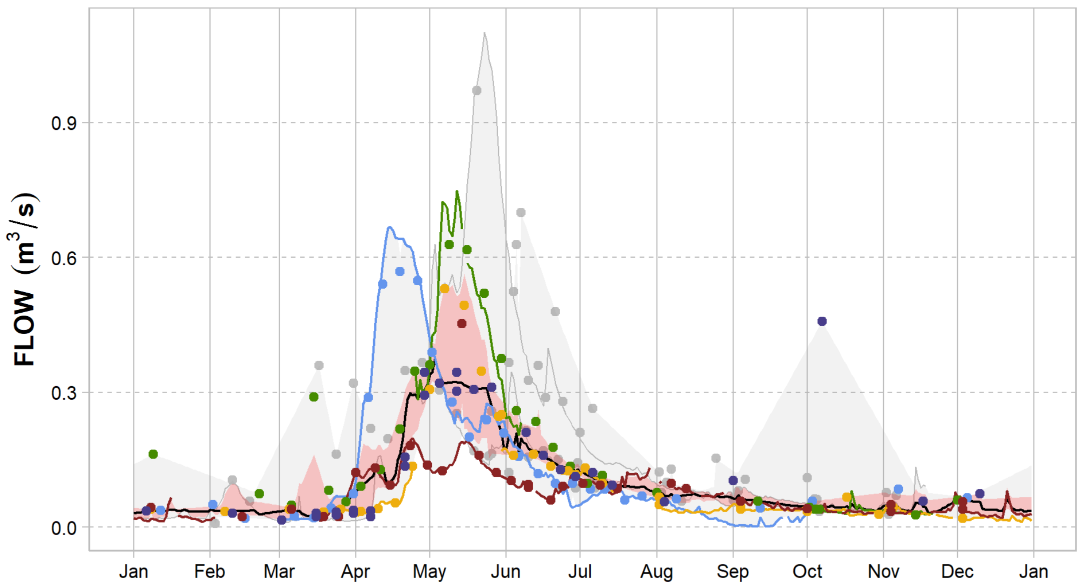


Figure 7. **(a) Daily streamflow (m^3/s) at EV_DC1 (Dry Creek at the Sedimentation Pond outlet) from 2005 to 2020. Plot (b) shows streamflow on a log scale.**

a)



b)

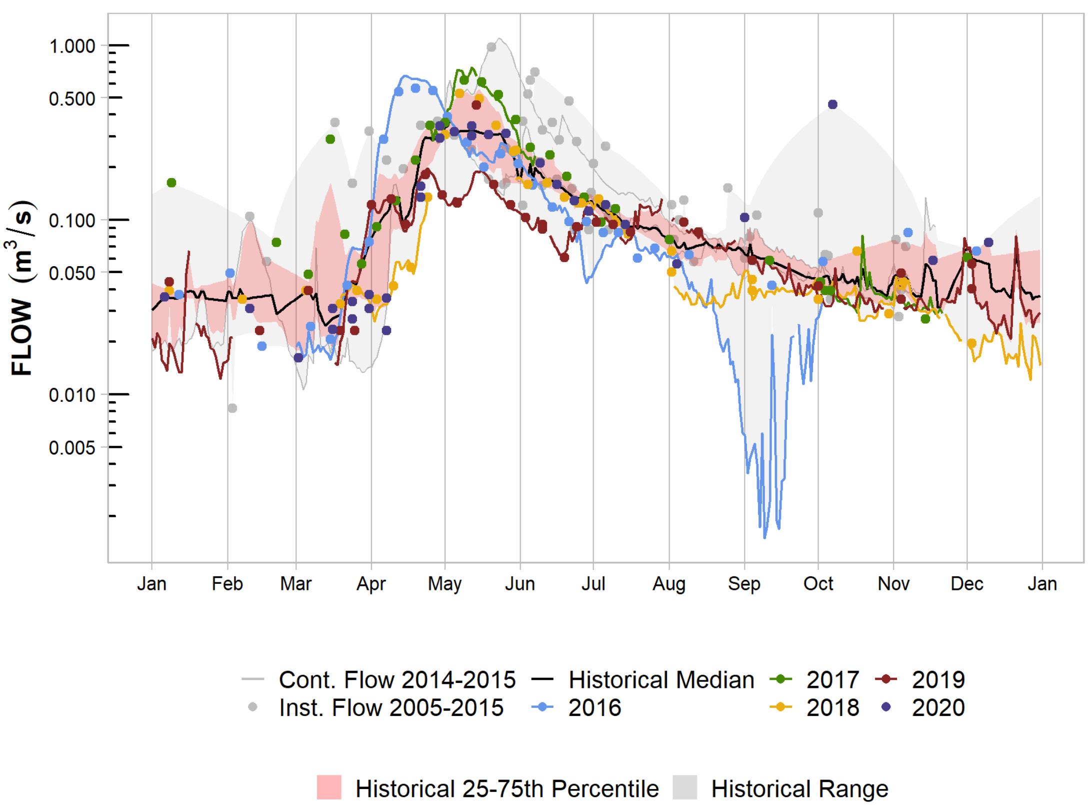
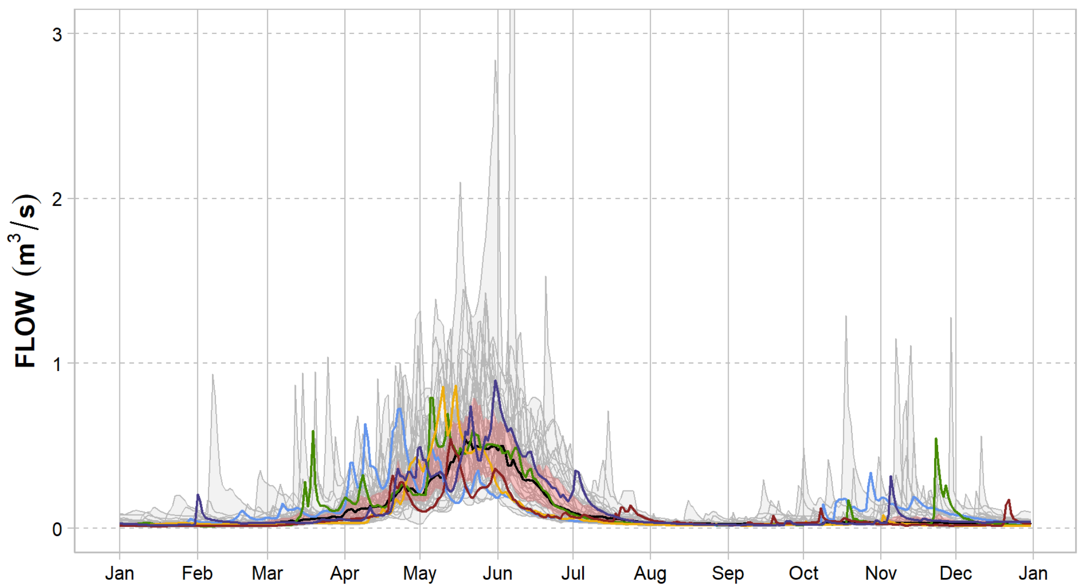
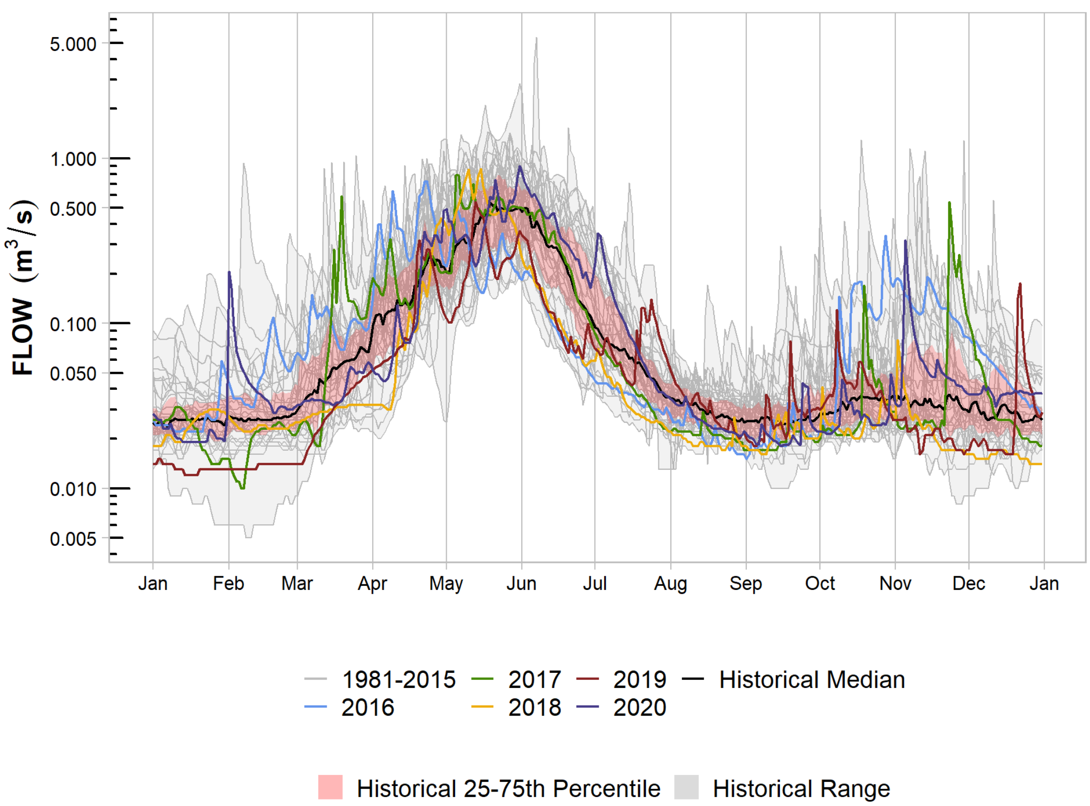


Figure 8. **(a) Daily streamflow (m³/s) at WSC Station 08NK026 (Hosmer Creek above Diversions) from 1981 to 2020. Plot (b) shows streamflow on a log scale.**

a)



b)



3.2. Ecologically Relevant Streamflow Trends and Anomalies

3.2.1. Magnitude of Flow During Key WCT Life Stage Periods

Mean daily streamflow at EV_DC1, EV_HC1, Elk River near Natal, and Hosmer Creek during each of the WCT life stages is summarized in Table 8 to Table 11.

Overall, average streamflow was lower than average from 2015 to 2019 at most gauges for all life stages except overwintering. Streamflow was low during the overwintering period of 2018-2019 and during the spawning period and early incubation period of 2016. Key trends and anomalies included:

- Elk River, EV_HC1, and Hosmer Creek had lower than average mean daily streamflow from 2015 to 2019 for all life stage periods except overwintering (and late incubation in the case of Hosmer Creek).
- Although a less complete record was available for EV_DC1, it showed lower than average streamflow for all life stage periods except overwintering in 2016, for all life stage periods except spawning and overwintering in 2018, and for the overwintering and spawning life stages in 2018-2019.
- Average streamflow during the 2018-2019 overwintering period was the lowest on record at EV_DC1. Flow during the 2018-2019 overwintering period was also very low at Hosmer, EV_HC1, and Elk near Natal (second, fourth, and fifth lowest on record, respectively).
- Average streamflow during the 2016 spawning period was the lowest on record at EV_DC1 and at Elk River near Natal, and third lowest on record at EV_HC1 and Hosmer.
- Streamflow during the early incubation period (June 12 – August 12) and the rearing period (May 28 – October 10) of 2016 was the lowest on record at EV_DC1. At EV_HC1, Hosmer Creek, and Elk River near Natal, these periods were lower than the median during 2016 but not record breaking.

Table 8. Mean daily streamflow at WSC Elk River near Natal station during key WCT life stages.

Year	Mean Flow (m^3/s)				
	Spawning	Early Incubation	Late Incubation	Rearing	Over-wintering[1]
	June 12 to July 11	June 12 to August 12	July 11 to October 31	May 28 to October 10	October 11 to May 27
1970	74.09	49.86	17.17	40.11	9.83
1971	79.11	62.21	25.52	52.12	16.71
1972	116.89	85.31	32.05	71.11	16.80
1973	75.02	52.50	19.37	41.50	13.73
1974	**187.41**	**118.61**	29.87	**74.56**	14.05
1975	106.77	76.41	28.14	54.76	11.35
1976	69.41	58.39	32.22	47.48	18.60
1977	36.49	**27.67**	18.19	26.88	11.26
1978	82.07	62.09	25.88	48.57	12.32
1979	53.97	39.35	16.72	33.88	12.58
1980	66.20	46.41	20.24	39.87	17.14
1981	94.50	74.48	30.75	57.98	17.73
1982	101.45	65.80	21.39	46.66	12.89
1983	47.79	41.07	19.32	35.49	11.34
1984	79.65	54.95	18.83	38.20	8.67
1985	47.57	34.34	18.72	32.28	12.38
1986	64.10	47.95	22.06	48.74	14.36
1987	40.84	34.45	17.80	28.04	18.71
1988	49.82	35.00	14.43	30.46	11.25
1989	55.60	40.89	18.49	33.87	11.50
1990	102.58	75.88	27.64	58.48	13.61
1991	109.22	81.56	29.49	60.26	18.42
1992	57.09	46.45	22.45	34.82	12.72
1993	64.05	59.75	32.40	47.02	14.12
1994	57.48	43.08	18.02	34.48	16.50
1995	93.16	66.85	24.33	57.67	10.04
1996	107.53	76.57	26.42	62.00	13.64
1997	76.19	53.41	21.34	47.19	15.30
1998	75.61	53.56	19.42	44.49	15.52
1999	86.20	67.86	28.00	48.53	11.39
2000	62.14	47.47	20.36	36.20	18.17
2001	37.35	28.42	**12.58**	**23.11**	8.82
2002	145.06	94.44	26.09	65.43	8.99
2003	65.67	45.08	18.07	38.84	11.61
2004	51.72	39.32	26.66	35.61	12.47
2005	99.01	69.81	**32.99**	54.88	16.04
2006	70.42	48.05	18.45	38.93	**22.80**
2007	73.48	51.83	18.79	42.72	17.33
2008	70.81	49.43	18.33	39.91	12.45
2009	56.13	44.73	21.95	36.08	**8.28**
2010	67.68	47.96	22.23	36.15	9.73
2011	114.97	77.27	23.29	54.27	11.88
2012	137.00	99.20	31.06	66.75	16.76
2013	147.93	91.24	24.93	63.10	18.98
2014	101.60	68.32	23.81	54.82	17.65
2015	43.08	32.70	17.58	31.61	14.60
2016	**34.96**	33.08	20.13	28.74	16.33
2017	67.20	46.12	16.51	41.63	17.68
2018	51.32	38.65	16.77	32.79	18.03
2019	62.03	49.02	21.49	37.13	9.31
2020	87.19	61.34	20.86	48.24	11.96

[1] Overwintering period starts on October 11 of the previous year and goes to May 27 of the current year.

Red shades show years that are lower than median, while blue shades show years that are higher than median.

Bold values are highest and lowest on record.

Table 9. Mean daily streamflow at EV_HC1 during key WCT life stages.

Station	Year	Spawning June 12 to July 11 Mean Flow (m³/s)[2]	n[2]	Early Incubation June 12 to August 12 Mean Flow (m³/s)[2]	n[2]	Late Incubation July 11 to October 31 Mean Flow (m³/s)[2]	n[2]	Rearing May 28 to October 10 Mean Flow (m³/s)[2]	n[2]	Over-wintering[1] October 11 to May 27 Flow (m³/s)[2]	n[2]
EV_HC1	1993	1.30	3	1.10	4	0.34	3	0.98	9	0.36	15
	1994	0.50	4	0.45	5	0.18	3	0.55	9	0.55	17
	1995	1.54	4	1.38	5	0.40	3	1.29	10	0.42	16
	1996	1.26	4	1.11	5	0.37	3	1.45	9	0.82	16
	2001	0.45	4	0.40	5	**0.12**	2	0.42	8	**0.29**	14
	2002	1.34	1	0.89	2	0.45	3	0.67	4	0.33	3
	2003	0.79	3	0.77	4	0.46	2	0.98	7	0.49	2
	2004	**0.38**	4	**0.38**	5	0.30	3	**0.40**	9	0.63	12
	2005	1.65	4	1.42	5	**0.58**	3	1.29	8	0.58	16
	2006	0.88	1	0.67	2	0.42	3	0.53	4	0.68	13
	2007	1.32	4	1.15	5	0.44	3	1.18	9	0.99	10
	2008	0.73	1	0.61	2	0.43	3	0.90	5	0.49	2
	2009	0.60	4	0.57	5	0.33	3	0.61	9	0.45	15
	2010	0.94	4	0.62	8	0.28	6	0.66	12	0.46	17
	2011	1.96	4	1.70	5	0.45	3	1.69	9	0.66	12
	2012	**2.29**	4	**1.98**	5	0.51	3	**1.81**	9	**1.27**	13
	2013	1.54	3	1.29	4	0.45	3	1.29	9	0.81	16
	2014	1.46	3	1.22	4	0.49	3	1.31	8	0.75	18
	2015	0.66	4	0.57	6	0.32	5	0.71	10	0.85	17
	2016	0.49	5	0.42	8	0.30	9	0.45	13	0.69	20
	2017	0.79	5	0.65	8	0.31	9	0.82	13	0.76	21
	2018	0.71	5	0.65	6	0.28	7	0.64	12	0.75	20
	2019	0.50	4	0.46	6	0.31	8	0.47	15	0.40	25

[1] Overwintering period starts on October 11 of the previous year and goes to May 27 of the current year.

[2] n is the number of flow measurement records during each year that were used to calculate mean flow during the period.

Red shades show years that are lower than median, while blue shades show years that are higher than median.

Bolded values are the highest and lowest values from 1993-2019.

Table 10. Mean daily streamflow at EV_DC1 during key WCT life stages.

Year	Spawning June 12 to July 11 Mean Flow (m³/s)[2]	% Complete	Early Incubation June 12 to August 12 Mean Flow (m³/s)[2]	% Complete	Late Incubation July 11 to October 31 Mean Flow (m³/s)[2]	% Complete	Rearing May 28 to October 10 Mean Flow (m³/s)[2]	% Complete	Over-wintering[1] October 11 to May 27 Flow (m³/s)[2]	% Complete
2014	**0.242**	100%	**0.175**	100%	**0.071**	96%	**0.165**	100%	0.186	64%
2015	0.136	100%	0.107	100%	0.066	100%	0.102	100%	-	19%
2016	**0.084**	100%	**0.074**	100%	**0.035**	74%	**0.064**	94%	**0.200**	55%
2017	-	0%	-	0%	-	23%	-	12%	-	14%
2018	0.117	63%	0.088	56%	0.041	86%	0.066	75%	-	34%
2019	0.089	97%	0.094	87%	0.062	85%	0.077	89%	**0.063**	79%

[1] Overwintering period starts on October 11 of the previous year and goes to May 27 of the current year.

[2] Mean flow reported only for years with greater than 50% complete record during period. This is calculated as the number of days with flow data available divided by the total number of days in the period, expressed as a percentage. Years with <50% of days (during period) with data are shown with a "-".

Red shades show years that are lower than median, while blue shades show years that are higher than median. White/light shades show values that are at/close to the median.

Bolded values are the highest and lowest values from 2014-2019.

Table 11. Mean daily streamflow at WSC Hosmer Creek station during key WCT life stages.

Year	Mean Flow (m^3/s)				
	Spawning	Early Incubation	Late Incubation	Rearing	Over-wintering[1]
	June 12 to July 11	June 12 to August 12	July 11 to October 31	May 28 to October 10	October 11 to May 27
1982	0.308	0.173	0.042	0.146	0.194
1983	0.126	0.138	0.069	0.145	0.172
1984	0.239	0.141	0.032	0.119	0.129
1985	0.147	0.086	0.052	0.127	0.112
1986	0.081	0.060	0.037	0.092	0.145
1987	**0.050**	0.041	0.025	**0.044**	0.142
1988	0.080	0.053	0.026	0.068	0.103
1989	0.151	0.098	0.048	0.138	0.121
1990	0.264	0.159	0.045	0.150	0.124
1991	0.352	0.205	0.039	0.175	0.152
1992	0.067	0.057	0.039	0.057	0.090
1993	0.136	0.131	0.067	0.105	0.092
1994	0.114	0.070	0.023	0.065	0.107
1995	0.296	0.172	0.060	0.219	0.085
1996	0.236	0.139	0.033	0.141	0.132
1997	0.162	0.097	0.035	0.203	0.161
1998	0.122	0.077	0.028	0.105	0.111
1999	0.327	0.190	0.043	0.156	0.114
2000	0.124	0.076	0.028	0.082	0.141
2001	0.118	0.080	0.031	0.073	0.064
2002	**0.498**	**0.275**	0.042	**0.243**	0.116
2003	0.104	0.069	0.037	0.105	0.077
2004	0.092	0.069	0.057	0.083	0.092
2005	0.233	0.135	**0.119**	0.165	0.133
2006	0.145	0.094	0.034	0.106	**0.202**
2007	0.285	0.153	0.028	0.159	0.183
2008	0.231	0.141	0.034	0.146	0.108
2009	0.119	0.078	0.029	0.090	**0.054**
2010	0.170	0.112	0.045	0.103	0.066
2011	0.445	0.256	0.054	0.206	0.105
2012	0.369	0.217	0.052	0.166	0.127
2013	0.360	0.198	0.053	0.153	0.162
2014	0.250	0.141	0.031	0.137	0.121
2015	0.051	**0.036**	**0.022**	0.053	0.127
2016	0.062	0.046	0.049	0.051	0.130
2017	0.156	0.091	0.027	0.102	0.142
2018	0.070	0.047	0.023	0.056	0.114
2019	0.078	0.071	0.042	0.073	0.062
2020	0.263	0.153	0.033	0.148	0.095

[1] Overwintering period starts on October 11 of the previous year and goes to May 27 of the current year.

Red shades show years that are lower than median, while blue shades show years that are higher than median.

Bold values are highest and lowest on record.

3.2.2. Magnitude and Duration of Mean Extreme Flow

The magnitude of high and low flow extremes of various duration provides a measure of environmental stress during the year, though conversely these extremes may be ecologically important for maintaining habitat features (e.g., flushing flows and channel maintenance flows) and triggers for the reproduction of certain species (Richter *et al.* 2006). The magnitude and duration of extreme flow, represented as the one-, three-, seven-, and 30-day minimum and maximum flow at WSC Elk River near Natal, EV_DC1, and Hosmer Creek, are presented for each WCT life stage in Figure 9 to Figure 13. Only these stations are provided as no other stations had a continuous multi-year record that included years up to 2019. Years with less than 50% complete data record were not included in the calculations.

- During the spawning period, the magnitude of minimum and maximum flow at EV_DC1 for all durations was unusually high in 2014. Minimum and maximum flow for all durations was lowest in 2016 at both the EV_DC1 and the WSC Elk River gauges. At Hosmer, 2016 was the second lowest year for minimum flow.
- During the early incubation period, the magnitudes of the one-day to seven-day minimum flows at EV_DC1 were lowest in 2018, but the lowest 30-day minimum flow was in 2016. The lowest 30-day maximum flow also occurred in 2016 at Elk River. Minimum flows in 2016 and 2018 were not particularly low at the Hosmer or Elk stations.
- During the late incubation period at EV_DC1, the lowest minimum flows were in 2016; these flows were extremely low compared to other years on record. This year was not particularly low at the Hosmer or Elk stations. Thirty-day maximum flows at EV_DC1 were lowest in 2018; 30-day maximum flows were also low (although not the lowest) at Hosmer in 2018.
- The 2016 minimum flows during the rearing period at EV_DC1 were particularly low compared to other years. At Hosmer, seven-day and 30-day minimum flow was lower from 2015-2018 than previous years.
- The minimum flow during the overwintering period was lowest in 2013-2014, except for the 30-day minimum, which was lowest in 2018-2019 winter at EV_DC1. At Hosmer and Elk River, the 2018-2019 minimum flow was low but not the lowest on record.
- At EV_DC1, maximum flow during the overwintering and rearing periods was highest in 2014. Record high maximum flow also occurred at Elk River during the 2014 overwintering period, but flow was not remarkable at Hosmer or at Elk River during the rearing period.

Figure 9. Magnitude and duration of annual extreme streamflow (m^3/s) at Elk River near Natal, EV_DC1, and Hosmer stations during WCT spawning (June 12 to July 11). Note the y-axis range is different for each station.

Figure 10. Magnitude and duration of annual extreme streamflow (m^3/s) at Elk River near Natal, EV_DC1, and Hosmer stations during WCT early incubation (June 12 to August 12). Note the y-axis range is different for each station.

Figure 11. **Magnitude and duration of annual extreme streamflow (m^3/s) at Elk River near Natal, EV_DC1, and Hosmer stations during WCT late incubation (July 11 to October 31). Note the y-axis range is different for each station.**

Figure 12. **Magnitude and duration of annual extreme streamflow (m^3/s) at Elk River near Natal, EV_DC1, and Hosmer stations during WCT rearing (May 28 to October 10). Note the y-axis range is different for each station.**

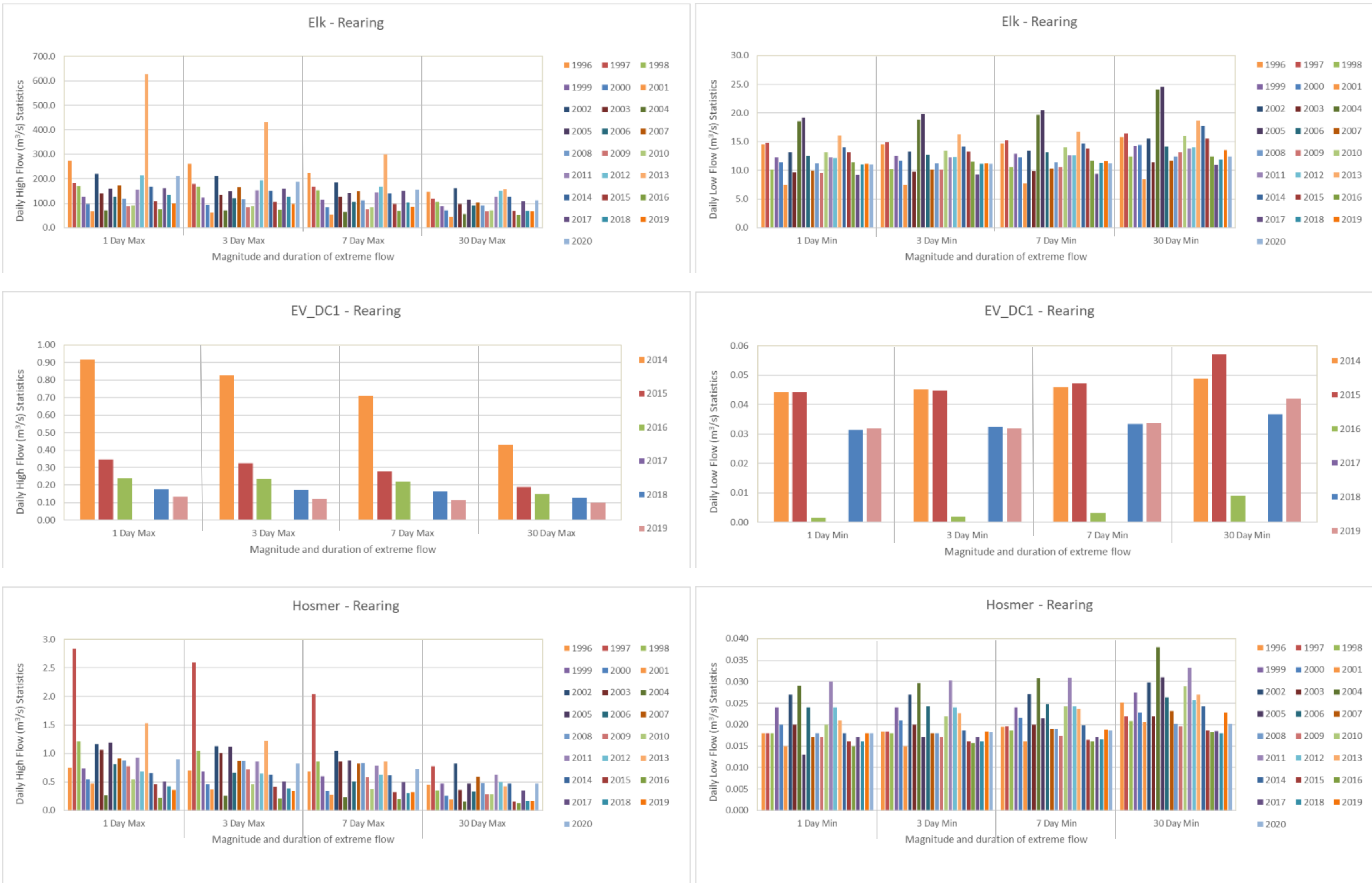


Figure 13. **Magnitude and duration of annual extreme streamflow (m^3/s) at Elk River near Natal, EV_DC1, and Hosmer stations during WCT overwintering (October 11 to May 27). Note the y-axis range is different for each station.**

3.2.3. Timing of Mean Extreme Flow

The timing of annual flow extremes at Elk River near Natal, EV_DC1, and Hosmer Creek during each WCT life stage period is presented in Table 12 to Table 16. Only these stations are provided as no other stations had a continuous multi-year record that included all years up to 2019. The ecological mechanisms associated with timing are less clear than magnitude and duration but are presented for completeness rather than to illustrate specific linkages to effects on fish or habitat.

- During the spawning period, the timing of the minimum and maximum daily flow at EV_DC1 varied from year to year.
- During the early incubation period, the timing of minimum annual flow at EV_DC1 was in mid-August during most years but occurred much earlier (in June) in 2019. Conversely, the timing of maximum flow was similar (June 12 to July 2) from 2014 to 2018 but was later (July 29) in 2019. A similar late maximum flow was also seen at Hosmer in 2019.
- During the late incubation period, minimum flow was in late October during all years at EV_DC1 except 2016, when minimum flow occurred in early September.
- During the rearing period, minimum flow timing was variable at EV_DC1. Maximum flow timing was consistent at EV_DC1 from 2014 to 2018 (May 28 – June 3) but was much later (July 29) in 2019.
- During the overwintering period, minimum and maximum flow timing were variable at EV_DC1, though only three years had more than a 50% complete record for the overwintering period.

Table 12. Timing of annual extreme (minimum and maximum) streamflow during the WCT spawning period (June 12 to July 11).

Year	Date of Annual Extreme Flow					
	Elk River near Natal		EV_DC1		Hosmer	
	Min	Max	Min	Max	Min	Max
1970	11/Jul	17/Jun	-	-	-	-
1971	9/Jul	12/Jun	-	-	-	-
1972	11/Jul	12/Jun	-	-	-	-
1973	10/Jul	23/Jun	-	-	-	-
1974	11/Jul	18/Jun	-	-	-	-
1975	1/Jul	8/Jul	-	-	-	-
1976	28/Jun	21/Jun	-	-	-	-
1977	9/Jul	12/Jun	-	-	-	-
1978	5/Jul	12/Jun	-	-	-	-
1979	5/Jul	13/Jun	-	-	-	-
1980	9/Jul	12/Jun	-	-	-	-
1981	11/Jul	2/Jul	-	-	9/Jul	1/Jul
1982	11/Jul	15/Jun	-	-	11/Jul	15/Jun
1983	22/Jun	12/Jun	-	-	27/Jun	12/Jun
1984	11/Jul	16/Jun	-	-	2/Jul	14/Jun
1985	11/Jul	16/Jun	-	-	6/Jul	12/Jun
1986	11/Jul	12/Jun	-	-	11/Jul	12/Jun
1987	2/Jul	17/Jun	-	-	11/Jul	12/Jun
1988	11/Jul	12/Jun	-	-	10/Jul	12/Jun
1989	9/Jul	15/Jun	-	-	9/Jul	13/Jun
1990	11/Jul	25/Jun	-	-	11/Jul	12/Jun
1991	19/Jun	12/Jun	-	-	11/Jul	12/Jun
1992	3/Jul	10/Jul	-	-	27/Jun	9/Jul
1993	26/Jun	10/Jul	-	-	3/Jul	10/Jul
1994	11/Jul	14/Jun	-	-	11/Jul	17/Jun
1995	11/Jul	12/Jun	-	-	11/Jul	12/Jun
1996	9/Jul	12/Jun	-	-	11/Jul	17/Jun
1997	11/Jul	13/Jun	-	-	8/Jul	12/Jun
1998	11/Jul	20/Jun	-	-	9/Jul	16/Jun
1999	12/Jun	19/Jun	-	-	11/Jul	15/Jun
2000	8/Jul	12/Jun	-	-	11/Jul	15/Jun
2001	11/Jul	23/Jun	-	-	11/Jul	13/Jun
2002	7/Jul	18/Jun	-	-	11/Jul	15/Jun
2003	11/Jul	12/Jun	-	-	26/Jun	12/Jun
2004	11/Jul	13/Jun	-	-	28/Jun	12/Jun
2005	11/Jul	12/Jun	-	-	8/Jul	12/Jun
2006	11/Jul	16/Jun	-	-	11/Jul	12/Jun
2007	11/Jul	12/Jun	-	-	11/Jul	18/Jun
2008	11/Jul	23/Jun	-	-	10/Jul	14/Jun
2009	11/Jul	18/Jun	-	-	11/Jul	15/Jun
2010	9/Jul	25/Jun	-	-	11/Jul	18/Jun
2011	11/Jul	22/Jun	-	-	11/Jul	12/Jun
2012	8/Jul	25/Jun	-	-	11/Jul	27/Jun
2013	11/Jul	21/Jun	-	-	11/Jul	20/Jun
2014	11/Jul	21/Jun	11/Jul	18/Jun	11/Jul	18/Jun
2015	10/Jul	12/Jun	7/Jul	13/Jun	9/Jul	12/Jun
2016	11/Jul	12/Jun	28/Jun	12/Jun	11/Jul	12/Jun
2017	11/Jul	15/Jun	-	-	9/Jul	14/Jun
2018	11/Jul	25/Jun	11/Jul	2/Jul	9/Jul	12/Jun
2019	12/Jun	25/Jun	18/Jun	28/Jun	10/Jul	12/Jun
2020	11/Jul	15/Jun	-	-	11/Jul	14/Jun

Table 13. Timing of annual extreme (minimum and maximum) streamflow during the WCT early incubation period (June 12 to August 12).

Year	Date of Annual Extreme Flow					
	Elk River near Natal		EV_DC1		Hosmer	
	Min	Max	Min	Max	Min	Max
1970	12/Aug	17/Jun	-	-	-	-
1971	12/Aug	12/Jun	-	-	-	-
1972	12/Aug	12/Jun	-	-	-	-
1973	12/Aug	23/Jun	-	-	-	-
1974	12/Aug	18/Jun	-	-	-	-
1975	12/Aug	8/Jul	-	-	-	-
1976	2/Aug	9/Aug	-	-	-	-
1977	24/Jul	12/Jun	-	-	-	-
1978	12/Aug	12/Jun	-	-	-	-
1979	11/Aug	13/Jun	-	-	-	-
1980	8/Aug	12/Jun	-	-	-	-
1981	11/Aug	2/Jul	-	-	11/Aug	1/Jul
1982	11/Aug	15/Jun	-	-	27/Jul	15/Jun
1983	10/Aug	12/Jun	-	-	7/Aug	15/Jul
1984	12/Aug	16/Jun	-	-	9/Aug	14/Jun
1985	12/Aug	16/Jun	-	-	17/Jul	12/Jun
1986	10/Aug	12/Jun	-	-	9/Aug	12/Jun
1987	9/Aug	17/Jun	-	-	3/Aug	12/Jun
1988	12/Aug	12/Jun	-	-	30/Jul	12/Jun
1989	7/Aug	15/Jun	-	-	12/Aug	13/Jun
1990	12/Aug	25/Jun	-	-	12/Aug	12/Jun
1991	12/Aug	12/Jun	-	-	10/Aug	12/Jun
1992	12/Aug	10/Jul	-	-	5/Aug	9/Jul
1993	12/Aug	13/Jul	-	-	11/Aug	13/Jul
1994	12/Aug	14/Jun	-	-	11/Aug	17/Jun
1995	5/Aug	12/Jun	-	-	5/Aug	12/Jun
1996	10/Aug	12/Jun	-	-	12/Aug	17/Jun
1997	12/Aug	13/Jun	-	-	12/Aug	12/Jun
1998	12/Aug	20/Jun	-	-	9/Aug	16/Jun
1999	4/Aug	19/Jun	-	-	3/Aug	15/Jun
2000	10/Aug	12/Jun	-	-	2/Aug	15/Jun
2001	12/Aug	23/Jun	-	-	10/Aug	13/Jun
2002	12/Aug	18/Jun	-	-	12/Aug	15/Jun
2003	12/Aug	12/Jun	-	-	12/Aug	12/Jun
2004	3/Aug	13/Jun	-	-	12/Aug	12/Jun
2005	7/Aug	12/Jun	-	-	2/Aug	12/Jun
2006	8/Aug	16/Jun	-	-	2/Aug	12/Jun
2007	12/Aug	12/Jun	-	-	3/Aug	18/Jun
2008	12/Aug	23/Jun	-	-	12/Aug	14/Jun
2009	11/Aug	18/Jun	-	-	7/Aug	15/Jun
2010	12/Aug	25/Jun	-	-	10/Aug	18/Jun
2011	11/Aug	22/Jun	-	-	8/Aug	12/Jun
2012	12/Aug	25/Jun	-	-	11/Aug	27/Jun
2013	1/Aug	21/Jun	-	-	31/Jul	20/Jun
2014	12/Aug	21/Jun	12/Aug	18/Jun	12/Aug	18/Jun
2015	12/Aug	12/Jun	11/Aug	13/Jun	11/Aug	12/Jun
2016	12/Aug	12/Jun	12/Aug	12/Jun	5/Aug	12/Jun
2017	12/Aug	15/Jun	-	-	10/Aug	14/Jun
2018	10/Aug	25/Jun	10/Aug	2/Jul	10/Aug	12/Jun
2019	9/Aug	25/Jun	18/Jun	29/Jul	9/Aug	24/Jul
2020	12/Aug	15/Jun	-	-	12/Aug	14/Jun

Table 14. Timing of annual extreme (minimum and maximum) streamflow during the WCT late incubation period (July 11 to October 31).

Year	Date of Annual Extreme Flow					
	Elk River near Natal		EV_DC1		Hosmer	
	Min	Max	Min	Max	Min	Max
1970	31/Oct	11/Jul	-	-	-	-
1971	31/Oct	16/Jul	-	-	-	-
1972	31/Oct	18/Jul	-	-	-	-
1973	30/Oct	12/Jul	-	-	-	-
1974	31/Oct	11/Jul	-	-	-	-
1975	31/Oct	11/Jul	-	-	-	-
1976	30/Oct	9/Aug	-	-	-	-
1977	28/Oct	26/Aug	-	-	-	-
1978	31/Oct	11/Jul	-	-	-	-
1979	26/Oct	11/Jul	-	-	-	-
1980	28/Oct	11/Jul	-	-	-	-
1981	31/Oct	14/Jul	-	-	13/Sep	11/Jul
1982	31/Oct	11/Jul	-	-	27/Jul	23/Oct
1983	29/Oct	15/Jul	-	-	23/Sep	15/Jul
1984	31/Oct	13/Jul	-	-	5/Sep	11/Jul
1985	16/Oct	14/Sep	-	-	17/Jul	28/Oct
1986	25/Oct	11/Jul	-	-	16/Aug	1/Oct
1987	31/Oct	23/Jul	-	-	11/Sep	19/Jul
1988	31/Oct	12/Jul	-	-	3/Sep	25/Sep
1989	31/Oct	17/Jul	-	-	9/Oct	21/Oct
1990	24/Oct	27/Jul	-	-	24/Sep	31/Oct
1991	30/Oct	11/Jul	-	-	31/Oct	11/Jul
1992	19/Oct	11/Jul	-	-	20/Aug	11/Jul
1993	31/Oct	13/Jul	-	-	29/Oct	13/Jul
1994	25/Oct	11/Jul	-	-	25/Sep	27/Oct
1995	31/Oct	11/Jul	-	-	11/Sep	11/Oct
1996	31/Oct	11/Jul	-	-	1/Oct	11/Jul
1997	31/Oct	11/Jul	-	-	20/Aug	5/Oct
1998	31/Oct	11/Jul	-	-	9/Sep	12/Jul
1999	29/Oct	12/Jul	-	-	11/Sep	31/Oct
2000	31/Oct	11/Jul	-	-	5/Oct	19/Oct
2001	30/Oct	11/Jul	-	-	22/Sep	11/Jul
2002	31/Oct	11/Jul	-	-	31/Oct	11/Jul
2003	15/Oct	23/Oct	-	-	30/Aug	21/Oct
2004	31/Oct	27/Aug	-	-	16/Aug	18/Sep
2005	9/Sep	11/Jul	-	-	2/Aug	18/Oct
2006	31/Oct	11/Jul	-	-	31/Oct	11/Jul
2007	28/Sep	11/Jul	-	-	3/Aug	11/Jul
2008	31/Oct	11/Jul	-	-	30/Sep	11/Jul
2009	12/Oct	15/Jul	-	-	27/Sep	15/Jul
2010	31/Oct	13/Jul	-	-	28/Aug	21/Sep
2011	30/Oct	14/Jul	-	-	11/Sep	11/Jul
2012	28/Oct	11/Jul	-	-	18/Sep	31/Oct
2013	31/Oct	11/Jul	-	-	31/Jul	29/Sep
2014	22/Oct	11/Jul	31/Oct	16/Jul	9/Oct	3/Sep
2015	29/Oct	13/Jul	29/Oct	11/Jul	11/Aug	21/Sep
2016	27/Sep	18/Jul	9/Sep	12/Jul	1/Sep	28/Oct
2017	17/Oct	11/Jul	-	-	31/Aug	19/Oct
2018	25/Oct	11/Jul	19/Oct	11/Jul	7/Sep	11/Jul
2019	30/Oct	11/Jul	24/Oct	29/Jul	4/Sep	24/Jul
2020	26/Oct	11/Jul	-	-	15/Sep	11/Jul

Table 15. Timing of annual extreme (minimum and maximum) streamflow during the WCT rearing period (May 28 to October 10).

Year	Date of Annual Extreme Flow					
	Elk River near Natal		EV_DC1		Hosmer	
	Min	Max	Min	Max	Min	Max
1970	10/Oct	7/Jun	-	-	-	-
1971	10/Oct	9/Jun	-	-	-	-
1972	10/Oct	2/Jun	-	-	-	-
1973	9/Oct	9/Jun	-	-	-	-
1974	10/Oct	18/Jun	-	-	-	-
1975	3/Oct	8/Jul	-	-	-	-
1976	10/Oct	29/May	-	-	-	-
1977	10/Oct	9/Jun	-	-	-	-
1978	10/Oct	7/Jun	-	-	-	-
1979	8/Oct	28/May	-	-	-	-
1980	12/Sep	28/May	-	-	-	-
1981	9/Oct	28/May	-	-	13/Sep	29/May
1982	10/Oct	15/Jun	-	-	27/Jul	28/May
1983	10/Oct	30/May	-	-	23/Sep	28/May
1984	9/Oct	16/Jun	-	-	5/Sep	31/May
1985	10/Oct	9/Jun	-	-	17/Jul	9/Jun
1986	22/Sep	1/Jun	-	-	16/Aug	28/May
1987	10/Oct	8/Jun	-	-	11/Sep	31/May
1988	1/Oct	8/Jun	-	-	3/Sep	31/May
1989	10/Oct	7/Jun	-	-	9/Oct	6/Jun
1990	3/Oct	31/May	-	-	24/Sep	30/May
1991	10/Oct	4/Jun	-	-	30/Sep	2/Jun
1992	11/Sep	10/Jul	-	-	20/Aug	28/May
1993	10/Oct	2/Jun	-	-	31/Aug	2/Jun
1994	10/Oct	7/Jun	-	-	25/Sep	28/May
1995	9/Oct	7/Jun	-	-	11/Sep	7/Jun
1996	14/Sep	9/Jun	-	-	1/Oct	8/Jun
1997	2/Oct	1/Jun	-	-	20/Aug	31/May
1998	10/Oct	1/Jun	-	-	9/Sep	28/May
1999	7/Oct	19/Jun	-	-	11/Sep	28/May
2000	10/Oct	10/Jun	-	-	5/Oct	28/May
2001	10/Oct	29/May	-	-	22/Sep	28/May
2002	8/Oct	18/Jun	-	-	14/Sep	30/May
2003	10/Oct	30/May	-	-	30/Aug	29/May
2004	10/Oct	13/Jun	-	-	16/Aug	6/Jun
2005	9/Sep	8/Jun	-	-	2/Aug	10/Jun
2006	10/Oct	16/Jun	-	-	12/Sep	8/Jun
2007	28/Sep	6/Jun	-	-	3/Aug	5/Jun
2008	3/Oct	3/Jun	-	-	30/Sep	31/May
2009	10/Oct	1/Jun	-	-	27/Sep	31/May
2010	4/Sep	25/Jun	-	-	28/Aug	3/Jun
2011	4/Oct	22/Jun	-	-	11/Sep	6/Jun
2012	10/Oct	7/Jun	-	-	18/Sep	2/Jun
2013	10/Oct	21/Jun	-	-	31/Jul	20/Jun
2014	10/Oct	28/May	6/Oct	28/May	9/Oct	28/May
2015	10/Oct	4/Jun	9/Oct	3/Jun	11/Aug	3/Jun
2016	27/Sep	9/Jun	9/Sep	28/May	1/Sep	28/May
2017	10/Oct	1/Jun	-	-	31/Aug	28/May
2018	20/Sep	28/May	22/Aug	31/May	7/Sep	28/May
2019	7/Oct	4/Jun	6/Oct	29/Jul	4/Sep	31/May
2020	7/Oct	1/Jun	-	-	15/Sep	31/May

Table 16. Timing of annual extreme (minimum and maximum) streamflow during the WCT overwintering period (October 11 to May 27).

Year	Date of Annual Extreme Flow					
	Elk River near Natal		EV_DC1		Hosmer	
	Min	Max	Min	Max	Min	Max
1969/1970	28/Dec	26/May	-	-	-	-
1970/1971	7/Mar	27/May	-	-	-	-
1971/1972	27/Jan	24/May	-	-	-	-
1972/1973	7/Dec	19/May	-	-	-	-
1973/1974	12/Jan	27/May	-	-	-	-
1974/1975	25/Mar	17/May	-	-	-	-
1975/1976	1/Mar	11/May	-	-	-	-
1976/1977	5/Jan	12/May	-	-	-	-
1977/1978	23/Nov	23/May	-	-	-	-
1978/1979	1/Jan	27/May	-	-	-	-
1979/1980	28/Jan	27/May	-	-	-	-
1980/1981	6/Dec	27/May	-	-	11/Apr	30/Apr
1981/1982	6/Jan	26/May	-	-	10/Nov	22/May
1982/1983	19/Mar	27/May	-	-	31/Dec	26/May
1983/1984	1/Mar	21/May	-	-	14/Oct	18/May
1984/1985	4/Mar	26/May	-	-	4/Mar	7/May
1985/1986	17/Feb	27/May	-	-	19/Feb	27/May
1986/1987	25/Feb	13/May	-	-	9/Nov	1/May
1987/1988	1/Feb	24/May	-	-	4/Jan	13/May
1988/1989	4/Feb	11/May	-	-	2/Feb	7/May
1989/1990	17/Feb	27/May	-	-	5/Feb	25/May
1990/1991	2/Mar	22/May	-	-	20/Oct	19/May
1991/1992	15/Dec	9/May	-	-	15/Dec	30/Apr
1992/1993	20/Feb	16/May	-	-	4/Dec	14/May
1993/1994	11/Feb	13/May	-	-	23/Nov	10/May
1994/1995	5/Jan	26/May	-	-	27/Nov	19/May
1995/1996	4/Feb	27/May	-	-	6/Nov	29/Nov
1996/1997	25/Jan	18/May	-	-	27/Dec	17/May
1997/1998	12/Jan	27/May	-	-	11/Jan	27/May
1998/1999	10/Feb	27/May	-	-	23/Dec	25/May
1999/2000	20/Mar	23/May	-	-	12/Feb	13/Nov
2000/2001	10/Feb	27/May	-	-	8/Feb	24/May
2001/2002	9/Mar	22/May	-	-	29/Dec	22/May
2002/2003	9/Mar	27/May	-	-	26/Nov	26/May
2003/2004	5/Jan	23/Oct	-	-	26/Jan	4/May
2004/2005	4/Jan	18/May	-	-	4/Jan	17/May
2005/2006	18/Feb	21/May	-	-	18/Feb	18/Oct
2006/2007	30/Nov	19/May	-	-	13/Jan	7/Nov
2007/2008	22/Jan	26/May	-	-	22/Jan	18/May
2008/2009	16/Dec	27/May	-	-	27/Jan	19/May
2009/2010	8/Dec	20/May	-	-	8/Dec	19/May
2010/2011	24/Nov	27/May	-	-	24/Nov	23/May
2011/2012	18/Jan	17/May	-	-	9/Dec	25/Apr
2012/2013	24/Feb	14/May	-	-	11/Oct	12/May
2013/2014	3/Mar	25/May	4/Mar	23/May	7/Jan	23/May
2014/2015	3/Mar	27/May	-	-	1/Jan	15/Mar
2015/2016	24/Feb	9/May	15/Mar	15/Apr	24/Oct	23/Apr
2016/2017	9/Feb	25/May	-	-	6/Feb	5/May
2017/2018	18/Feb	17/May	-	-	30/Dec	15/May
2018/2019	8/Mar	17/May	27/Dec	24/Apr	14/Jan	13/May
2019/2020	14/Mar	23/May	-	-	11/Nov	21/May

3.3. Factors Potentially Influencing Streamflow Trends

3.3.1. Mining Activities and other Watershed Factors

Mining activities in the headwaters of Dry Creek have the potential to impact hydrology by: 1) removing vegetation and overburden and compacting soils, and 2) causing accumulation of minespoil and valley fill. Hydrological effects of these two practices can be opposite to each other and local, complex interactions may be important in determining the resulting total effect; however, the general causal effect pathways are summarized below.

By removing overburden and compacting soils, mining practices can result in increased runoff especially during individual storm events (Miller and Zegre 2014). However, evidence also suggests that peak streamflow may decrease with increased mining within a large watershed (Zegre et al. 2014), likely due to the attenuating effects of valley fill. Valley fill and surface minespoil appear to act as storage reservoirs that dampen storm responses and result in slower release of water; this storage effect can also result in higher baseflows during low flow conditions (Miller and Zegre 2014). However, the effects of valley fill can be complex and may depend on how the fill was constructed and on local topography. Flow within the valley fill may be controlled by matrix flow characterized by torturous, slow pathways during non-storm conditions, which result in storage and gradual release of water that sustains baseflows (Zegre et al. 2014). Flow within the valley fill may also be controlled by large preferential flow paths during storm conditions resulting in rapid response to storm events and increased peak flows downstream of valley fills (Zegre et al. 2014). Furthermore, the magnitude of the response to mining and valley fill will vary with the proportion of the catchment that is altered.

It is notable that EV_DC1 is located at the outlet of a sedimentation pond and EV_HC1 is below a dam. This means that regulation of streamflow immediately upstream of these locations could also affect streamflow. For example, it is possible that flow in downstream reaches is generally lower than it would be naturally during some freshet conditions (as the pond/reservoir fills prior to spilling) and could potentially be higher than natural flow during some winter or fall low-flow conditions (due to releasing stored water within the pond/reservoir). Thus, low streamflow observed during the winter of 2018-2019 may have been ameliorated (or exacerbated) by dam/pond regulation, although the extent to which amelioration (or exacerbation) of low flows may have occurred is unknown at this time.

No consumptive water licences are located within the current watershed area of Grave Creek, although some consumptive use occurs within the headwaters of the original Dry Creek watershed at Breaker Lake and Breaker Pocket. This portion of land no longer drains to Grave Creek due to mining-related landscape changes (Little and Healey 2020).

Mining and spoiling activities, logging, and other industrial and construction activities within the Grave Creek watershed were not notably different during recent years than historically (Chapter 2, Harmer Creek Evaluation of Cause Team 2022). Cumulative disturbance within the watershed may have affected the timing and amount of water entering the creeks by altering the amount of water that could be stored (e.g., snow accumulation, soil infiltration, interception by vegetation), but the available evidence does not indicate substantive changes coincident with the Reduced Recruitment.

3.3.2. Climate Factors

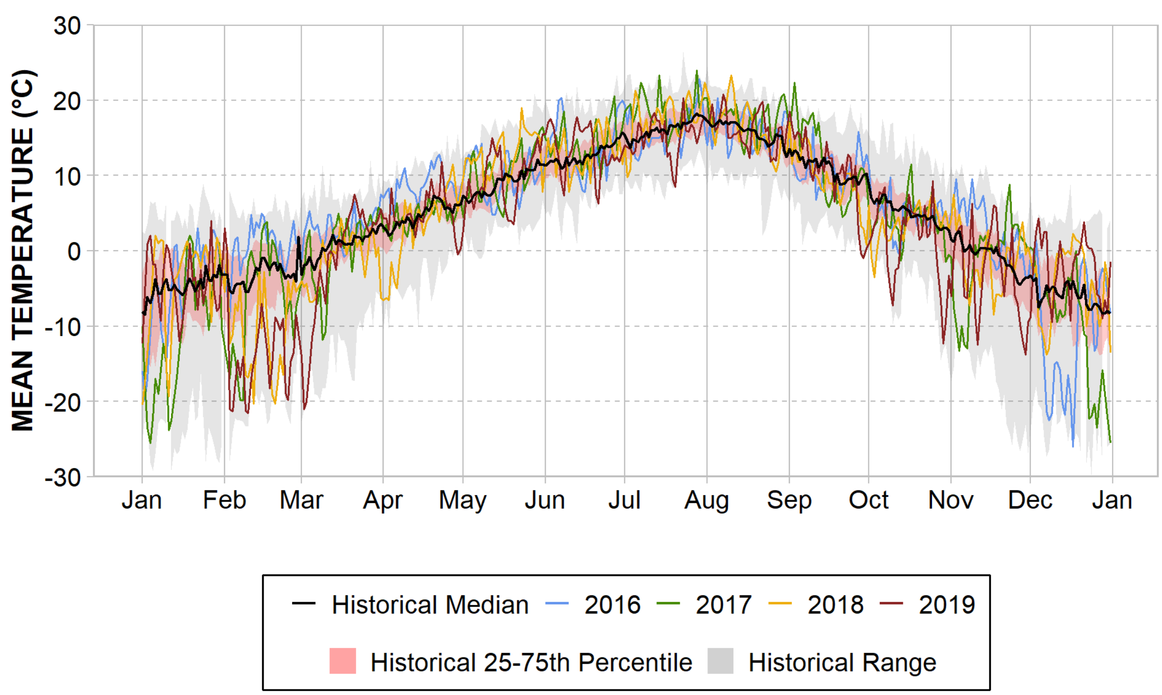
Data from nearby climate monitoring stations were examined to investigate potential causes of (1) the 2018-2019 low winter streamflow observed at EV_HC1, EV_DC1, and Hosmer Creek and (2) the early freshet and low June/July flow of 2016 observed at all gauges. Data analysis indicated that low 2018-2019 winter streamflow may have occurred due to a combination of low precipitation during late summer and early fall 2018 and ice formation resulting from low air temperatures during February and March 2019. Meanwhile record high air temperatures in early spring 2016 likely caused the early freshet and low June/July flow in that year.

3.3.2.1. Air Temperature

Air temperature from the ECCC Sparwood extended record (see Section 1.3) was very low (below the 25th percentile) during February and early March 2019, which could have contributed to low winter streamflow due to sudden ice formation (Figure 14). However, streamflow was low at EV_HC1, EV_DC1, and Hosmer Creek prior to the onset of these cold temperatures, indicating that temperature was not a sole driving factor (Figure 6 to Figure 7).

Air temperature during April 2016 reached record high levels, which would likely have resulted in early snowmelt, driving an early freshet and leaving little snowmelt to contribute to flows during WCT spawning and the subsequent rearing period (June/early July).

Figure 14. Air temperatures at the ECCC Sparwood (extended; elevation 1,138 m) during recent years compared to the historical (1980-2019) median precipitation.

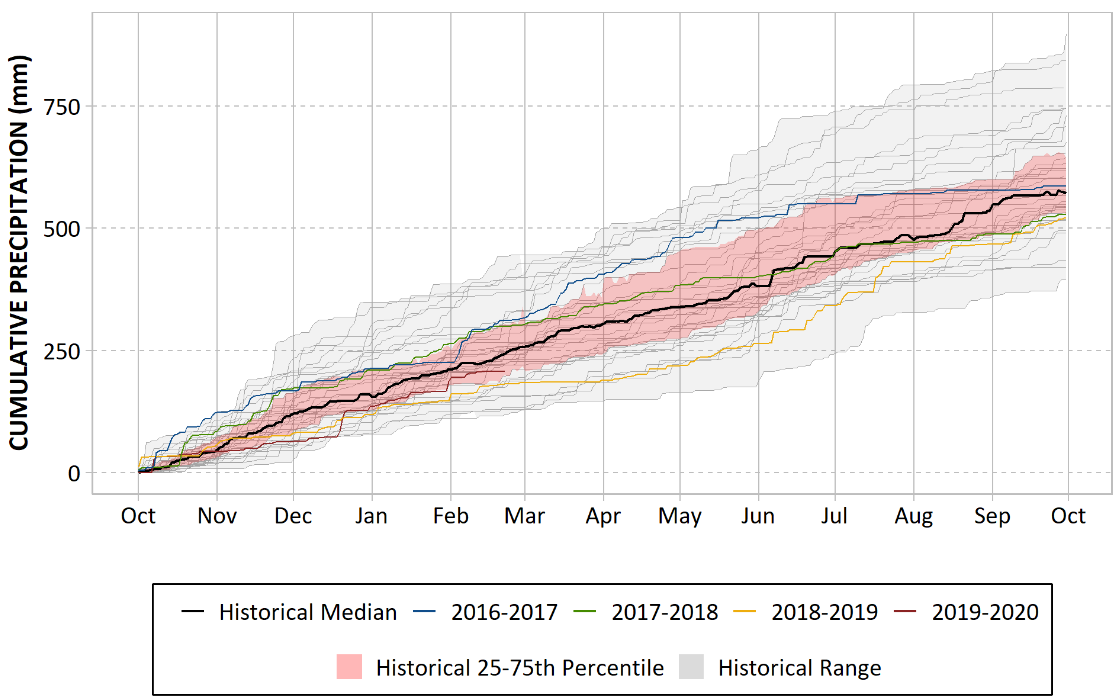


3.3.2.2. Precipitation

Low precipitation from late summer and early fall 2018 may have contributed to the low winter streamflow during 2018-2019 in small watersheds such as Dry Creek, Harmer Creek, and Hosmer Creek. The precipitation record indicates anomalously low precipitation may have been a driving factor of low winter streamflow. Cumulative precipitation from the ECCC Sparwood extended record was at or slightly below the 25th percentile from mid-August to October 2018 (Figure 15).

Low precipitation in winter likely contributed to a smaller snowpack during 2018-2019. Cumulative precipitation from the ECCC Sparwood record was normal (within the interquartile range) or above average during October 2018, although cumulative snowfall was the highest on record, meaning more precipitation than normal fell as snow (Figure 15). Morrissey Ridge snow monitoring station (1860 masl) records indicated that the high snowfall during the beginning of October melted by the end of the month. It is possible that some snow at higher elevation persisted as snowpack rather than melting and contributing to streamflow, which could have resulted in lower flow contributions to high elevation creeks during this month and later months (i.e., October onwards). Cumulative precipitation at Sparwood was slightly below the historical median during November 2018, and from December onward precipitation was below the 25th percentile (Figure 15). The lowest precipitation of any month during the past decade at Sparwood was observed in March 2019.

Figure 15. Cumulative precipitation recorded at the ECCC Sparwood climate station during recent years compared to the historical (1980-2019) median precipitation.



4. DISCUSSION

Reduced recruitment in the Harmer Creek population of Westslope Cutthroat Trout (WCT) was observed for the 2017, 2018, and 2019 spawning-year cohorts, and in the Grave Creek population of WCT in the 2018 spawn year. The historical streamflow record was examined to identify anomalies and trends that may be related to the Reduced Recruitment in the Harmer Creek WCT population. Streamflow is a "master variable" that influences myriad components of flowing water systems (Poff et al. 1997). This report focussed on streamflow as a proxy for habitat availability for fish and therefore examined a specific subset of potential mechanisms (see Section 1.1.1) that may be related to the Reduced Recruitment. Broadly, we examined evidence of anomalous low flows during the non-freshet period (to infer habitat limitations during an activity period) or anomalous high flows during freshet (to infer direct effects to fish (e.g., scour of redds or displacement of free-swimming individuals) or rapid changes to stream morphology).

Two prominent anomalies in the streamflow records were noted.

- The spring freshet of 2016 occurred earlier than average at all gauges analyzed. This early freshet resulted in early recession of flow and very low flows in June and July of that year. Streamflow was the lowest on record during parts of June at EV_DC1 and Elk River near Natal and was lower than the 25th percentile at all gauges during much of June and July 2016. Large reductions in streamflow during the summer of 2016 in the Harmer Creek population area may have influenced availability of fish habitat for the 2016 spawning-year cohort.
- The lowest average annual streamflow of the past decade occurred at EV_DC1, EV_HC1, and reference streams Hosmer Creek and Elk River near Natal in the 2018-2019 water year. The winter of 2018-2019 was also particularly low at gauges within the Grave Creek watershed and at the small Hosmer Creek reference stream, according to mean monthly flow records and visual analysis of annual hydrographs. Streamflow was low within the larger Elk River during that winter, but was not as low, relative to other years on record, as in the smaller watersheds. Reductions in streamflow during the winter of 2018-2019 may have influenced availability of fish habitat for the 2018 spawning-year cohort, the cohort with recruitment failure.

4.1. Evaluation of Explanatory Factors

For each of five explanatory factors, conditions were defined that needed to be met in order to conclude that streamflow (and inferred effects on habitat availability) in Harmer Creek caused or contributed to the observed Reduced Recruitment (see descriptions in Section 2.4). The evidence provided in this report supports conclusions that streamflow was contributory to the WCT Reduced Recruitment in Harmer Creek and the recruitment failure that was observed in both the Grave Creek population and the Harmer Creek population. Since only some of the conditions described for the five explanatory factors were met, the evidence does not indicate that streamflow conditions were the sole cause of the Reduced Recruitment. However, some of the conditions were met, which suggests that streamflow conditions were contributors to the Reduced Recruitment. The rationale for these conclusions is elaborated below, and potential uncertainties are described.

Cause of the Reduced Recruitment was not met because:

- EV_DC1 at Dry Creek, within the Harmer Creek watershed, reported record low streamflow in 2016 and in the winter of 2018-2019, but the data record was short, and it is unclear how low these flows were relative to the long-term record. For all WCT life stages in Harmer Creek, the EV_HC1 gauge reported no record low streamflow averages in recent years. This suggests that the observed low streamflow at EV_DC1 was low relative to streamflow at EV_HC1, but these observations could not be compared to a longer record. Although observed streamflow within the Harmer watershed was low generally, similar low flow conditions were recorded at other regional monitoring locations (Elk River and Hosmer Creek). Low streamflow during the summer of 2016 in the Harmer Creek population area is expected to influence the amount and the physical characteristics of fish habitat for the 2016 spawning-year cohort. The influence would not have extended to cohorts in subsequent years.
- No anomalies in the streamflow record were observed during the spawning, incubation, and rearing periods that coincided with the timing of recent Reduced Recruitment.
- For the overwintering life stage in Harmer Creek, record low streamflow was identified in the winter of 2018-2019 at EV_DC1. This low streamflow coincided with the timing of the recruitment failure noted in the 2018 spawning-year cohort, but is unlikely to have influenced other spawning-year cohorts. Streamflow at EV_HC1 and at regional monitoring locations was also very low during this time, but it was not the lowest on record.
- No extremely high annual maximum flows (that may have resulted in scouring or other effects) were observed during the period of Reduced Recruitment, nor were persistent (multi-year) low annual maximum flows (that could have led to a lack of flushing flows) observed.
- **Contribution** to the Reduced Recruitment was met because:
- Large reductions in streamflow may have affected fish habitat availability in Harmer Creek and would have led to lower habitat quality during the spawning, incubation, and rearing period of 2016 and during the winter of 2018-2019 at all stations. Low streamflow during the summer of 2016 in the Harmer Creek population area would likely have influence the 2016 spawning-year cohort, but not subsequent cohorts.
- Lower than average streamflow occurred during spawning, early and late incubation, and rearing periods in Harmer Creek over the five-year period from 2015-2019. These lower streamflows may have affected several cohorts, but the magnitude of effect cannot be determined from streamflow data alone.

- An anomalous reduction in streamflow occurred during the 2018-2019 overwintering period in Dry Creek and Harmer Creek, which could have affected WCT present in Harmer Creek during that time. Particular attention is drawn to effects on fry from the 2018 spawning-year cohort, and is discussed in detail in the Water Temperature and Ice report (see Hocking et al. 2022).

4.2. Uncertainties

Key uncertainties in the conclusions of this assessment are:

- This report uses streamflow as a proxy for habitat availability for fish; however, the true influence of streamflow on recruitment is unknown with respect to the explanatory factors examined. For example, there is no explicit response relationship between streamflow magnitude or duration versus recruitment. This uncertainty required a qualitative assessment of anomalies and trends in the available record.

- Large temporal gaps existed in the dataset. Most sites were monitored for relatively short durations, did not have recent records (2017-2020), and/or had few data points. EV_DC1 was the only gauge within Harmer Creek watershed upstream of the dam, and this gauge had a relatively short record of instantaneous measurements (2005-2020) and an even shorter record of continuous streamflow monitoring (2014-2019). This analysis could not evaluate potential effects during periods of no data. Where long-term monitoring data did exist within the watershed, some of these data were obtained from spot measurements taken at weekly or monthly intervals, so anomalous conditions could have occurred between measurements (although spot measurements are typical of hydrological records in interior ice-affected streams).

- Large spatial gaps existed in the dataset. Substantial recent data were available only at two sites, EV_DC1 and EV_HC1. EV_DC1 was far upstream in the Harmer watershed and did not accurately indicate conditions within the mainstem of Harmer and Grave creeks. EV_HC1 was below the Harmer Dam outlet and did not fully capture conditions within the mainstem of Harmer Creek upstream of the dam or downstream of the confluence with Grave Creek. Both stations were below sedimentation ponds and therefore may have been affected by the hydrological damping effects of the ponds.

5. CONCLUSION

This assessment evaluated the potential for streamflow (and inferred effects on habitat) to have caused or contributed to the observed WCT Reduced Recruitment in Harmer Creek. Potential effects from streamflow on WCT were evaluated using data from two hydrometric stations located in Harmer Creek and Dry Creek, and two regional stations provided additional context.

Data from each station were assessed for potential effects on WCT using standard temporal periods (months, years) to determine spatial and temporal trends in the available data, and using ecologically relevant statistics to compare streamflow during key WCT activity periods. The results were compared within and among streams to identify trends and/or anomalies in recent years. Results for Harmer Creek and Dry Creek were compared against the explanatory factors described in Section 2.4 to determine whether streamflow events caused or contributed to the Reduced Recruitment.

Conditions for Cause of Reduced Recruitment were not met. Streamflow in Harmer and Dry creeks was of similar magnitude in recent years relative to the prior period and was consistent with regional stations. Anomalously low streamflow with potential for large effects to WCT habitat availability were limited in their spatiotemporal overlap with the period of Reduced Recruitment and were not uncommon when compared with older data from Harmer and Dry creeks. Uncertainties such as spatial and temporal gaps in the dataset limit the conclusions.

Conditions for Contribution to the Reduced Recruitment were identified. Available data indicated that streamflow conditions in recent years may have singly or in combination with other stressors influenced recruitment. Specifically, low streamflow during the summer of 2016 in the Harmer Creek population area likely influenced the amount and the physical characteristics of fish habitat for the 2016 spawning-year cohort, but not for subsequent cohorts. Low streamflow in the winter of of 2018-2019 coincided with the timing of the recruitment failure noted in the 2018 spawning-year cohort, but is unlikely to have influenced other spawning-year cohorts.

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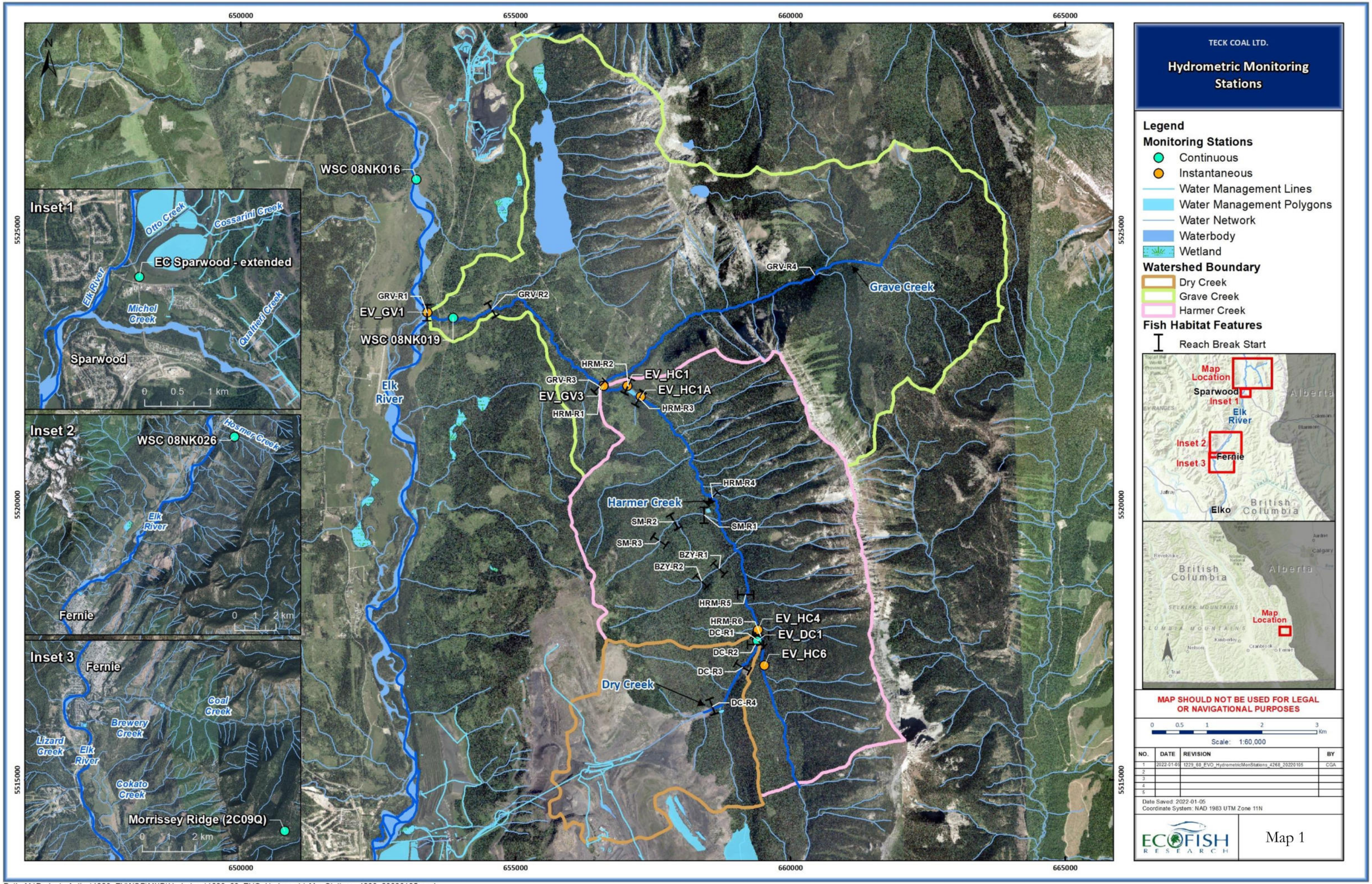
PROJECT MAPS



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APPENDICES

Appendix A. Flow Records from Grave – Harmer Hydrometric Stations with Limited Data

LIST OF FIGURES

Figure 1. Instantaneous flow measurements at EV_GV1 (Grave Creek near the mouth) from 2014 to 2016.

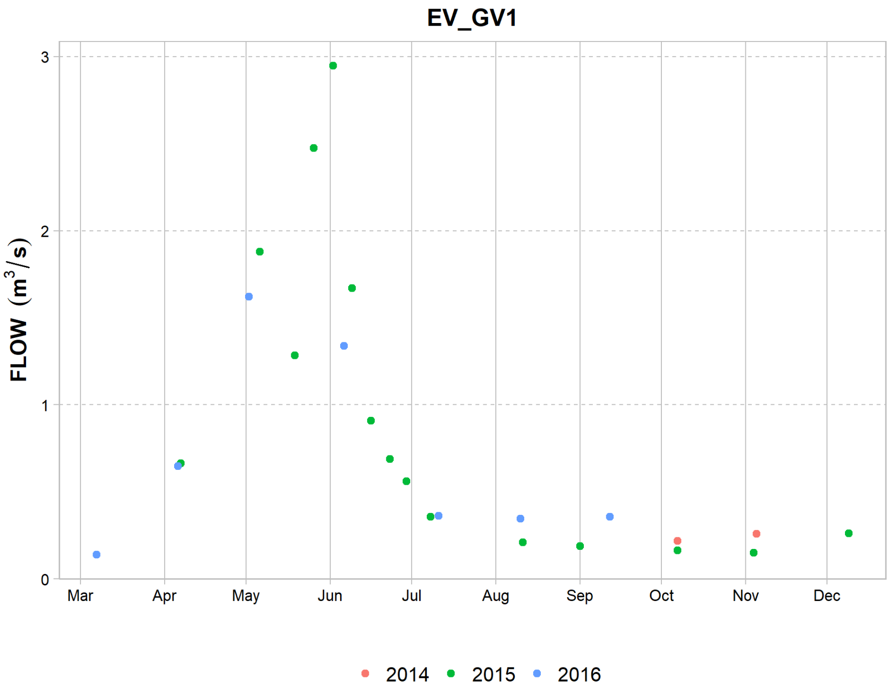

Figure 2. Instantaneous flow measurements at EV_GV3 (Grave Creek upstream of Harmer Creek) from 2013 to 2015.

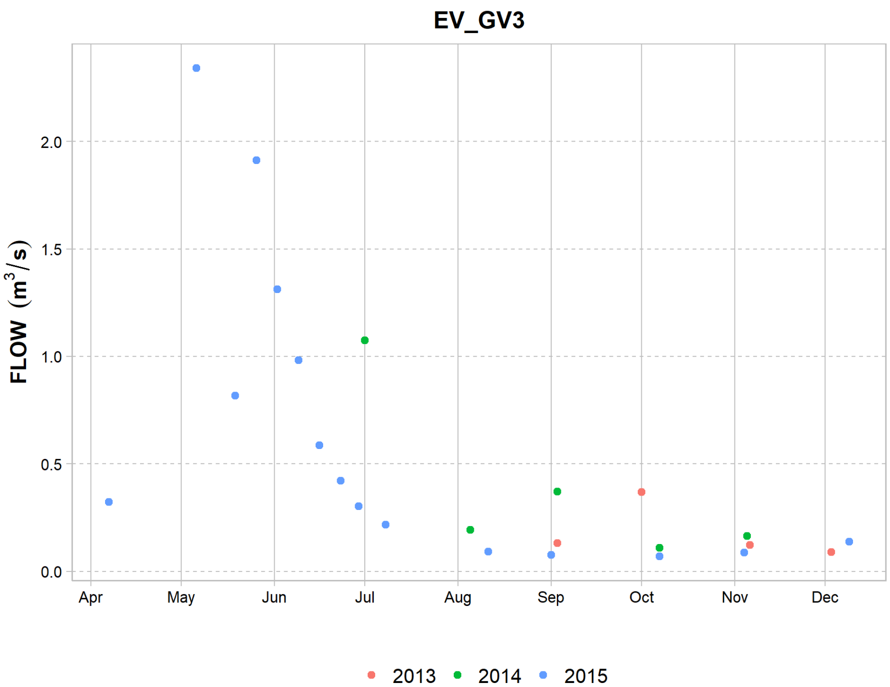

Figure 3. **Instantaneous flow measurements at EV_HC1A from 2000 to 2001.**

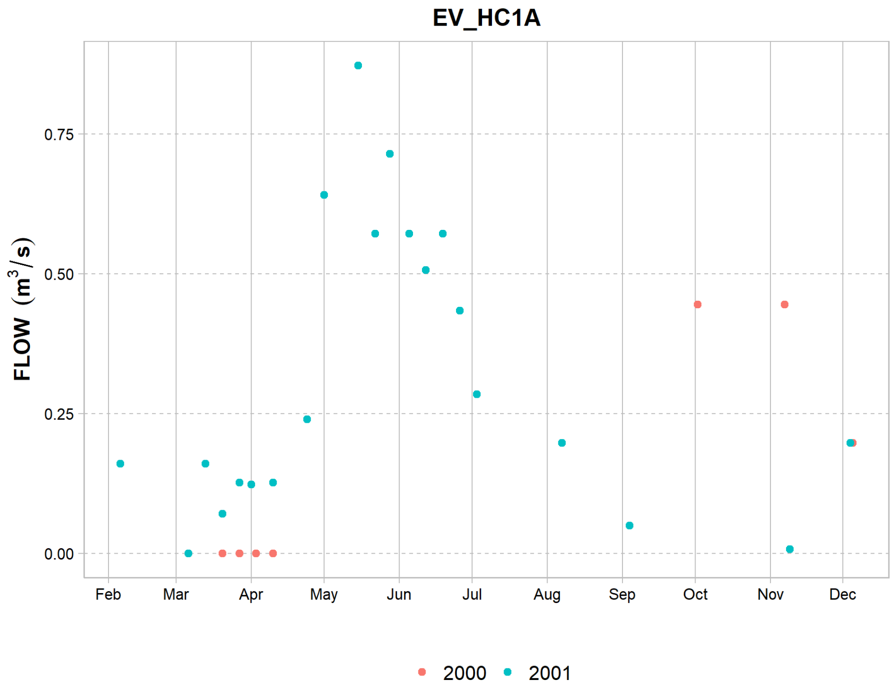

Figure 4. **Instantaneous flow measurements at EV_HC4 (Harmer Creek downstream of EVO Dry Creek) from 2019 to 2020.**

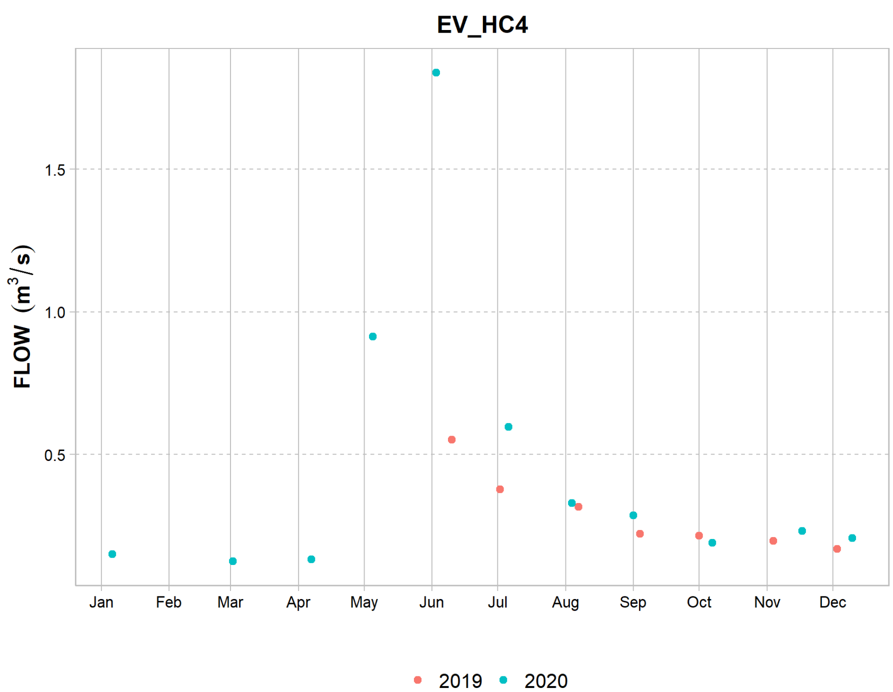

Figure 5. Instantaneous flow measurements at EV_HC6 (Harmer Creek upstream of EVO Dry Creek) from 2013 to 2016.